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Mobility Inequality of Disadvantaged Groups in Greater Cairo Region

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ABSTRACT

Mobility inequality in the Greater Cairo Region (GCR) affects disadvantaged groups of women, children and adolescents, elderly people, and persons with disabilities. These groups require inclusive mobility arrangements or protection on the streets. The research aims to explore the existing mobility inequality in GCR, through reviewing the trips of an introductory sample of disadvantaged groups and their transport choice. The paper reviews the concepts of mobility inequality, disadvantaged groups, and the United Nations standards of adequate urban mobility, which are utilized as a guide for the empirical study. The primary data collection applied two qualitative research methods, which are semi-structured interviews, and on-site trips/investigations of the urban mobility in GCR. Additionally, general figures on the target groups in GCR and Egypt are deployed as the secondary data. Subsequently, the research demonstrates a sample of the existing experiences of mobility inequality, local context realities, and consequential life compromises in GCR. The paper then aligns the priorities of the interviewed sample with their transport choices, which is the focus of the study. The investigated sample demonstrated high interest in car ownership, only to avoid challenges they encounter via walking and public transport, including issues like harassment and the inadequate, unsafe urban mobility experience. Finally, the paper suggests two sets of recommendations, the first set addresses the mobility inequality and proposed solutions as per the investigated sample. The second set incepts further research on mobility inequality, towards integrating the needs of the disadvantaged groups in GCR within the planning and delivering of urban mobility.

Index-words: *disadvantaged groups, mobility inequality, transport choice, urban mobility*

I. INTRODUCTION

Mobility is "*the ability to move freely or be easily moved*" (Cambridge Dictionary, n.d.). Such a brief and general definition of mobility associates the ability to move with the convenience of the environment/process to be easily moved within. This explains how the limitations within the urban context can restrain the mobility choices of many people in cities. This aligns with the period when cities expanded enormously into metropolitan areas; where millions of people commute every day and trips have become a long, crowded, costly, unpleasant, and unsafe experience for many inhabitants (Rodrigue *et al.*, 2013). Similarly, multiple disadvantages and exclusion acts occur that burden the mobility of many citizens. For instance, being a teenage girl who must walk every day to school in an unsafe area, or a child with visual impairment or a wheelchair for that matter (McConachie *et al.*, 2006).

Labelling individuals as disadvantaged seems subjective; however, the word "disadvantaged" refers to missing an aspect that others have. According to Merriam Webster dictionary, it was first used in 1893 to refer to the "*lacking in the basic resources or conditions (such as standard housing, medical and educational facilities, and civil rights) believed to be necessary for an equal position in society*" (Merriam-Webster, n.d.). The term "disadvantaged groups/populations" was coined by the United Nations in 1948 to refer to groups that are deprived of equal participation in life aspects. These groups usually encounter social, political, or economic barriers within their societies (Estes, 2014). Disadvantaged groups include children, the elderly, persons with disabilities (physical/mental/emotional), and women and indigenous groups (Estes, 2014; Social Protection & Human Rights, 2015). The term then developed to include other groups such as migrants, refugees, and ethnic minorities, as well as persons with chronic

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infections such as HIV/AIDS (Estes, 2014).

As a result, the world realized the importance of equity and enabling all populations to connect and obtain various life opportunities and benefits. This led many cities to rethink and transform their masterplans (Tsavachidis and LePetit, 2022; Lopez, 2022); towards generating better sustainable and inclusive communities (Jones, 2014). However, many citizens until this day lack equal access to functional and adequate mobility. This state of mobility inequality prevents their acquisition of different educational, health, and other vital services (LERU, 2015). Many critical reviews are against traditional mobility planning because it realizes one prototype with standard capabilities, whereas variables such as age, gender, and physical abilities are ignored (Litman, 2003; Hidayati *et al.*, 2021). Thus, urban mobility is no longer rotated in the horizons of the vehicles industry, roads, and fuels (El-Sherif, 2020); but the concept of moving people or goods has developed into responsive and inclusive services (Schneider Electric, ARUP and The Climate Group, 2014).

This research focuses on the disadvantaged groups of women, children, adolescents, the elderly , and persons with disabilities; in which the existing mobility inequality across the city directly affects them (LERU, 2015). The study attempts to understand the forms of mobility inequality in GCR. Hence, the paper identifies issues as per the choices of transport modes of a sample of disadvantaged populations to commute in GCR. The paper's sections overview mobility inequality and disadvantaged groups and then review the United Nations standards of adequate mobility. Afterwards, the paper proceeds with illustrating methods adopted in the empirical study, then demonstrates the views of the interviewed sample of the target disadvantaged groups; to provide an introductory overview of mobility inequality in GCR.

II. LITERATURE REVIEW

The core of this section stands by the United Nations' value to "*Leave no one behind*"; which summarizes the SDGs and NUA[1] global agendas and rights such as adequate urban mobility.

A. *Mobility Inequality*

The role that mobility plays in our lives is elemental in obtaining services and transporting people and goods, while on the other side lies the projected disparity onto those persons with no/limited mobility choices, which ends up in their isolation (Litman, 2003). In 2022, only half of the world's urban population (51.6 percent) had convenient access to public transportation, with considerable regional differences (United Nations, 2022). Levels and intensity of the experienced inequality vary as per the different spatial and sociocultural contexts (Hidayati *et al.*, 2021). Hence, mobility inequality is highly context-dependent and is understood in its socio-spatial context. This premise aligns with Ferreira *et al.'s* conceptualization of mobility inequality to be analyzed as per two components of physical inaccessibility and socioeconomic disparity and its impacts (Ferreira *et al.*, 2012; Hidayati *et al.*, 2021).

The result is a state of mobility inequality that generates disadvantages for groups whose needs are not considered. Mobility inequality is described in the literature as a transport disadvantage, transport inequality, transport poverty, mobility justice, and transport justice (Hidayati *et al.*, 2021). The commonly recurrent terms when searching for attributes or causes to identify mobility inequality were transport disadvantage and transport poverty. Transport disadvantage looks at mobility inequality from a broader perspective that considers the geography of the land, the distribution of services and activities, health conditions, and socioeconomic status (Murray & Davis, 2001; Gasparovic, 2016). Alternatively, transport poverty refers to households and individuals who struggle or are unable to make the journeys that they need; subsequently, they fail to obtain their everyday needs. According to (Lucas et al., 2016) transport poverty is due to one or multiple

1 The United Nations has adopted outstanding agreements of:
- In 2015, Sustainable Development Goals (SDGs) were accepted by 193 nations. SDGs are 17 goals towards ending poverty, protecting the planet, and ensuring overall well-being for all (United Nations, 2015).
- The 2016 New Urban Agenda (NUA) was accepted by 167 nations and sets an updated global structure and guidelines for planning, managing, and living in cities (United Nations, 2017).

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challenges within the provided urban mobility such as:

- Unavailability,
- Inaccessibility,
- Unaffordability,
- Inadequacy,
- and Timely inefficient.

Hence, mobility inequality is associated with the state of being disadvantaged and the impacts of social stigma and exclusion (Estes, 2014; Social Protection & Human Rights, 2015). However, the research focuses on the disadvantaged groups related to improving urban mobility and not discussing issues such as racism, marginalization, or conflicts. Consequently, the target disadvantaged groups in this research are identified as the four generic groups of women, children and adolescents, elderly people, and persons with disabilities; their suffering from moving around the city is a direct consequence of the urban mobility deficiencies (LERU, 2015; Hidayati *et al*, 2021).

Still, the focus of many references on mobility inequality is usually fragmented according to the institution's interest (Law Insider Inc., n.d.). For instance, if the interest is gender equality, the tackled issues would imply topics such as security against harassment and assaults (Viswanath, 2015; UN-Habitat, 2019; Ding, Loukaitou-Sideris *et al*., 2020); while if the interest is persons with disabilities or elderly, the focus is more about ramps and accessible designs (WHO, 2017; United Nations, 2018; Azevedo *et al*., 2021); while if the children's mobility is the scope, the subject would be the walking distance, safety, crossings and quality of sidewalks (Porter & Turner, 2019; ITDP, 2021; United Nations Environment Programme and United Nations Human Settlements Programme, 2022).

B. Equal Right to Adequate Urban Mobility

The United Nations led advocacy events and agendas towards equity and sustainability, included discussions on adequate urban mobility. One of the key direct references in this regard is SDG 11.2 which associates the right to urban mobility with safety, affordability, accessibility, and sustainability of the transport systems for all, and responding to the needs of women, children, persons with disabilities, and older persons (United Nations, 2015). Another example is the Habitat III New Urban Agenda which states the role of urban mobility to enhance the life opportunities and well-being of communities. Article 13 (f) stimulates cities and human settlements to apply age- and gender-responsive planning and investment towards sustainable, safe and accessible urban mobility for all (United Nations, 2017). Additionally, article 114 (a) provides further elaboration and steps towards such a vision by stating that associated urban mobility success with the "*increase in accessible, safe, efficient, affordable and sustainable infrastructure for public transport, as well as non-motorized options such as walking and cycling, prioritizing them over private motorized transportation*" (United Nations, 2017).

Reviewing the Global Mobility Report GMR[2]; it clustered the collective results of SUMP, SDGs, and NUA into four global objectives that are Universal access, Efficiency, Safety, and Green (SuM4All, 2017). Also, Egyptian research efforts to apply SDGs are revised; for instance, the parameters introduced in TADAMUN's[3] article on urban mobility, and the report of Transport for Cairo TFC[4] and Takween Integrated Communities Development TICD[5] on adequate urban mobility. TADAMUN identified six parameters matching the Egyptian context that are affordability, availability, accessibility, acceptability, safety, and sustainability (TADAMUN, 2016; TICD and TfC, 2017). Hence, the scope of the empirical study employs these holistic reviews on adequate urban mobility with a focus on NUA as it provides collective, recent, and global references among the other discussed studies (Table I).

2 The GMR was developed under the umbrella of the World Bank-led Sustainable Mobility for All global platform (SuM4All), in collaboration with other 55 influential public and private international organizations, from the United Kingdom and German Governments (The World Bank, 2020)

3 TADAMUN: The Cairo Urban Solidarity Initiative, develops tools to raise the profile of urban rights (TADAMUN, n.d.)

4 Transport for Cairo (TfC) is a strategic advisory practice in the domain of sustainable urban mobility (Transport for Cairo, n.d.)

5 Takween, an urban development company for architectural and urban design solutions (Takween ICD, 2020).

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TABLE I
SAMPLE OF THE STANDARDS OF ADEQUATE URBAN MOBILITY AS AN EQUAL RIGHT FOR ALL

SDGs	NUA	GMR	TADAMUN
Safety	Accessible	Universal access	Affordability
Affordability	Safe	Efficiency	Availability
Accessibility	Efficient	Safety	Accessibility
Sustainability	Affordable	Green	Acceptability
	Sustainable		Safety
			Sustainability

Source: Illustration by the authors as stated by SDGS (United Nations, 2015), NUA (United Nations, 2017), GMR (SuM4All, 2017), TADAMUN (TADAMUN, 2016; TICD and TfC, 2017).

Accordingly, many international events pursued the endorsement of international agendas and discussed transforming the general standards into an associated list of laws, planning and design guidelines, policy and operational frameworks, and stakeholder mapping (United Nations, 2020).

C. *Synthesis and Gap*

This research tackles the literature gap in terms of the insufficient primary data on mobility inequality of the aforementioned four groups in Egypt. The reviewed body of published studies on mobility and transport studies in Egypt mainly focuses on:

- Quantitative perspective of measuring the trip duration and distance, or smart mobility and reducing carbon emissions.
- Investigating a certain transport mode, which does not apply to many citizens that shuffle between multiple modes across GCR.
- Upgrading and redesigning of certain zone or district, which are scattered studies that overlook the fact that travel pattern in GCR is associated with commuting across various districts at arrive to their destinations.

This demonstrated synthesis and gap analysis derived from the empirical study focuses on qualitative investigations and direct interaction tools such as semi-structured interviews (Creswell, 2007; Corbin & Strauss, 2015); which uncovers knowledge in this new study area. On another level, the study attempts to complement the fragmented views of literature and international agendas on mobility inequality that focus on the needs assessment of one group and one issue, for instance, women and sexual assaults in Egypt. Thus, this research recognizes that the union of the mobility inequality issues of the four groups of women, children and adolescents, elderly people, and persons with disabilities, would demonstrate an active call to consider their integral presence. Furthermore, it works to showcase the potential of formulating their needs into a set of applicable participatory recommendations/solutions.

III. METHODOLGY

Data collection for the empirical study followed a qualitative approach, it is subdivided into three main methods. The first method is semi-structured interviews with an introductory sample of the disadvantaged groups (primary data); whereas the researchers choose this particular method because:

- In-depth interviews provided trustful context to explain sensitive or embarrassing situations than written and numerical surveys.
- Direct communication with the interviewees allowed follow-up on many topics that revealed more details on their transport preferences and their travel behavior in addition to brainstorming of solutions that were brought up as discussions developed with other respondents.
- Unwillingness and inaccessibility of many participants to fill out surveys/ questionnaires.

This coincides with existing literature discussing the advantages of qualitative methodologies, and the advantages of conducting detailed semi-structured interviews, especially when focusing on groups with specific needs or unique behavior (Creswell, 2007; McNeeley, 2012). McNeeley explains that surveys on

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sensitive topics are problematic, because of the reluctance of target groups to participate in such surveys and discomfort to answer questions transparently due to embarrassment (2012).

The second method is conducting field visits via a sample of the different transport modes mentioned in the semi-structured interviews (primary data). The third method is reviewing data through desk research to obtain insights and figures on the target groups in Egypt and GCR (secondary data). The research analyzed the collected data in the findings section to identify inequality struggles across a sample of GCR trips and the associated transport modes.

A. Interview Design

The interviews were divided into six consolidative sections. The first section identified the general demographic information of the interviewees such as age, gender, marital status and number/ages of kids if applicable, type of disability if present, income, profession, literacy level, and car ownership. Besides, mapping their home as the origin point and their frequently visited destinations; while, measuring the time and distance of the routes of their frequent trips. The type of questions in this part were open-ended general questions.

The consequent five sections of the interview investigated urban inequality as per the NUA's five standards of adequate urban mobility which are accessibility, affordability, efficiency, safety, and sustainability. The five standards were subdivided in each section into a set of guiding indicators; to preserve the study focus within the mentioned situations by the interviewees. The types of questions in this part started with open-ended questions to encourage them to explain details of their city trips, for example, "How would you describe your everyday trip from your home to the metro station?" or "Why do you prefer using the metro instead of the microbus if both are available?". The open-ended questions tackled the five standards through starting topics inspired by their profile and information received in the first section. Also, the interview utilized yes/no questions for example, "Were you subjected to verbal/physical harassment or discrimination?" Or "Are you willing to shift from private car to public transport if available and accessible?"

The researchers then followed up on their answers through examples-type questions to validate their general responses. Questions in this regard investigated real situations and pursued further understanding of the context and types of barriers whether physical, social, economic, administrative, or technological. Hence, their mentioned needs were further discussed in terms of many analysis layers of urban context, timing, and individuality aspects; to differentiate between repeated situations and the one-time situations in the received responses.

B. Sample Size and Selection

Usually, the sampling size in qualitative studies is different than in quantitative studies, as the sample size is smaller to manage the detailed layers of the received narratives and extracted material. Sample size in qualitative research should be only sufficient to produce a new and richly textured understanding of the investigated experience (Fugard & Potts, 2015), which is subjective and identified as per the research focus and goal (Fugard & Potts, 2015; Creswell & Clark, 2017). Thus, this paper selected a controlled sample size, which allowed the authors to tackle further details regarding their mobility biographies. The research studied trips of an introductory sample of 31 interviewees who belonged to one or more of the four target groups. Some interviewees represented intersectional cases such as a child with a disability, which are counted once (per one group), and additional data are noted in the other group (see Table II). The research adopted the snowball sample selection where many respondents nominated each other. The included sample doesn't necessarily live in the same district, and if they coincidently lived in the same district they do not commute to the same destinations or via the same transport modes.

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TABLE II
SAMPLE SIZE AND THEIR GENERAL CHARACTERISTICS

Group	No. respondents	Ages	Notes
Women	10	20-46	Supplementary data from other groups • Women at age above 60 are 3 • Girls aged less than 18 are 4 • Women with Disabilities are 3
Children/ Adolescents	7	5-17	Supplementary data from other groups • 1 Child with Disability
Elderly People	5	64-71	Supplementary data from other groups • 1 Person with Disability
Persons with Disabilities	9	5-66	The interview with the guardian (mother) of the 5-year-old child with a disability revealed the disadvantaged status of representing women with no private car and having two children (one with physical impairment).

Source: the authors

Although this number does not indicate a full representation of all disadvantaged groups in GCR, the characteristics of the selected sample covered a variety of ages, physical abilities, gender, and socio-economic levels (see Table II). It also fulfilled the average number of qualitative interviews as agreed upon through the body of literature to range between 20 and 30 (Creswell & Clark, 2017; Deterding & Waters, 2018). The number of respondents in each group was based on the concept of data saturation[6] that continues to bring new participants until data replication or redundancy occurred. The selection of the included interviewees considered the diversity in the location of the origin point (home) to cover several districts in the three governorates composing the GCR which are Cairo, Giza, and al-Qalyubiyya.

C. *Observatory Trips*

This method is utilized to provide supporting and validation research (Gray, 2022) . It examined the received explanations behind the respondents' preferences, besides whether the interviewees missed grasping or expressing any details. In this respect, the research planned and applied 35 field trips at different times across GCR that involved transect walks and riding many of the mentioned transport modes such as microbuses, buses, minibuses, metro (3 lines), tuk-tuk, taxis, uber and similar applications, SWVL, private car. The full urban context was observed (human behaviors, built environment and street conditions, transport modes, and riding practices), whereas different sorts of inadequacy incidents were noted. This contributed to obtaining a comprehensive picture of the urban context in different neighborhoods.

D. *Desk Research*

The secondary data collection implemented desk research of fact sheets and official data across the Egyptian websites of the Ministry of Transportation and the Central Agency for Public Mobilization and Statistics CAPMAS. Similarly, the research investigated officials' interviews and governmental statements and figures in official Egyptian newspapers such as Al-Ahram. On another side, the desk research examined 30+ published academic references as well as reports of Egyptian-International joint mobility development projects[7].

IV. RESULTS

This section introduces the results of the desk research and empirical study on the transport mode preferences of the interviewed sample. It continues then to demonstrate interpretations in alignment with the notions of mobility inequality and urban mobility standards.

6 It was developed for grounded theory studies but is applicable to all qualitative research that employs interviews as the primary data source. Hence, the estimation of the adequate size in this research was based on saturation (Bowen, 2008; Marshall *et al*, 2013; Creswell & Clark, 2017).

7 For instance, studies that were conducted through cooperations between credible international agencies such as UN or the German Agency for International Cooperation GIZ, the Egyptian government, and local urban and transport offices/labs in Egypt.

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A. GCR Context: Insights

Overviewing the situation in GCR, thousands of people commute every day internally or from other governorates[8], pursuing work or services in governmental agencies and major hospitals (Cairo Metro, n.d.). These massive trips in GCR create a pressuring demand for mobility and infrastructure (TICD, TfC, 2017). The current metro services transport up to 2.5 million passengers per day (Cairo Metro, n.d.), which is expected by the Egyptian government to increase to reach 3.5 million passengers after the completion of the in-progress stations (Soliman, 2022). Also, in 2020, around 3% of passengers traveled in CTA buses, while 74% traveled using microbuses that expanded to connect the city and fill the supply gap (Hegazy and Women For Justice, 2022). At the same time, there are attempts to initiate projects towards smart and environmentally sustainable urban mobility such as the Cairo Bike project (Sami, 2022), the production of Egyptian electric cars (SIS, 2023), Cairo Monorail (Railway Technology, 2019), and more projects that implied the expansions of metro and public transit lines. Yet, most of the projects are recent, or still in progress. As a result, there are no available published evaluations indicating the impacts on improving urban mobility in GCR.

Population counts and demographics of the four target groups indicate their existence not as a minority but more of an integral part of the society structure. For instance, results based on Egyptian official statistics in 2017 and updated reports in the following years, which are released by the Central Agency for Public Mobilization and Statistics CAPMAS show that:

- There are 45.9 million women in Egypt, representing nearly half of the population. Their contribution to the workforce was 15.6% of the total workforce (15+ years), which is a relatively small share compared to 67.3% for men. Still, the percentage of female-headed households reached 18.1% (CAPMAS, 2020).
- Persons with Disabilities that are 5+ years old represent 10.6 % of the population and are given only a quota of 5% in a few services and jobs (CAPMAS, 2020).
- The total number of Egyptian children (under 18 years) is about 38 million children, representing 40% of the total population in the census 2017 (CAPMAS, 2017).
- The number of elderly persons reached about 6.8 million which represents 6.7% of the total population and is expected to increase to 7.9% in 2052 (CAPMAS, 2021).

Mostly, literature targeting mobility inequality is concerned with women, in addition to a few scattered studies to promote active mobility for children. For instance, the research utilized updated results by the Institute for Transport and Development Policy (ITDP) that conducted a survey for 2500 female respondents in Cairo. The study revealed that the majority spend 2+ hours on public transport for daily commutes, in addition to enduring safety and harassment problems (ITDP, 2023). According to the study, more than 80% experienced harassment, and 35% referred to Cairo Transport Authority (CTA) buses as the least secure due to overcrowding (ITDP, 2023). More than 60% reported incidents of physical harassment, besides, the more respondents who reported verbal harassment (ITDP, 2023). Another interesting study that this paper builds on, examined the independent mobility of children in six schools in Heliopolis, one of Cairo districts. The study revealed that 30% commute to school by public transport, and 42% by a small van/private bus (Shafik *et al*, 2021). Also, 69% of the surveyed children expressed anxiety about crossing streets (Shafik *et al*, 2021).

Regarding the other two groups of elderly people and persons with disabilities, there are no significant quantitative or qualitative studies that address their mobility inequality in Egypt. However, there are multiple attempts by civil society organizations (e.g. Helm Foundation); towards improving accessibility for persons with disabilities in Egypt. Projects that target installing ramps and tactile tiles for visual impairment and similar initiatives are still in

8 GCR is the biggest in Arab countries in terms of inhabitants and surface area. it's the seventh globally in terms of population (20+ million, est. 2020), which is 20+ % of the total population of Egypt. (Cairo Metro, n.d.)

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the early stages and are not supported by sufficient national plans or academic research.

B. The Revealed Main Transport Choices

The combination of gender, age, ability, and income level in correspondence to their main transport options is demonstrated in Table III.

TABLE III
DEMONSTRATION OF INTERVIEWEES' DEMOGRAPHICS AND THEIR MAIN TRANSPORT OPTIONS

			Disadvantaged group				Income			Main Transport
Code	Gender	Age	Women	Children/ Adoles-cents	Elderly people	Persons Disabilities	Low	Middle	High	
IW1	Female	33	■					■		Minibus
IW2	Female	41	■				■			Minibus/ Microbus
IW3	Female	31	■						■	Car
IW4	Female	46	■				■			Bus/ Minibus
IW5	Female	20	■					■		Minibus/Uber
IW6	Female	25	■					■		Uber
IW7	Female	37	■						■	Car
IW8	Female	36	■						■	Car/ Uber or in drive
IW9	Female	40	■					■		Minibus/ Microbus
IW10	Female	43	■				■			Microbus/Metro
IA1	Male	12		■					■	Car
IA2	Female	12		■				■		Car
IA3	Male	11		■				■		Car
IA4	Male	14		■				■		Car
IA5	Female	16		■			■			Walking
IA6	Female	17		■			■			Walking/ Microbus
IA7	Female	15		■			■			Walking/ Microbus
IE1	Male	67			■			■		Car/ Metro
IE2	Female	64			■				■	Car
IE3	Female	65			■			■		Walking/ Taxi
IE4	Female	71			■			■		Microbus/ Metro
IE5	Male	68			■			■		Car/ Taxi
IPD1	Female	35				■	■			Metro/ Walking
IPD2	Female	25				■		■		Uber/ Car
IPD3	Male	22				■		■		Car/ Microbus
IPD4	Male	31				■		■		Uber/ Walking
IPD5	Male	42				■		■		Car (Special)
IPD6	Male	5				■		■		Uber
IPD7	Female	27				■		■		Uber
IPD8	Male	35				■	■			Motorcycle
IPD9	Male	66				■	■			Microbus/ Minibus

Source: Prepared by the authors

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C. Factors Influencing Transport Choices

These findings correlate the decision of selecting transportation with the demographic profile and physical abilities of the interviewees; in which their choices of transport mode serve their specific needs and responsibilities.

Car: All groups' representatives with high income (IW3, IW7, IW8, IA1, IE2) prefer using cars that represent to them privacy, safety, accessibility, and timesaving. Also, they agreed that the lack of adequate walking infrastructure for the first/last mile underlies this transport choice. For example, walking in New Cairo involves crossing high-speed streets or walking long distances to reach the nearest transportation station. Another point of view that favors cars was mentioned by one of the persons with disabilities (IPD5), in which he used to shuffle between three transport modes for his homework trip every day. He bought a car that is customized for special needs, to avoid encountering the inaccessibility and exhaustion in public transport. He expressed his preference for using his car; despite it not being the most financially viable choice, as it consumes around 40% of his monthly income, not to mention the initial purchase cost.

Walking: It was mentioned as the first choice for interviewees living in areas of downtown, historic Cairo, and Shubra, where these areas represent old and compact districts in Cairo. Thus, walking is highly associated with central areas of old Cairo that were planned essentially as livable and dense areas. Interviewee (IE3) explained that as an elderly person, she appreciates the diverse blend of mixed land uses and the proximity of different services and activities along the streets. Also, all girls under 18 years old (IA5, IA6, IA7) walk to their school for around 20 minutes and agree that walking is the most economical and realistic option. However, on the other side, the three girls mentioned that they encounter verbal harassment and sexual assaults on a daily basis. Moreover, the interviewee (IA7) is subjected to safety hazards as she walks across a railway separating her neighborhood from her school. She explained that she and the majority of her neighbors opt for this to avoid the pedestrian bridges, which have become unsafe spots due to the presence of criminals and drug addicts.

All elderly people and persons with disabilities repeatedly noted that walking becomes an unpleasant choice for them. This is due to the lack of adequate space for pedestrian movement on the streets; for instance, the sidewalks are occupied by shop expansions or parked cars. Similarly, they mentioned that sidewalks are too crowded in commercial and mixed-use streets; in which they get physically knocked by others. They encounter difficulties as well due to the uneven surfaces of the sidewalks, leading to incidents of tripping and falling. Besides the height of the sidewalks (many cases 30-40 cm high) and the absence of ramps or handrails for assistance multiply their challenges. These two groups in particular expressed dissatisfaction with the lack or inaccessible pedestrian bridges and tunnels;, they endure risks of crossing the high-speed street instead of the painful experience of climbing stairs. On another note, a common issue (20/31 respondents) was being afraid of stray dogs, which was raised coincidentally without being in the questions list.

Minibuses and Buses: They are preferred by the sample of women who belong to middle and low-income economic classes (IW1, IW2, IW4, IW5, IW9). They find them available, affordable, and relatively safe methods of navigating the city. Interviewees from middle-income group prefer a newly introduced type of buses, which are more expensive but air-conditioned (cost is 1.5 and 2.5 times the basic bus fare). Also, these new buses have distinctive lines that connect long-distance trips. However, the arrival of these new buses is not frequent; also at rush hours, the trips take longer times because of the many scattered stops on the route.

Altogether, elderly people and persons with disabilities stated that they avoided minibuses and buses because of several reasons: the necessity to climb stairs for boarding, the lack of designated seats for people with special needs, and if available, passengers refuse to offer them to sit. Additionally, they echoed the concerns of children and adolescents regarding the hazardous experience of departing the vehicle,

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which is dangerous, as drivers tend to slow down without stopping, leading passengers to jump out.

Metro: It was mentioned as one of the primary choices by four interviewees, for example, the respondent (IW10) has no faster option during rush hours to reach her work (one hour away from her home) except shuffling between metro lines. Similarly, the interviewee (IE4) depends on the metro occasionally if she is running late. While the interviewee (IE1) uses the metro as a park-and-ride system to go downtown, he only rides the third line as it is air-conditioned. This option allowed him to access one of his favorite destinations regularly and without worrying about where to park his car or enduring traffic jams. The only person with a disability who rides the metro is (IPD1). She depends on the metro to access all GCR. However, she has a mobility impairment in one hand and one leg and she suffers to climb the enormous number of stairs to cross between platforms as not all stations are equipped with escalators and elevators. This painful experience coincides with the avoidance of other persons with disabilities to use the metro as a transport choice; in which some of them memorize the number of stairs that they had to climb in pain in order to exit a station or cross to the other side.

Microbuses: This transport choice was favored by IW2, IW9, IW10, IA6, IA7, IE4, IPD3, IPD9. They favor microbuses for their availability and connectivity to many destinations across GCR. Sometimes they shuffle between two or three microbuses or mix with other transportation modes. However, all the interviewed sample who ride microbuses agreed that they get scared by the drivers' attitudes such as rushing the riders, keeping the remaining change money, heavily smoking or allowing others to smoke, speeding and fear of road accidents, and aggressive behaviors and engaging in fights with other passengers or drivers on the streets. Like buses and minibuses, many persons with disabilities avoid riding microbuses due to the vehicle's height and narrow spaces for maneuvering inside.

Motorcycle: Mentioned by one case only (IPD8) who is a wheelchair user. He explained that it is convenient for short distances, yet he rides a taxi or UBER if commuting for long routes or riding with his family.

Taxis/ Ride hailing such as Uber: All these transport choices marked incidents of harassment by women between the ages of 20 and 40. All passengers of this transport choice including other riders with disabilities expressed concerns about the significant expenses, which account for 30-40% of their monthly income, representing a substantial financial burden for accessibility.

Tuk-tuk: It was mentioned in the scale of micro-mobility to usually access the nearest public transport in low-income neighborhoods. The respondents who use it mentioned it is relatively high-cost that can be substituted by 10-15 minutes of walking. Correspondingly, they all agreed that they prefer to avoid the tuk-tuk drivers, who are commonly underage, reckless, or drug addicts.

Bicycle: None of the interviewees used bicycles except (IA5) who uses it occasionally if with her sister. Mainly all youth and children and adolescents' group at ages between 10 and 20, referred to their wishes to cycle more. Nevertheless, they emphasized that they cannot compromise their safety in the absence of bicycle lanes, not provided right of the way nor adequate space adjacent to sidewalks. Riding a bicycle under such circumstances can become deadly dangerous.

SWVL and Uber bus: They are not mentioned by any of the respondents. When the researchers introduced and explained such choices, the low-income respondents replied with their discomfort to the relatively higher cost as compared to similar transport modes such as microbuses. Also, the elderly persons stated that they are not comfortable to book through mobile applications. While two women respondents who tried SWVL (IW1, IW6) agreed that they do not prefer it anymore. Both stated that that if they missed the arrival time by one minute; they lost the full ticket price.

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A. Interpretations and Discussions

In reference to the semi-structured interviews' findings, field observations, and desk reviews, the mobility inequality characteristics of different transport modes show that:

- Walking/Cycling implies negative probabilities of harassment, road accidents, and inaccessibility (physical/ visual).
- Public Transport (Roads such as buses or rail such as subway) causes diverse struggles such as harassment, unreliable times of arrival, inaccessibility (physical/ visual), and drivers' negative and offending behaviors.
- Cars are inaccessible for many types of disabilities and younger ages, more expensive than other modes, and hold risks of road accidents.
- Taxis/ Ride hailing is reported by many women in Egypt for harassment, also not preferred as a more expensive option than other modes.
- Motorcycle riders are commonly exposed to road accidents, besides barriers such as the inaccessibility (physical/ visual), and cultural barriers for women in some areas.

There is an obvious overlap between many of the urban mobility issues that are endured by the target disadvantaged groups, however, each individual/ group reacts in a different way. One common thing is that the suffering of the four groups has limited their transport modes to certain choices that are not necessarily adequate. Thus, Table IV reviews the best and least transport preferences for the interviewed sample and the key urban mobility standard that contributed to this decision.

TABLE IV
PREFERNCES OF TRANSPORT MODE BY THE INTERVIEWED SAMPLE

NUA Standards	High Preferences	Less Preferences
Accessible	Car, Uber	Minibus, Bus
Affordable	Walking, Minibus, Metro, Microbus	Car, Uber
Efficient (Time)	Walking, Metro, Car	Minibus, Bus
Safe	Metro, Car	Walking, Uber, Bicycle
Sustainable	Walking, Metro, Bicycle	Car, Uber

Source: Prepared by the authors, the indicators column is based on the NUA standards.

B. Limitations and Recommendations

The study encountered limitations in the desk research due to the scarcity of published research and data on the urban mobility of disadvantaged groups in Egypt. Also, some studies are conducted for specific areas or per each group solely in GCR which still does not provide sufficient comprehension of the current situation. Thus, this paper depended on qualitative approaches and in depth semi-structured interviews to address this new area of research, while building on quantitative figures from previous literature even if based on a single-transport mode or examines single neighborhood or district. As a result, the recommendations of this study are divided into two sets,

- the first set is the direct results from the empirical study and as per the travel behavior of the examined sample.
- the second set postulates a thread of integrated academic studies towards future research and actionable projects; to mitigate mobility inequality in GCR.

As a result of the empirical study, the researcher suggests applying:

- Accessibility and universal design standards should be enforced by law in the streets and sidewalk design, stations, and vehicle design.
- Supervision and awareness of drivers to respect and consider the conditions of different disabilities.
- Promotion of walking and cycling should be associated with strict land use plans, feasible travel distances, and infrastructure alignment.

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- Pedestrian bridges and tunnels require strict monitoring to become safer and to have elevators and escalators accessible.
- Provision of various public transport lines to include short routes and long routes that connect downtown with new urban communities. Some of them should have direct lines and fewer stops to become time-efficient.
- Provision of nearby shuffle transportation to main transportation hubs to improve the experience of the first/last miles with affordable prices or an inclusive ticketing system.
- Carpooling applications should be developed and promoted and should consider safety and security measures to encourage their use by the target groups.

Regarding the proposed future research opportunities, the research underscores the lack of coordination between urban land use planning, street network design, and the provision of transportation services. Hence, it emphasizes the necessity to conduct inclusive needs assessment studies on the existing urban mobility which focus on the sustainable urban mobility approaches rather than the rigid transport planning approaches. Hence, urban mobility and equality are not only calculated by time and distance, but also through human interaction, emotions, sense of safety, social engagement, and humanity. Also, GCR is a complex setting where around 20 million people mostly commute every day which requires:

- Studying this metropolitan region holistically within long term official research projects and integrate with independent academic studies.
- conducting auxiliary research towards the evolution of participatory methods, generating geographic interactive maps and crowdsourcing data collection tools.
- Increasing the outreach of academic researchers and accessing a diverse spectrum of these disadvantaged populations through qualitative studies building on quantitative and statistical studies, and vice-versa.

C. Conclusion

The mobility networks and infrastructure in GCR advance the vehicular connectivity of the region; and do not necessarily consider the accessibility specifications of those vehicles, or the diverse needs of the passengers. Furthermore, walking becomes an unsafe or painful experience for many populations in GCR due to inadequate street designs, inappropriate behaviours, and lack of safety and security measures. Hence, the empirical study investigated the factors influencing transport choices for an exploratory sample of the target groups. The majority of the respondents either preferred their cars or wished they could afford cars to avoid the existing mobility inequality. Similarly, the majority of the interviewed sample, regardless of their abilities, economic status, and age, expressed their willingness to walk more (average 10-20 minutes) if the streets were better designed with sidewalks that have sufficient widths, and safely connected across their neighborhoods; besides supervising and mitigating the inappropriate attitudes and verbal assaults against women and young girls. In conclusion, this study pinpoints the importance of including the needs and voices of women, children and adolescents, elderly people, and persons with disabilities within the intricate local context of GCR. The researchers suggest future surveys, in order to quantify the identified issues. This should be composed of database generation, statistical analysis, and geographic mapping of barriers and solutions across the trips of target groups. Also, this paper strongly suggests involving the actors responsible for planning and delivering urban mobility in GCR as an integral partner in the research process. Hence, investigating coordination and implementation opportunities to provide a more inclusive and equitable city experience for all.

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V. References

[1] G. M. Ahlfeldt and E. Pietrostefani, "The compact city in empirical research: A quantitative literature review," *Spatial Economics Research Centre,London*, no. June, 2017.

[2] G. A. Azevedo, R. R. Sampaio, A. S. N. Filho, M. A. Moret, and T. B. Murari, "Sustainable urban mobility analysis for elderly and disabled people in São Paulo," *Sci Rep*, vol. 11, no. 1, 2021, doi: 10.1038/s41598-020-80906-w.

[3] G. A. Bowen, "Naturalistic inquiry and the saturation concept: A research note," *Qualitative Research*, vol. 8, no. 1, 2008, doi: 10.1177/1468794107085301.

[4] J. Breuste, "The Green City: General Concept," in *Cities and Nature*, vol. Part F338, 2023. doi: 10.1007/978-3-030-73089-5_1.

[5] J. Corbin and A. Strauss, "Techniques and Procedures for Developing Grounded Theory," in *Basics of Qualitative Research*, 2018.

[6] J. Creswell, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches. Sage Publication*, vol. 3, no. June. 2016.

[7] J. w. ; Creswell and V. L. P. Clark, "Designing and Conducting Mixed Methods Research.," *Organ Res Methods*, vol. 12, no. 4, 2009.

[8] N. M. Deterding and M. C. Waters, "Flexible Coding of In-depth Interviews: A Twenty-first-century Approach," *Sociol Methods Res*, vol. 50, no. 2, 2021, doi: 10.1177/0049124118799377.

[9] H. Ding, A. Loukaitou-Sideris, and A. W. Agrawal, "Sexual Harassment and Assault in Transit Environments: A Review of the English-language Literature," *J Plan Lit*, vol. 35, no. 3, 2020, doi: 10.1177/0885412220911129.

[10] D. M. El-Sherif, "Urban mobility systems components," in *Solving Urban Infrastructure Problems Using Smart City Technologies: Handbook on Planning, Design, Development, and Regulation*, 2020. doi: 10.1016/B978-0-12-816816-5.00004-8.

[11] European Commision, "Quantifying the Effects of Sustainable Urban Mobility Plans Third Main Title Line Third Line," *Report EUR*, 2013.

[12] A. Ferreira, P. Batey, M. Te Brömmelstroet, and L. Bertolini, "Beyond the dilemma of mobility: Exploring new ways of matching intellectual and physical mobility," *Environ Plan A*, vol. 44, no. 3, 2012, doi: 10.1068/a44258.

[13] A. J. B. Fugard and H. W. W. Potts, "Supporting thinking on sample sizes for thematic analyses: a quantitative tool," *Int J Soc Res Methodol*, vol. 18, no. 6, 2015, doi: 10.1080/13645579.2015.1005453.

[14] Global Data Thematic Research, "History of smart cities: Timeline," *Verdict.co.uk*. 2020.

[15] D. Gray, "Doing Research in the Real World, Fourth edition," *Qualitative Research Journal*, vol. 5, no. 2, 2017.

[16] I. Hidayati, W. Tan, and C. Yamu, "Conceptualizing Mobility Inequality: Mobility and Accessibility for the Marginalized," *J Plan Lit*, vol. 36, no. 4, 2021, doi: 10.1177/08854122211012898.

[17] P. Jones, "The evolution of urban mobility: The interplay of academic and policy perspectives," *IATSS Research*, vol. 38, no. 1, 2014, doi: 10.1016/j.iatssr.2014.06.001.

[18] T. Litman, "Social Inclusion As A Transport Planning Issue in Canada," *Transp Policy (Oxf)*, 2003.

[19] K. Lucas, G. Mattioli, E. Verlinghieri, and A. Guzman, "Transport poverty and its adverse social consequences," *Proceedings of the Institution of Civil Engineers: Transport*, vol. 169, no. 6, 2016, doi: 10.1680/jtran.15.00073.

[20] M.-N. Lv and X. Li, "A Comparative Study on the 'Social Disadvantaged Group' and 'Social Vulnerable Group,'" 2019. doi: 10.2991/icmesd-19.2019.5.

[21] B. Marshall, P. Cardon, A. Poddar, and R. Fontenot, "Does sample size matter in qualitative research?: A review of qualitative interviews in is research," *Journal of Computer Information Systems*, vol. 54, no. 1, 2013, doi: 10.1080/08874417.2013.11645667.

[22] H. McConachie, A. F. Colver, R. J. Forsyth, S. N. Jarvis, and K. N. Parkinson, "Participation of disabled children: How should it be characterised and measured?," *Disability and Rehabilitation*, vol. 28, no. 18. 2006. doi: 10.1080/09638280500534507.

[23] S. McNeeley, "Sensitive issues in surveys: Reducing refusals while increasing reliability and quality of responses to sensitive survey items," in *Handbook of Survey Methodology for the Social Sciences*, 2012. doi: 10.1007/978-1-4614-3876-2_22.

[24] G. Porter and J. Turner, "Meeting young people's mobility and transport needs: Review and prospect," *Sustainability (Switzerland)*, vol. 11, no. 22, 2019, doi: 10.3390/su11226193.

[25] J. Speck, "Walkable City: How Downtown Can Save America, One Step at a Time," Urban planning.

[26] R. Acciona, "Do you know when sustainability first appeared _ Sustainability for all," Acciona.

[27] M. Tsavachidis and Y. Le Petit, "Re-shaping urban mobility – Key to Europe´s green transition," *Journal of Urban Mobility*, vol. 2, 2022, doi: 10.1016/j.urbmob.2022.100014.

[28] U. Nations, "The World 's Cities in 2018," *The World's*

Cities in 2018 - Data Booklet (ST/ESA/ SER.A/417), 2018.

[29] United Nations, "New Urban Agenda: with subject index," in *Habitat III*, 2017.

[30] J. P. Rodrigue, C. Comtois, and B. Slack, *The geography of transport systems*. 2016. doi: 10.4324/9781315618159.

[31] Cambridge Dictionary, "Mobility," Cambridge Dictionary.

[32] CAPMAS, "On the occasion of the International Day of elderly persons," CAPMAS.

[33] Ecocity Builders, "An Ecologically Healthy CIity. Retrieved from Ecocity Builders," https://ecocitybuilders.org/what-is-an-ecocity/.

[34] R. Estes, "Disadvantaged Populations. In A. Michalos (Ed.), Encyclopedia of Quality of Life and Well-Being Research ," https://link.springer.com/referenceworkentry /10.1007/ 978-94-007-0753-5_742.

[35] M. , & W. F. J. Hegazy, "Egypt transport policies 2014-2021. Arab Reform Initiative." 2022.

[36] J. Hine, "Transport Disadvantage and Social Exclusion," International conference on public transport and urban citizenship. Dublin: Trinity College.

[37] P. , D. M. , C. , M. , & H. Jones, "Understanding Travel Behaviour," *Gower Pub Co*. 1983.

[38] Kenya Law, "The National Council for Law Reporting. (2015)," Public Procurement and Asset Disposal Act- Laws of Kenya .

[39] LERU, "Gendered research and innovation: Integrating sex and gender analysis into the research process," www.leru.org/files/Gendered-Research-and-Innovation-Full-paper.pdf.

[40] L. Lopez, "5 Cities, 5 Ways to Make Urban Mobility More Sustainable and More Equitable," https://impakter.com/5-cities-5-ways-to-make-urban-mobility-more-sustainable-and-more-equitable/.

[41] Maas Alliance Group 3, "Interoperability for Mobility, Data Models, and API. Creative Commons license," https://maas-alliance.eu/wp-content/uploads/2021/11/20211120-Def-Version-Interoperaability-for-Mobility.-Data-Models-and-API-_-FINAL.pdf.

[42] L. Makkonen, "Compound and Intersectional Discrimination: Bringing the Experiences of The Most Marginalized to The Fore," Turku: Institute For Human Rights, Åbo Akademi University.

[43] A. , & D. R. Murray, "Equity in Regional Service Provision," Journal of Regional Science, 41(4), 557-835. Retrieved from https://onlinelibrary.wiley.com/doi/epdf/10.1111/0022-4146.00233.

[44] Cairo Monorail, "Cairo Monorail," https://www.railway-technology.com/projects/cairo-monorail/.

[45] J.-P. , C. C. , & S. B. Rodrigue, "The Geography of Transport ," Routledge, Taylor and Francis Group.

[46] S. Sami, "Cairo Bike: Egypt's first bicycle sharing project," Ahram Online. Retrieved from https://english.ahram.org.eg/News/467260.aspx.

[47] N. , M. Y. , K. S. , & M. R. Shafik, "The Impact of the Cairo Streets Development Project on theIndependent Mobility of Children," *A Field Study on the Streetsof Heliopolis, Egypt. infrastructures* . 2021.

[48] SIS, "PM follows up project to manufacture Egyptian EV," Retrieved from State Information System SIS: https://www.sis.gov.eg/Story/177778/PM-follows-up-project-to-manufacture-Egyptian-EV?lang=en-us.

[49] TADAMUN, "Urban Mobility: More than Just Building Roads," http://www.tadamun.co/urban-mobility-just-building-roads/?lang=en#.YyPa2HZBwdV.

[50] T. TICD, *How can Transit Mapping contribute to achieving Adequate Urban Mobility?* 2017.

[51] U. UN Women, "Intersectionality Resource Guide and Toolkit. An Intersectional Approach to Leave No One Behind," 2021.

[52] UN-Habitat, "Gender Sensitive Mini-Bus Services & Transport Infrastructure for African Cities: A Practical Toolkit," United Nations Human Settlements Programme (UN-Habitat). Retrieved from https://unhabitat.org/sites/default/files/download-manager-files/Gender%20Toolkit.pdf.

[53] The Department of Economic and Social Affairs of the United Nations Secretariat, "UN Flagship Report on Disability and Development," 2018.

[54] United Nations, "UN-Habitat ," Retrieved from United Nations: https://sdgs.un.org/un-system-sdg-implementation/united-nations-human-settlements-programme-un-habitat-24511.

[55] United Nations, "United Nations," Department of Economic and Social Affairs; Statistics Division. Retrieved from United Nations: https://unstats.un.org/sdgs/report/2023/Goal-11/.

[56] United Nations, "United Nations," Department of Economic and Social Affairs; Statistics Division. Retrieved from United Nations: https://unstats.un.org/sdgs/report/2023/Goal-11/.

[57] United Nations Environment Programme and United Nations Human Settlements Programme, "Walking and Cycling in Africa, Evidence and

Good Practice to Inspire Action," United Nations Environment Programme and United Nations Human Settlements Programme. Retrieved from https://wedocs.unep.org/20.500.11822/40071.

[58] S. Werland, "Diffusing Sustainable Urban Mobility Planning in the EU. Sustainability," https://d-nb.info/1223023281/34.

[59] Cairo Metro. (n.d.)., "Metro History," https://cairometro.gov.eg/en/about/1.

[60] Cairo Metro. (n.d.)., "Passenger Services," https://cairometro.gov.eg/en/passengers/1.

[61] Central Agency for Public Mobilization and Statistics (CAPMAS)., "On the occasion of the International Day of Child Rights," CAPMAS.

[62] Central Agency for Public Mobilization and Statistics (CAPMAS), "On the Occasion of International Day of People with Disabilities (IDPD) 2020," CAPMAS.

[63] Central Agency for Public Mobilization and Statistics (CAPMAS), "On the occasion of International Women's Day," CAPMAS.

[64] ITDP, "EXECUTIVE SUMMARY | First Steps: Urban Mobility in Early Childhood," from https://itdpbrasil.org/wp-content/uploads/2021/08/First-Steps-Urban-Mobility-in-Early-Childhood.pdf.

[65] ITDP, "Challenges and Opportunities for Gender-Equitable Transport in Cairo, Egypt," Institute for Transport and Development Policy ITDP .

[66] Law Insider Inc. (n.d.), "disadvantaged group definition," https://www.lawinsider.com/dictionary/disadvantaged-group.

[67] Merriam-Webster, "disadvantaged," : https://www.merriam-webster.com/dictionary/disadvantaged#h1.

[68] Rupprecht Consult, "Sustainable Urban Mobility Plans– Planning for People." 2012.

[69] A. and T. C. G. Schneider Electric, "Urban mobility in the smart city age," https://www.arup.com/perspectives/publications/research/section/urban-mobility-in-the-smart-city-age.

[70] Social Protection & Human Rights, "Disadvantaged and vulnerable groups," Retrieved from Social Protection & Human Rights: https://socialprotection-humanrights.org/key-issues/disadvantaged-and-vulnerable-groups/.

[71] M. Soliman, "Pilot operation of phase three of Cairo Metro's third line to launch on Sunday," Ahram Online. Retrieved from https://english.ahram.org.eg/News/465942.aspx.

[72] TADAMUN, "About TADAMUN," Retrieved from TADAMUN: http://www.tadamun.co/about/?lang=en.

[73] Takween ICD, "ABOUT," Retrieved from Takween ICD: https://www.takween-eg.com/about.

[74] The United Nations Network on Racial Discrimination and Protection of Minorities, "Guidance Note on Intersectionality, Racial Discrimination & Protection of Minorities," OHCHR.

[75] The World Bank, "Global Mobility Report: Measuring Progress Toward Safe, Clean, Efficient, and Inclusive Transport," Retrieved from The World Bank Group: https://www.worldbank.org/en/results/2020/11/11/global-mobility-report-measuring-progress-toward-safe-clean-efficient-and-inclusive-transport.

[76] Transport for Cairo, "Our Work," Retrieved from Transport for Cairo: https://transportforcairo.com/work/.

[77] K. Viswanath, "Creating Engagement in Public Spaces for Safer Cities for Women," Retrieved from United Nations Human Settlements Programme: https://unhabitat.org/public-spaces-for-safer-cities-for-women.

[78] WHO. "Age-friendly environments in Europe, A handbook of domains for policy action," World Health Organization. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/334251/9789289052887-eng.pdf.

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A Comprehensive Study of Travel Mode Captivity: A Nuanced Perspective on Car Captivity in New Cairo, Egypt

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ABSTRACT

The distinction between 'captive' and 'choice' user categories has long been a prevalent framework in transportation literature and planning circles. While 'captive' users rely on a sole mode, 'choice' users intentionally choose a particular mode based on perceived benefits. However, this binary classification is increasingly critiqued for its failure to capture the complexities of non-transit users. Not all individuals reliant on cars necessarily fit the traditional definition of "captive" users. This study delves into a nuanced perspective on car dependency, focusing on the degree of attachment to cars, and aims to categorize car-captive individuals beyond traditional definition. Examining the feasibility and implications of such categorization, this research adopts a tailored approach within the context of New Cairo, Egypt. An online geo-referenced survey was employed to measure car dependency potential clustering. The survey encompassed demographic information, travel behaviours, car dependency motives, and experimental travel mode change scenarios. Participants were deliberately selected from a comparable built environment to mitigate external factors' influence. The analysis encompassed both descriptive and inferential statistics, employing IBM SPSS Statistics 22 for a two-step clustering approach. This method, utilizing log-likelihood, revealing inherent groupings in the dataset, elucidating unique clusters related to car dependency. Iterative attempts were made to create a cohesive model, focusing on key variables such as dependency extent, time, and distance. In conclusion, the study findings proposed two other clusters, 'car reluctant' and 'car inclined' which differ in their level of attachment to car and level of intervention. By exploring potential categorizations beyond the conventional binary, this research contributes to urban planning and transportation design, fostering a more sustainable and user-centric mobility system. Also, it offers insights into the choice dynamics and the rigid concept of 'car captivity'.

Index-words: *Car dependent users, Car captivity clusters, and Two-step clustering method.*

I. INTRODUCTION

The categorization of travellers into 'captive' and 'choice' groups has long been a prevalent terminology in transportation literature and planning circles. 'Captive' users rely on a singular mode option. For example, car captives feel obligated to use automobiles due to insufficient transit choices or specific circumstances or simply because they have a personal preference for using cars. Conversely, 'choice' users have various options at their disposal but intentionally opt for a specific mode due to perceived benefits. This dichotomy is facing growing scrutiny, given its limited ability to capture the complexities of individuals' travel behaviours and preferences. Dividing travellers into just two categories, namely 'captive' or 'choice,' is overly simplistic and fails to provide an accurate and nuanced representation. The definitions associated with these labels often lack the necessary precision and consistency, casting doubts on their practical applicability in real-world scenarios.

In the realm of public transportation, mode captivity has emerged as a crucial term influencing decisions regarding transit planning, services, and investment. Transit ridership models tended to underestimate the diversity or range of transportation choices available to captive users. In other words, they may oversimplify the options or assume that everyone in this category uses the same mode of transportation, has the same preference and the same quality of transportation service.

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Reconsidering the concept of mode captivity, and recognizing its significance in segmentation is important to address market requirements and anticipate future demands. However, the challenge of making suitable definitions for mode captivity that seamlessly integrate into the transportation choices of individuals poses difficulties. This prompts a comprehensive investigation of the mode captivity concept, highlighting the significance of including motives, preferences and circumstances around mode dependency.

The existing literature in this field suffers from limitations, being either too scarce or overly reliant on rigid, established terminology. To address this issue, some researchers have introduced an intermediary concept that falls between the two extremes of 'captive' and 'choice' users, known as 'potential riders.' These are individuals who may consider using public transit under specific conditions and might abstain from car usage. Also, the concept of categorizing 'choice' users into different segments based on the nature of their transportation choices has been explored to some extent. However, there remains a notable gap in the literature regarding the categorization of 'captive' users, particularly in the context of 'car captivity.' Additionally, the transfer of research findings from developed countries to developing ones often lacks the necessary contextual adaptation. This underscores the importance of conducting studies that are specifically tailored to the unique settings and conditions of a given region. As exemplified by the focus of this paper on New Cairo, Egypt, it is essential to account for the local context and circumstances when conducting transportation research.

This study aims to examine captive users' segmentation, believing that segmenting the captivity into more categories enhances the accuracy of decision-making strategies and interventions, focusing on car captivity. The study delves into the possibility of categorizing individuals based on the degree of attachment they have to their cars and their willingness to shift to alternative modes of transportation. Not all car-dependent users may neatly align with the conventional understanding of "captive" users. This complexity prompts the researchers to embrace a precise outlook on car dependency and the underlying reasons for this dependence. This becomes crucial as the researchers delve into understanding their requirements for shifting to alternative modes. The implications of such categorization are particularly noteworthy for urban planners and designers, especially in a context that embraces automobile-oriented planning. The study also examines the factors and motives affecting car dependency in order to deeply understand the decision-making criteria and justify their degree of attachment to the car.

To delve into this exploration, the research utilized an online geo-referenced survey to explore the travel patterns and motives for car reliance and the potential categorization within the community of New Cairo. The selection aimed to include participants from a similar built environment to mitigate the influence of factors like built environment, travel mode options, and accessibility. The analysis employed descriptive and inferential statistics, including Chi-Square tests due to categorical data. IBM SPSS Statistics 22 was used for two-step clustering. This method was used to reveal inherent groups within the dataset based on key variables such as dependency extent, time and distance. The outcome clusters were then verified with the degree of change that is discussed later in the study.

In summary, this study explores travel decision behaviours, by shedding light on car dependency while delving into the concept of "car captivity" and its potential categorization. This study helps to provide valuable insights into the nuanced levels of captivity driven by personal preferences and motives, offering a profound understanding that can be instrumental in meeting market demands and effectively motivating specific segments of individuals who heavily lean on automobiles. This reliance often arises from their discontent with transit services or the limited availability of practical alternatives that meet their needs. The researchers aspire to enrich understanding of car dependency dynamics and the factors influencing it. Ultimately, the findings could contribute valuable insights to guide urban planning and transportation design, fostering a more sustainable and user-centric mobility

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system.

A. Background

The transportation literature broadly categorizes users into two main groups, 'captive' and 'choice' users. These terms have been widely used in academic literature and in professional transportation planning circles for many years such as Brown (1983), Polzin, Chu, and Rey (2000), Peng, Yu, and Beimborn (2002), Beimborn, Greenwald, and Jin (2003), Krizek and El-Geneidy (2007) among others as cited in Jacques et al. (2012). In the public transit industry, transit captivity has long been a fundamental factor influencing transit planning, service, and transport investment decisions (Polzin et al., 2000). In light of this context, it is essential to re-examine the concept of captivity, given its importance in decision-making and in exploring potential strategies for promoting more sustainable travel choices. Despite the ambiguity associated with these terms, the definitions of captive and choice remain vague and have a lot of variations. The absence of a precise and consistent definition for captive and choice users of a particular mode creates confusion regarding their practicality (Polzin et al., 2000).

The American Public Transportation Association defined captive riders as individuals "who lack access to a personal vehicle or the ability to drive (for any reason) and rely on transit for their intended trips" (2002). Captive users predominantly depend on transit as their primary mode of transportation (particularly for specific locations, like work). On the other hand, choice users (also termed discretionary riders) have alternative transportation options to reach diverse destinations but opt for transit for specific reasons (Beimborn et al., 2003; Krizek and El-Geneidy, 2007). Beimborn et al. (2003) described individuals who have no other option available to them as captive users. Transit captives are those individuals who do not have a driver's license or do not own a car while car captives feel compelled to use cars due to inadequate transit options or specific circumstances. Conversely, choice users are those who possess multiple options but deliberately choose a particular mode due to perceived advantages. However, the rigid distinction between these categories fails to encompass all scenarios (Krizek and El-Geneidy, 2007; Jacques et al., 2012).

Increasing ridership represents a substantial goal within transportation sector development, yet it often fails to target an understanding of non-transit riders' preferences (such as car captive users). The literature frequently uses these two terms, failing to make an effort to comprehend individuals' inclinations and preferences concerning their levels of captivity (El-Badawy et al., 2021). Changes in captivity status are not correlated with preferences (enjoyment), and circumstances such as finding satisfaction in using transit despite owning a car or experiencing shifts in income can lead individuals to shift from being captive riders to becoming choice riders (Singleton, 2019). Cervero and Radisch (1996) emphasized that the built environment significantly shapes decisions regarding travel modes. In this context, nothing aligns more seamlessly with car-oriented planning than the car itself. In this situation, it is merely a necessity, but their preference varies.

Discerning various levels of captivity based on preferences holds significance in catering to market needs and motivating specific groups of individuals who heavily rely on cars, either due to dissatisfaction with transit service or the absence of viable alternatives. A study on the opening of the Orange Line in Chicago revealed that a portion of transit users were former automobile commuters who switched to transit (Krizek and El-Geneidy, 2007). This hints at the existence of a latent demand for new transit users. However, there is limited research on the characteristics of the two users. Non-users can be categorized as potential riders and auto captives, as cited by Krizek and El-Geneidy (2007). Potential riders are individuals who might consider using transit under specific circumstances, while auto captives are exclusively automobile users who do not realistically consider transit as an option.

The transit sector primarily targets potential riders to increase ridership, emphasizing the importance of understanding the factors that encourage potential riders to become choice riders while disregarding car captive. Challenges arise when attempting to categorize individuals who engage in transportation modes other than car ownership or opt for transit, irrespective of the options available to them, their preferences, and circumstances. As a result, relying on the

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captive and choice labels becomes uncertain, as these classifications cannot be generalized and instead must be understood within specific contexts.

The application of literature from developed countries to developing countries is limited and lacks contextualization (Fang et al., 2021). For instance, while car usage is a choice in developed countries, it plays a significant role in developing countries due to insufficient public transportation and limited alternatives located in car-oriented planning like the study area. This highlights the need for studies tailored to specific contexts. In Cairo, Egypt, old neighbourhoods with crowded streets and grid street patterns discourage the use of public transport, leading residents to opt for private alternatives. In contrast, modern neighbourhoods with lower density and distinct land use make public transportation less feasible, resulting in a similar reliance on private alternatives and the associated negative consequences (Ghonimi, 2017). Although Egypt is a developing country, the number of car ownership is increasing rapidly. When individuals' income gets higher, they tend to choose private car ownership, whether paid in full or through instalments, rather than using public transportation. This preference is reinforced when public transport modes are perceived as unsafe, unreliable, uncomfortable, and of subpar quality (Abdel Wahed Ahmed and Abd El Monem, 2020). In the literature concerning the Egyptian context, the focus is primarily on identifying the variables influencing travel patterns and choices, with an emphasis on understanding the reasons for car dependence. However, these discussions often overlook individuals' preferences and their willingness to consider alternatives or abandon car usage if other viable options that meet their needs are offered. This underscores the significance of this paper in addressing these aspects and emphasizes the necessity for further studies specifically tailored to the Egyptian context. Such research is crucial for advancing mobility solutions with a user-centric approach.

B. The Case Study 'New Cairo'

New Cairo was founded in the late 90's to ease downtown congestion and extend the borders of Cairo's capital. It was one of the new urban communities (NUCs) that emerged in the east to counter the swift urbanization occurring nationwide and address persistent challenges. Although the initial vision for New Cairo aimed at fostering inclusive urban development, its actual evolution led to social exclusion, largely attributed to the emergence of enclosed gated communities and social segregation. As analysed from the fieldwork of the study, the gated compounds constitute 31% of the entire built-up area, in contrast to 0.05% of the social housing. Consequently, New Cairo became a magnet for affluent and upper-middle-class segments of society. New Cairo is vital for connecting old and new capitals, becoming a transit hub through projects like monorails, metro expansions, and the BRT system (see Figure 2) (Hegazy et al., 2019).

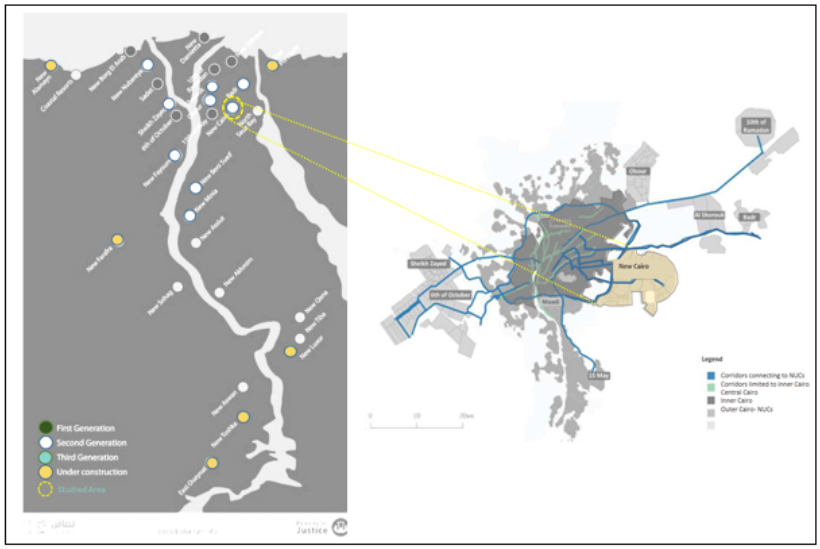

Fig. 1. New Cairo (the study area)
Source: www.Tadamun.info and TFC Report

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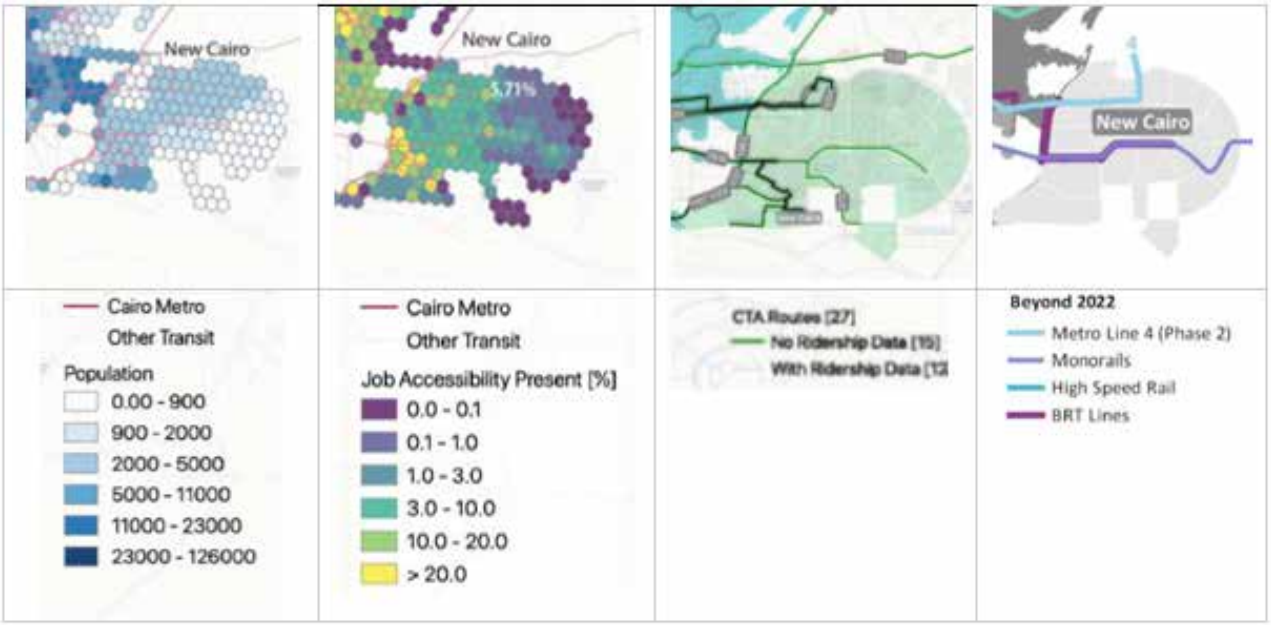

Fig. 2. Population distribution, job accessibility and public transport routes
Source: TFC Report

Population density within the region exhibits an uneven distribution, with the north-western sector boasting a higher concentration of residents (see Figure 2). This phenomenon can be attributed to several factors. Firstly, this area offers affordable housing options, making it an attractive choice for many. Secondly, its close proximity to the ring road, facilitating swift connections to the city centre and neighbouring districts, contributes to its popularity. Additionally, the presence of public transportation buses, shuttling passengers from New Cairo to the city centre. On the contrary, the eastern part of the region remains less developed, characterized by a prevalence of gated compounds and pockets of vacant land interspersed throughout (see Figure 3). The availability of public transportation in this area is comparatively more limited, underscoring the disparities in development and accessibility. The substantial distances between destinations and the homogeneity of land use patterns in this area have amplified the reliance on cars, making it less conducive for residents to opt for pedestrian travel to access nearby services. Especially given the absence of shaded streets, which renders walking during the summer months particularly challenging (see Figure 3). The primary mixed-use hub is strategically positioned at the heart of the plan, aligning with the two main arterial roads. In addition, local commercial zones are thoughtfully distributed within the core of each neighbourhood, ensuring accessibility and convenience for residents. As seen in Figure 4, the road network begins with main arterial roads, which typically have widths ranging from 70 to 90 meters. These primary roads then branch out into almost a grid system, dividing the overall plan into distinct zones (neighbourhoods) where local streets are situated. Unfortunately, the pedestrian network in this area is inadequate as the car is prioritized due to the streets' width and the absence of safe crossing areas. Public transport is primarily available on the primary roads. As a result, there is a significant challenge when it comes to covering the first and last mile distances, as there are no transportation options readily available for these short distances.

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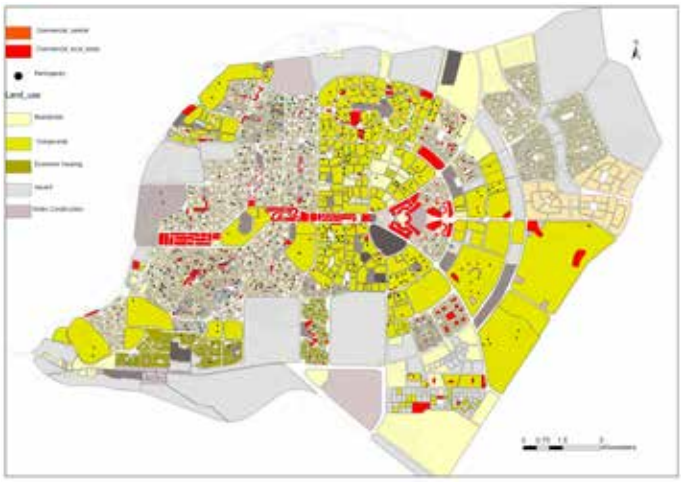

Fig. 3. Land use distribution New Cairo
Source: The authors

Fig. 4. Sample distribution, road hierarchy
Source: the authors

II. METHOD AND PARTICIPANT SELECTION

The study relied on an online geo-referenced survey. The survey was carried out online (voluntary and anonymous) across multiple platforms associated with the New Cairo residents. Participants who willingly responded to the survey were requested to share the survey with people residing in the designated study area. The study intended to choose participants residing within the similar built environment, in order to mitigate the effects of factors of the built environment itself, available travel mode options, and the degree of accessibility to services.

In order to attain a strong 95% confidence level while maintaining a 5% margin of error in the survey outcomes, the sample size was calculated employing Cochran's sample size formula (Megahed et al., 2020). The population was estimated to be 300,000 as per the estimations of the New Cairo Authority 2020, resulting in the identification of a representative sample comprising 384 respondents as the intended target (Governorate, 2022). As seen in Table I, the sample demonstrated a relatively even distribution across age and gender groups. However, owing to the predominantly high socio-economic status of New Cairo's residents, the sample exhibited a bias towards certain economic level, residential block type, and primary mode of travel. The high percentages of travel intensity is also noticed due to the low densities and the long distances of the studied area.

$$n = \frac{x^2 \times P(p-1)}{e^2}$$ *Cochran's sample size formula*

The presented study relied on 351 participants out of 400, all of whom indicated that their primary mode of transportation is the car. This purposeful selection is intended to align with the study's aim of classifying car-dependent users into clusters according to their level of attachment to their cars. This classification, when combined with the attitudinal section of the survey, seeks to achieve a more profound understanding of the reasons behind the attachment to cars.

TABLE I: SOCIO-DEMOGRAPHIC DISTRIBUTION OF THE SAMPLE

- Gender	***F*** *(57%)*	***M*** *(43%)*		
-Age	***18-24*** *(6%)*	***25-40 Year*** *(48%)*	***40-60 Year*** *(35%)*	***>60 Year*** *(10%)*
-Employment	***Employed*** *(63%)*	***Not/employed*** *(4%)*	***Freelancer*** *(15%)*	***Other*** *(17%)*
Economic level	***High*** *(56%)*	***middle*** *(41%)*	***Below middle*** *(3%)*	

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-Walkability of Neighbourhood* *(WN)*	***Highly WN*** *(27%)*	***Moderate WN*** *(53%)*	***Low WN*** *(20%)*	
-Residential block Type *(RB)*	***Gated Compound*** *(47%)*	***Social RB*** *(9%)*	***Upper RB*** *(44%)*	
-Travel Intensity *Mobile user (MU)*	***High MU*** *(53%)*	***Moderate MU*** *(38%)*	***Low MU*** *(9%)*	
-Primary Travel Mode	***Car*** *(88%)*	***Carpooling*** *(1%)*	***PT*** *(8%)*	***Ride-hailing apps*** *(3%)*

**The measurement of walkability was conducted by the participants to explore their perceptions of the surrounding built environment. It utilized a 5-point Likert scale addressing three primary aspects: promotion of active transportation modes, accessibility of shops and services within walking distance, and safety.*

A. Survey Design and Data Analysis

The survey was structured into four primary sections: the initial section aimed at gathering demographic information (such as Age, Gender, Economic level, and Employment status). The subsequent section concentrated on travel behaviours, patterns, and preferences. The third segment delved into the factors influencing the persistence of car dependency, encompassing an attitudinal section discussing the reasons for this dependency (von Behren et al., 2018). Lastly, the survey concluded with an experimental component that examined the potential for altering travel modes. This involved presenting new travel options and comparing them against the use of cars (see Figure 5).

1. Degree of Change

The degree of change was based on the willingness of the participant to change their primary mode to other sustainable choices. The participant has to choose one for short trips and one for long trips, which makes the Degree of Change index out of 2.00. As 1.00 for making one change in either the short or long trip, 2.00 for making a change in both designated trips, and 0.00 for no change. This helps in comparing car captivity clusters to the degree of change and the participant's willingness to change their primary mode.

Fig. 5. Experimental model offering other sustainable choices (source: author)

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The study used descriptive and inferential statistical methods to analyse questionnaire responses. Descriptive statistics were used to organize and summarize the data, including frequency distributions for individual questions. Inferential statistics, particularly Chi-Square tests due to the categorical nature of most variables, were used to investigate the significance between variables.

Two-step clustering was done using the log-likelihood measure to reveal natural groupings in the dataset, using IBM SPSS Statistics 22 (Rundle-Thiele et al., 2015). The datasets originated from the survey in which respondents were presented with a series of questions concerning their reliance on cars and the potential for transitioning to alternative modes of transportation. The variables were categorical with an ordinal nature. V1:Car_dependency, V2:Try_another_moder, and V3: Change_mode_Commuting_time. As seen in Table II, (V1 and V2) answers relied on a Likert-type scale designed to measure the degree to which individuals perform certain actions or could do some changes. V3 inquires about the circumstances under which individuals would opt not to use their car, whether it is for local trips or for regional travel outside of New Cairo. As indicated in Table II, V1 assesses the degree of dependency, V2 examines the impact of time, and V3 evaluates the effect of distance on car dependency. Numerous attempts were undertaken to achieve a successful model with a cohesion measure surpassing 0.0; in our case, it recorded 0.4, which stands as a reliable benchmark for evaluating the model, coupled with a good cluster ratio of 1.08.

TABLE II. VARIABLES QUESTIONS IN THE SURVEY
(Source: the authors)

Variables	*Questions in the Survey*
V1 $_{Dependency}$	*'I depend on the car as the only travel mode' to what extent it is true?*
V2 $_{Time}$	*Do you change your primary mode (car) if you have regional trips (long commuting time)?*
V3$_{Distance}$	*In which of the following cases, would you leave your car and try another mode?*

2. Study's Limitation

The study's limitation lies in the socio-economic makeup of the sample, predominantly comprising individuals from the upper-middle to upper social class. This composition might not fully capture the diversity of the broader population. However, this bias could be advantageous for the study's purpose, given that the focus is on car dependency, a capability more prevalent in this socioeconomic stratum.

III. RESULTS AND DISCUSSION

It was found from the survey that there are several factors that influence car dependency. Some of them were found to be statistically significant using the Chi-Square test. The "strongly true" and 'true' statements that indicate high agreement with the statement mentioned in Table II, 'I depend on the car as the only travel mode', are remarkably high among the "high mobile users" group, whose total trip duration per day is around 1 hour or more. They resemble more "lonely commuters" and "Drop off" companions. The age range varies from 25 to 60 years old, with a moderate to high economic status. Disagreement with the statement was negligible across most of the variables. This could be due to a consistent trend shared among the participants (see Figure 6).

TABLE III: P-VALUE TEST WITH RESPECT TO THE 'CAR_DEPENDENCY ' VARIABLE

Variable	P-value
Age	**<0.00**
Gender	**<0.20**
Economic level	**<0.75**
Traveller's Characteristics	**<0.00**
Degree of Change	**<0.11**
Total trips duration	**<0.03**
Travel Intensity	**<0.10**
Change mode commuting time	**<0.00**

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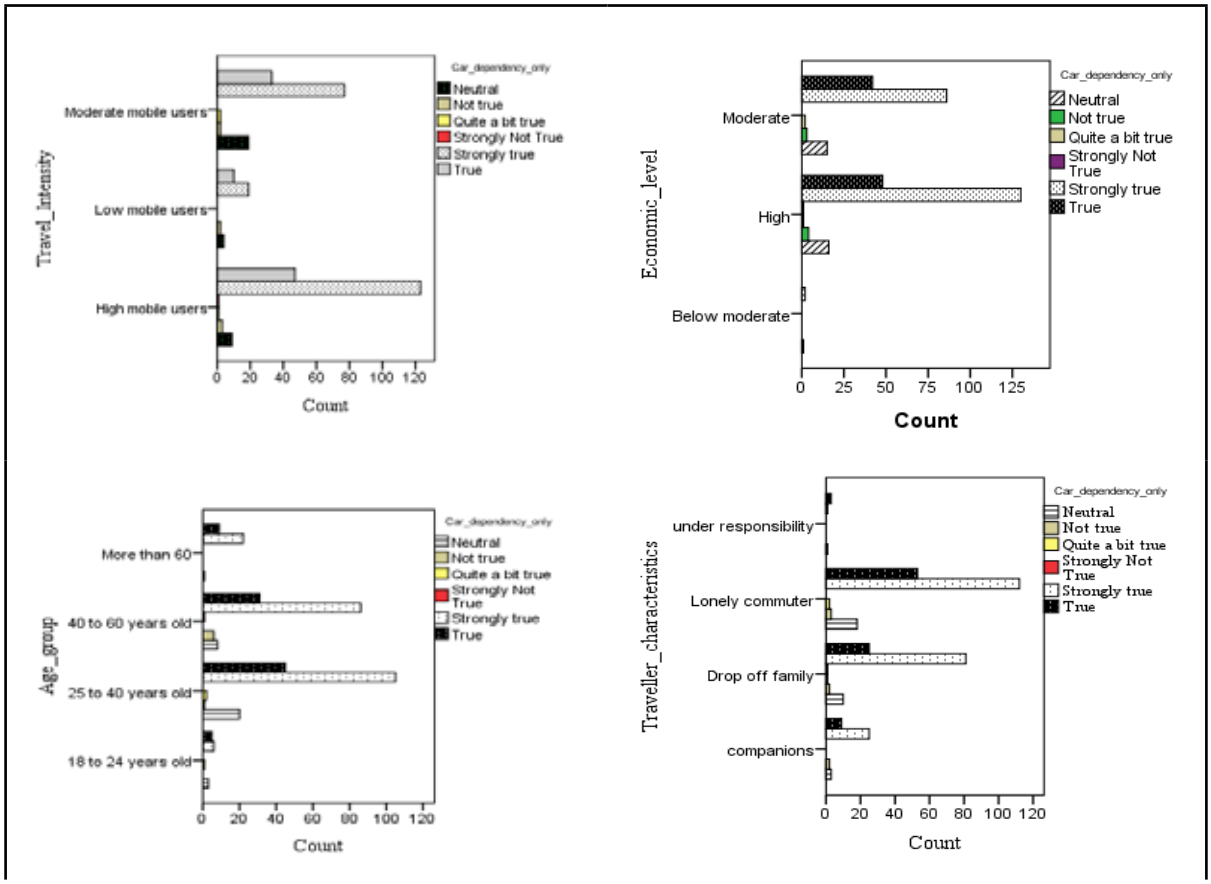
The variables underwent testing for significance with respect to 'Car_dependency.' Among these variables, 'age,' 'traveller's characteristics,' 'total trip duration per day,' and 'change mode according to commuting time' exhibited a high level of significance. However, 'Economic_level' did not show significance, which could potentially be attributed to the non-representative nature of the sample across the three economic groups (see Table III).

Regarding the attitudinal section, as shown in Table IV below, 42% of participants reported experiencing a sense of excitement when using cars. The car provided them with the luxury of increased flexibility, companionship, reduced waiting times, and the convenience of using the vehicle as storage for personal items. 77% of participants mentioned that challenging weather conditions during summer and winter, coupled with a lack of shaded streets, discouraged walking. This observation corresponds with their perception of the neighbourhood's walkability, as presented in Table I, where only 27% indicated high walkability. This situation might be attributed to the low-density built environment of the studied area, characterized by leapfrog development. The absence of integrated mobility solutions, along with deficiencies in public transport autonomy and smart modes, accounted for 37%, 33%, and 20%, respectively. These percentages underscore the transportation sector's failure to adequately address the requirements of New Cairo's intended residents. These individuals seek smart technologies such as online tracking and ticketing, as well as intermodal digital platforms. In terms of the built environment, they express a need for secure bike lanes and versatile unconventional transit hubs. Furthermore, in the realm of transportation modes, there is a demand for innovative mobility options like scooters and electric vehicles that align with their convenience preferences.



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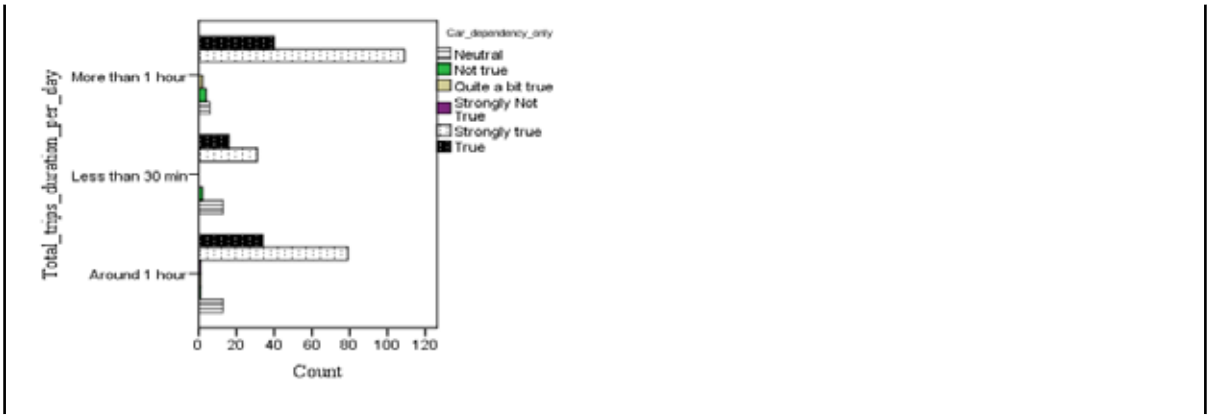

Fig. 6. Car dependency in relation to other variables
Source: the authors

TABLE IV: THE RESULTS OF THE ATTITUDAL FACTORS: REASONS FOR CAR DEPENDENCY

Car Excitement	***CE***
▪ *Driving my car makes me move around freely* ▪ *Pick up others and drop them* ▪ *Carry things that make my car as my bag* ▪ *A tight schedule makes me sensitive to waiting time*	*42%*
Integrated Mobility Deficiencies	***IMD***
• *Need Safe bike lanes* • *Need tram line that connects new Cairo main commercial centers* • *Need a transportation hub that has facilities like parking, commercial shops and banks* • *Need fixed route private buses* • *Need continuous maintenance within a high-standard interface* • *Need light rail that is well networked all over New Cairo*	*37%*
Public Transport Autonomy	***PTA***
• *No efficient and quick mobile app. that offers the best travel options* • *No online tracking of arrival/departure* • *No inter-modal digital platform*	*33%*
Weather Resistance	***WR***
• *Tough weather in summer & winter prevents using PT* • *Shaded streets for walking*	*77%*
Smart Modes Absence	***SMA***
• *Need unlock and go scooters* • *Need unlock and drive electrical vehicles*	*20%*
Privacy and Safety in Car	***PSC***
• *Feel more safe when I am in my car* • *Privacy issue, I don't feel comfortable in public transport* • *Sensitive to physical movement so car is the best option*	*24%*

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In summary, the absence of comprehensive integrated mobility solutions seems to play a role in fostering heightened car dependency among New Cairo's residents. Their preferences for smart technologies, improved built environment features, and innovative transportation options underscore their desire for more convenient choices. Addressing these elements in a comprehensive manner has the potential to diminish reliance on cars and promote a more sustainable and diverse mobility environment in the region.

A. Car Captivity Clusters

As a consequence of the Two-Step clustering process using the log-likelihood measure, depicted in Figure 7, which is a recognized method for handling categorical variables (Norusis, 2009), distinct groups of individuals reliant on cars were identified using pivotal variables derived from the survey outcomes (dependency, time and distance, see Table II). As presented in the figure, the model outcome was four clusters, but the researchers combined Cluster (1) and Cluster (2) due to their similar characteristic of displaying strong agreement regarding the lack of willingness to replace the car. The outcome of this analysis concluded in the formation of distinct clusters, subsequently inspiring an alternative approach to transportation market segmentation. This involves three distinct market segments; namely, car captive users, car inclined users, and car reluctant users, ranked in a descending order of attachment strength from the highest to the lowest.

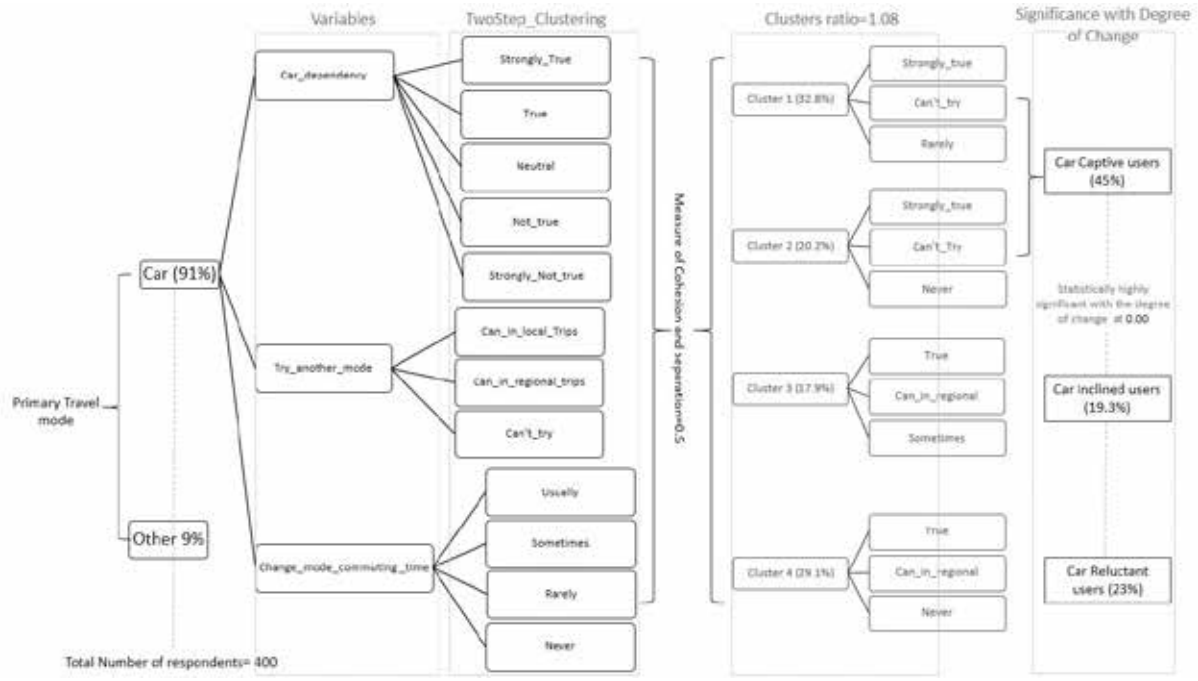

Fig. 7. Two-step Clustering for V1, V2, V3 to segment car dependency using SPSS
Source: the authors

To validate the clustering results, following Norusis (2009), Pearson's chi-squared test was applied to confirm significant differences among the clusters across the segmentation variables. The test yielded a p-value of <0.05, indicating high significance. After validating the clustering, One-way ANOVA was utilized to assess the relationship between the clusters and the degree of change variable.

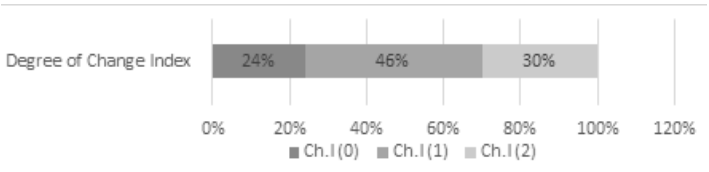

Fig. 8. Degree of change for the experimental section
Source: the authors

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The results, as shown in Table V, indicate that there are indeed differences among clusters in relation to the (Degree of Change) variable. The results of the One-way ANOVA analysis revealed statistically significant differences among the clusters concerning the degree of change variable. This implies that the clusters are not uniform in terms of their responses to changes, and there are distinct variations in how they respond. The high level of significance suggests that the observed differences are unlikely to occur by random chance alone. These findings strengthen the validity of the clustering results and underscore the importance of the identified clusters in relation to the degree of change variable.

TABLE V: SIGNIFICANCE BETWEEN CLUTERS AND DEGREE OF CHANGE USING ANOVA

ANOVA

Degree_of_Change

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.769	3	2.256	4.305	.005
Within Groups	181.853	347	.524		
Total	188.621	350			

1. Interrelationships between car captivity clusters and other variables

The analysis revealed a statistically significant relationship between car captivity clusters and walkability of the neighbourhood ($p < 0.05$). Also, the relation between car captivity clusters and traveller's characteristics was found to be statistically significant at ($p<0.05$). As shown in Figure 9, the group of lonely commuters exhibited the highest representation within the captive and reluctant clusters. Interestingly, individuals who consistently drop off their family members displayed a fair inclination, prompting considerations about its feasibility. Those who exclusively rely on their own driving and do not have dependents are likely to find transitioning to alternative modes less feasible compared to those responsible for transporting others, which needs further investigation.

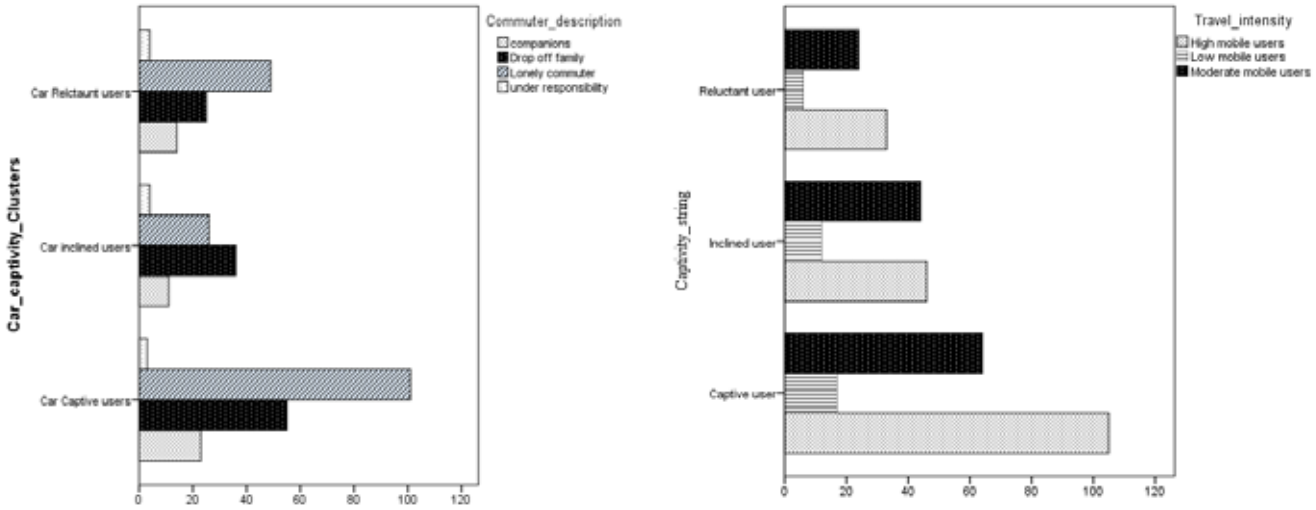

Fig. 9. Car captivity clusters with other variables

Travel intensity did not demonstrate statistical significance; however, the captive users prominently featured a substantial number of high travel intensities. In contrast, the inclined cluster exhibited an even distribution of both high and moderate mobile users. The results suggest a moderate influence of travel intensity on the degree of car captivity. As proposed by Jacques et al. (2012), the likelihood of individuals transitioning from automobile travel to other modes is diminished when confronted with potentially long travel distances, a circumstance applicable to the studied area.

Gender exhibited statistical significance with a significance level of $p < 0.05$. Tiikkaja & Liimatainen (2021) previously established a correlation between gender and car usage, noting that women often prioritize safety and privacy. This observation aligns with the

researchers' findings, as females displayed a greater tendency towards car captivity compared to males.

The relationship between car captivity clusters and age or economic level variables was not found to be statistically significant. However, this lack of significance does not necessarily imply the absence of an influence. As noted by Lansley (2016), car ownership and dependency have frequently been considered indicators in demographic assessments for gauging prosperity or societal status. This suggests the requirement for additional investigation.

The significance of this study is underscored primarily by its innovative methodology. The experimental section of the survey stands out for its efficacy in exposing alternative choices through the use of illustrative cards, strategically influencing participants' decisions in a positive direction. The introduction of illustrative cards during the survey induced a pronounced shift in the participants' decisions. This effect was especially prominent among those who were initially faithful proponents of 'car-dependency.' Remarkably, a substantial proportion of these participants exhibited a shift of 1.0 or 2.0 degrees in their preferences. This not only signifies a remarkable advancement in influencing perspectives but also underscores the critical importance of incorporating visual aids in survey design.

The study introduces a novel concept by challenging the conventional notion of treating "car captives" as a monolithic group. Instead, it innovatively segments this seemingly rigid category into clusters based on participants' varying degrees of attachment to their cars. This strategic approach not only breaks down a complex term but also refines interventions by tailoring them to the specific needs of users. The brilliance of this approach lies in its ability to capture the nuanced spectrum of individuals' attachments to their cars. By recognizing and categorizing different levels of attachment, the study provides a more granular understanding of user preferences and behaviours. This segmentation, in turn, enhances the precision of interventions, ensuring that strategies are finely tuned to address the distinct needs of each cluster within the broader category of "car captives."

In summary, the study utilized a comprehensive methodology, integrating survey data, an experimental approach, and advanced statistical techniques. This approach provided insights into participants' attitudes and behaviours related to car dependency and alternative transportation modes, contributing to a nuanced understanding of the factors influencing transportation choice.

B. Implications for Policy and Future Research

The study suggests a need for policy interventions that address the specific needs and preferences of different user groups, including gender-specific transportation solutions. Additionally, the findings highlight areas for further research, particularly in understanding the nuanced impacts of economic status and age on transportation preferences.

– **Towards Sustainable Urban Mobility:** Ultimately, the study advocates for a shift towards more sustainable, efficient, and inclusive urban mobility solutions. By acknowledging and addressing the varied reasons behind car dependency, New Cairo can pave the way for a more environmentally friendly and accessible transportation system, catering to the diverse needs of its residents.

– **Opportunities for Urban and Transportation Planning:** The findings present a compelling case for urban planners and transportation authorities to rethink and redesign the city's mobility landscape from a user-centric approach. Integrating smart transportation technologies, enhancing walkability, and developing comprehensive and integrated public transportation networks could significantly reduce car dependency.

IV. CONCLUSION

In summary, the survey results underscore a prevailing reliance on cars as the primary mode of transportation. Notably, 42% of respondents express excitement for car usage, aligning with the percentage observed for the 'car captives' cluster due to the convenience, comfort, and personal space it offers, as well as the social status it may confer. A clear correlation emerged between time and distance and an increase in car dependency, these relationships were found to be statistically significant. The

lack of comprehensive integrated mobility solutions and the absence of smart technology has proven to be discouraging factors for individuals heavily reliant on cars, inhibiting their willingness to embrace alternative modes of transportation. The absence of user-friendly and technologically advanced options could preserve car-centric behaviour, limiting the potential for sustainable mobility alternatives. Moreover, the presence of tough weather conditions during both summer and winter, coupled with a lack of properly shaded streets, contributed to the discouragement of active modes, as reported by 77% of participants. This observation was consistent with their perception of the low walkability of the neighbourhood. Regarding traveller characteristics, a significant association was discovered with car dependency. Individuals who consistently travel with companions, responsible for dropping off, exhibited a pronounced reliance on car usage, indicating challenges in substituting this mode of transportation.

Insights

- **Attitudinal Factors:** Residents cite excitement in using cars, and reduced waiting times as reasons for car dependency. Concerns about weather conditions discourage walking, while the lack of integrated mobility solutions and smart modes further push towards car usage.
- **Statistically Significant Variables:** Age, traveller's characteristics, total trip duration per day, and change mode according to commuting time are significant in relation to car dependency.

A. Captivity Clusters

The study's importance is presented in the innovative two-step cluster analysis approach designed to segment car-dependent users. This method proves highly effective in aligning with market demands and precisely targeting distinct user groups. Stratifying the segment of car captive users based on their tendency to adopt alternative modes are tested with time, distance and level of dependency variables, had unveiled two pivotal clusters: the 'inclined car users' and 'reluctant car users'. These groups hold significance due to the potential efficacy of transportation interventions in effecting a reduction in car dependency. The clusters identified in this study displayed a statistical significance with the degree of change variable, affirming the robustness of the segmentation process and highlighting the presence of distinct groups with closely aligned characteristics. First, there are the 'car captives' who see their cars as symbols of luxury and value the flexibility, companionship, reduced waiting times, and storage convenience they provide. Additionally, they may associate social status with their cars. On the other hand, 'car inclined' individuals maintain a positive view of cars, considering them essential for daily activities but are willing to explore alternative options for short trips if they come with smart technologies and luxurious transportation means. Lastly, the 'Car Reluctant' group harbours a generally negative attitude towards cars, yet they do not find convenient alternatives. For them, transportation network coverage, inter-modality, and fare system practicality are key factors in making travel decisions. These insights can inform tailored transportation solutions for each group, addressing their specific needs and preferences.

Insights

- **Walkability and Traveller Characteristics**: There is a significant relationship between car captivity clusters and the walkability of the neighbourhood and traveller characteristics.
- **Travel Intensity and Gender**: Travel intensity showed moderate influence, with captive users having high travel intensities. Gender was significant, with women showing a greater tendency towards car captivity.
- **Age and Economic Level:** These variables were not statistically significant, suggesting a need for further investigation.

In conclusion, this study does not only provide a detailed understanding of the current state of car dependency in New Cairo, but also

offers valuable insights for shaping future urban mobility strategies that are sustainable, inclusive, and responsive to the needs of the residents.

V. References

[1] M. M. Abdel Wahed Ahmed and N. Abd El Monem, "Sustainable and green transportation for better quality of life case study greater Cairo – Egypt," *HBRC Journal*, vol. 16, no. 1, pp. 17–37, Jan. 2020, doi: 10.1080/16874048.2020.1719340.

[2] E. A. Beimborn, M. J. Greenwald, and X. Jin, "Accessibility, Connectivity, and Captivity: Impacts on Transit Choice," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1835, no. 1, pp. 1–9, Jan. 2003, doi: 10.3141/1835-01.

[3] R. Cervero and C. Radisch, "Travel choices in pedestrian versus automobile oriented neighborhoods," *Transp Policy (Oxf)*, vol. 3, no. 3, pp. 127–141, Jul. 1996, doi: 10.1016/0967-070X(96)00016-9.

[4] M. Elharoun, S. M. El-Badawy, and U. E. Shahdah, "Captivity impact on modelling mode choice behavior," *Advances in Transportation Studies*, vol. 53, 2021, doi: 10.4399/97912804143426.

[5] D. Fang, Y. Xue, J. Cao, and S. Sun, "Exploring satisfaction of choice and captive bus riders: An impact asymmetry analysis," *Transp Res D Transp Environ*, vol. 93, p. 102798, Apr. 2021, doi: 10.1016/j.trd.2021.102798.

[6] I. R. Hegazy and W. S. Moustafa, "Toward revitalization of new towns in Egypt case study: Sixth of October," *International Journal of Sustainable Built Environment*, vol. 2, no. 1, pp. 10–18, Jun. 2013, doi: 10.1016/j.ijsbe.2013.07.002.

[7] I. Ghonimi Ibrahim, "THE IMPACTS OF NEIGHBORHOOD LAND USE PATTERNS ON RESIDENT'S SATISFACTION AND PERCEPTION TO SUSTAINABLE URBAN DEVELOPMENT: A COMPARISON OF FOUR NEIGHBORHOODS IN GREATER CAIRO REGION EGYPT," *JES. Journal of Engineering Sciences*, vol. 45, no. 4, 2017, doi: 10.21608/jesaun.2017.116349.

[8] C. Jacques, K. Manaugh, and A. M. El-Geneidy, "Rescuing the captive [mode] user: an alternative approach to transport market segmentation," *Transportation (Amst)*, vol. 40, no. 3, pp. 625–645, May 2013, doi: 10.1007/s11116-012-9437-2.

[9] K. Krizek and A. El-Geneidy, "Segmenting Preferences and Habits of Transit Users and Non-Users," *J Public Trans*, vol. 10, no. 3, pp. 71–94, Sep. 2007, doi: 10.5038/2375-0901.10.3.5.

[10] G. Lansley, "Cars and socio-economics: understanding neighbourhood variations in car characteristics from administrative data," *Reg Stud Reg Sci*, vol. 3, no. 1, pp. 264–285, Jan. 2016, doi: 10.1080/21681376.2016.1177466.

[11] G. Megahed, A. Elshater, and S. M. Z. Afifi, "Competencies urban planning students need to succeed in professional practices," *Archnet-IJAR: International Journal of Architectural Research*, vol. 14, no. 2, pp. 267–287, Jul. 2019, doi: 10.1108/ARCH-02-2019-0027.

[12] M. J. Norušis, "SPSS statistics 17.0: Statistical procedures companion," *Journal of Business ethics*, vol. 2, no. 13, 2008.

[13] S. E. Polzin, X. Chu, and J. R. Rey, "Density and Captivity in Public Transit Success: Observations from the 1995 Nationwide Personal Transportation Study," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1735, no. 1, pp. 10–18, Jan. 2000, doi: 10.3141/1735-02.

[14] S. Rundle-Thiele, K. Kubacki, A. Tkaczynski, and J. Parkinson, "Using two-step cluster analysis to identify homogeneous physical activity groups," *Marketing Intelligence & Planning*, vol. 33, no. 4, pp. 522–537, Jun. 2015, doi: 10.1108/MIP-03-2014-0050.

[15] P. A. Singleton, "Validating the Satisfaction with Travel Scale as a measure of hedonic subjective well-being for commuting in a U.S. city," *Transp Res Part F Traffic Psychol Behav*, vol. 60, pp. 399–414, Jan. 2019, doi: 10.1016/j.trf.2018.10.029.

[16] H. Tiikkaja and H. Liimatainen, "Car access and travel behaviour among men and women in car deficient households with children," *Transp Res Interdiscip Perspect*, vol. 10, p. 100367, Jun. 2021, doi: 10.1016/j.trip.2021.100367.

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http://dx.doi.org/10.21622/RESD.2024.10.1.751

[17] S. von Behren, C. Minster, M. Magdolen, B. Chlond, M. Hunecke, and P. Vortisch, "Bringing Travel Behavior and Attitudes Together: an Integrated Survey Approach for Clustering Urban Mobility Types," *Transportatio Reseach Record*, no. January, 2018.

[18] https://www.apta.com, "American Public Transportation Association ."

[19] http://www.cairo.gov.eg /ar/Statistics/ elmodonElgadida_2020.pdf, "New Cairo Demographics."

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Coastal Vulnerability Assessment in Urban Planning: A Comparative Tool-Based Selection Approach for the Egyptian Context

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ABSTRACT

In the context of coastal cities facing Sea Level Rise (SLR) and climate extremes, this study seeks to provide Coastal Vulnerability Assessment (CVA) tools for improved urban planning in Egypt. Through a comparative analysis and systematic application of exclusion criteria, the researchers evaluated 16 tools to identify the most suitable options. The objective was to select tools that exhibit the greatest relevance and potential applicability to effectively address CVAs in the region. Among the analyzed tools, 37.5% appeared to align well with the context. Composite Vulnerability Index (CoVI) is notably recommended due to its comprehensive dimension consideration. This approach improves coastal vulnerability understanding and aids planners in decision-making for coastal areas.

Index-words: *climate change, CVA tools, physical vulnerability, SLR, socio-economic vulnerability, tool selection methodology, urban planning.*

I. INTRODUCTION

Cities face high vulnerability to disasters due to their concentrated populations, extensive infrastructure, and diverse activities in relatively small areas (UN-Habitat, 2014; Pregnolato, et al., 2016; Pregnolato, et al., 2017). Coastal cities are prone to vulnerabilities due to climate change impacts, especially Sea Level Rises (SLR) and storm surges. Urban centers in coastal regions, due to their susceptibility to disasters, have socio-economic and physical vulnerability (Celliers & Ntombela, 2016; Helderop & Grubesic, 2019). Although urban disasters primarily impact certain urban areas, their repercussions can extend to a national scale due to the significant physical, social, and economic importance of cities (UN-Habitat, 2014; Celliers & Ntombela, 2016; Mycoo, et al., 2021). Internationally, approximately 500 million people reside in delta areas (Woodroffe, et al., 2006). Deltas are characterized by diverse physical environments, rich ecosystems, and significant socio-economic benefits, but often have a low elevation and are prone to subsidence due to the intensive constructions that facilitate high population densities. According to Islam et al. (2016), Wolters & Kuenzer (2015), Ghosh & Mistri (2021), and Pramanik et al. (2016), coastal vulnerability assessment tools have been widely used in various vulnerable coastal areas, including river deltas.

Egypt is considered a highly vulnerable country, facing challenges such as shoreline erosion, SLR, and land subsidence. Ali et al. (2022) and Torresan et al. (2020) also indicated that the temperature of the sea water and the atmosphere in the Mediterranean Basin region have been increasing and the region is considered a Climate Change (CC) hotspot. Egypt is one of the most vulnerable countries to the potential effects

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of CC, with its northern coastal region being a particularly vulnerable area with a diverse ecosystem, extensive infrastructure and socio-economic activities. The region is particularly susceptible to the anticipated sea-level rise, given its substantial proportion of low-lying lands and sandy or muddy beaches (Hereher, 2015). With a specific focus on the Nile Delta, with its sandy coastlines and low-lying lands as shown in Figure 1, it becomes clear that it is at risk from SLR, land subsidence, shoreline erosion and flooding (Samra et al., 2021). According to SLR scenarios, coastal infrastructures in the Nile Delta, including roads, railways, harbors, etc., will be threatened due to expected storm surges and SLR (Doluschitz & El-Nahry, 2010).

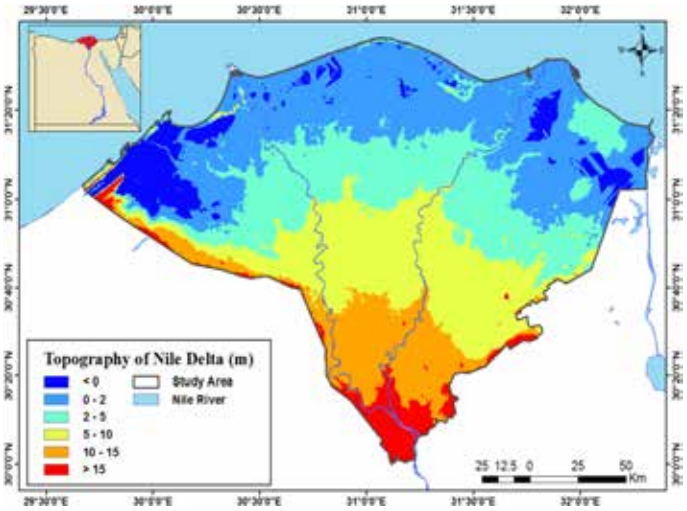

Fig. 1. Topography of Nile Delta region
Source: El-Quilish et al., 2023)

Urban mobility often relies on the road network as vital urban infrastructure, interconnecting major highways, commercial avenues, and residential streets essential for daily regional operations. Ensuring access to this network is significant for economic efficiency, personal and public transportation, and the provision of essential services like education, employment, and emergency services (Helderop & Grubesic, 2019). However, unexpected disruptions due to external factors like disasters can have serious consequences for communities relying on this infrastructure (Helderop & Grubesic, 2019; Pregnolo et al., 2016; Ji et al., 2022). Hence, understanding the impacts of extreme events on transportation systems is crucial, encompassing immediate disruptions, increased congestion, and isolated neighborhoods.

Increasing climate change risks, particularly SLR, highlight the need to enhance infrastructure resilience and durability (Helderop & Grubesic, 2019). Assessing coastal vulnerability is vital for urban planning due to infrastructure's lasting nature. Advanced flood models enable innovative urban modeling with enhanced capabilities and high resolution (Pregnolato et al., 2017).. The urgency of prioritizing physical variables in Coastal Vulnerability Assessment (CVA) for urban mobility arises as few coastal regions proactively strengthen their infrastructure against such challenges (Helderop & Grubesic, 2019). Also, it is worth highlighting that internationally the existing CVA researches lack sufficient studies that focus on the impact of natural disaster events on physical dimensions such as urban mobility performance studies (Singh et al., 2018).. As stated above, the Nile Delta faces significant vulnerability to SLR, storm surge, and coastal erosion (Hereher, 2015; Torresan et al., 2020; Mohamed 2020).. The presence of infrastructure like roads and urban areas intensifies this vulnerability, posing a risk of inundation and erosion (Torresan et al., 2020).. Urgent and effective adaptation measures are essential to mitigate these risks (Frihy, 2017).

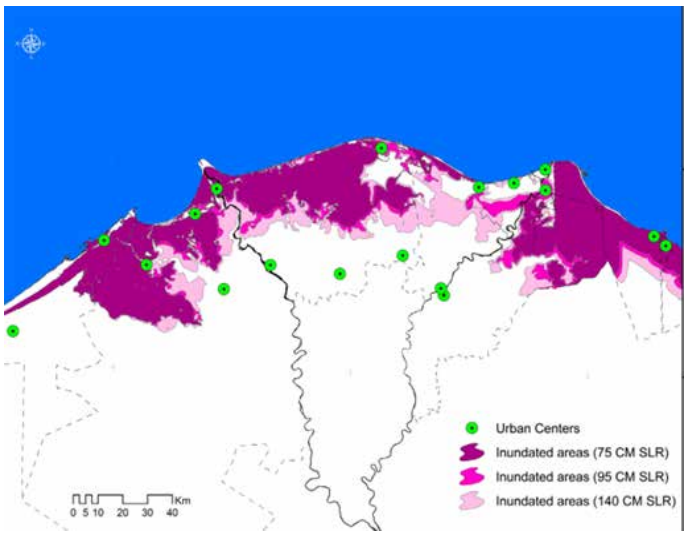

Fig. 2.Inundated areas based on SLR scenarios
Source: (M.A.Abdrabo & MahmoudA.Hassaan, 2015)

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Despite extensive research on coastal vulnerability in Egypt, a notable gap exists in assessing the physical aspect of roads and infrastructure. Studies by Kantamaneni (2016), Hereher (2015), Frihy (2017), and El-Raey (1997) have primarily concentrated on the susceptibility of coastal areas to sea-level rise, particularly along the Nile Delta coast. However, these studies have not specifically addressed the physical vulnerability of roads and infrastructure, critical components of coastal areas. This **literature gap** underscores the necessity for further research to evaluate the physical vulnerability of roads and infrastructure in the Egyptian context, particularly in the context of climate change and sea-level rise. Hence, **the problem** is focused on the significant need for CVAs that comprehensively consider and incorporate variables related to the physical dimension.

McLeod et al. (2015), McFadden et al. (2007), and Royo et al. (2016) also emphasized the lack of a comprehensive and user-friendly method to guide and facilitate the selection of appropriate tools. According to Hemida et al. (2023), existing CVA studies consistently lack justification for the selection of the tools used in the assessment. These studies highlighted another **gap in literature** about the lack of existence of effective methods for evaluating existing coastal vulnerability assessment tools and stressed the significance of a systematic tool selection process that caters for the specific requirements of individual studies. Therefore, the **research problem** revolves around the necessity for a systematic method to select the most appropriate CVA tool for conducting assessments in a specific context. **Two research questions** have arisen from the highlighted gaps in the literature. The first question is, "What effective methods can be employed to evaluate existing CVA tools, and how can a systematic tool selection process be developed to cater for the diverse needs of different studies?" The second question is, "How can a CVA tool be selected to encourage and prioritize the inclusion of the physical dimension?"

The **research aims** to develop a method for the selection of CVA tools by analyzing the characteristics of well-known existing tools and evaluating their success. It also seeks to apply selection criteria that specifically focus on including the physical dimension in the chosen tool. The ultimate goal is to recommend tools for future CVA studies, addressing the gap in attention to the physical dimension. The **research design** utilized a comparative analysis and applied inclusion and exclusion criteria to underscore the importance of effectively incorporating the physical dimension of vulnerability. The study specifically concentrates on the escalating rates of SLR and their repercussions on infrastructure, aligning with the objectives of Sustainable Development Goal (SDG) 13, which pertains to "Climate Action." This aligns with the overarching aim of taking urgent action to combat climate change and its associated impacts and SDG 9, which pertains to "Industry, Innovation, & Infrastructure." This aligns with building of resilient infrastructure.

The research develops a new systematic process for selecting comprehensive CVA tools tailored to the Nile Delta context. The proposed method incorporates both socio-economic and physical dimensions in the assessment, aiming to provide decision-making guidance for planners. The research is structured into four main sections, with an introductory part providing background information. The sections include: (1) Methodology: Outlining the process for selecting CVA tools. (2) Results: Presenting findings based on the comparative analysis and applied criteria. (3) Discussion: Analyzing the success factors derived from the comparative analysis and the shortlisted tools. (4) Conclusion and Future Research: Summarizing the results and providing insights for future research endeavors.

II. Methodology

This research follows an inductive approach to compare and evaluate existing CVA tools in order to select the most relevant tools for application in Egypt. The study aims to provide insights

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into the strengths and weaknesses of each tool, particularly with regard to their capacity to accommodate local scales and incorporate socioeconomic and physical dimensions. This analysis is designed to enhance the researchers' comprehension of how these tools can adeptly tackle the distinct challenges associated with coastal vulnerability as well as their influence on infrastructure and urban mobility. The **first part** of the research involved a desktop review of various sources to assemble a set of CVA tools. These tools were gathered according to the four methods, which are: index-based methods, indicator-based methods, GIS-based methods, and dynamic models. The research included 16 CVA tools, which were not exhaustive. However, the tools where selected based on being the mostly found to be used tools among the reviewed literature.

The **second part** is a comparative analysis conducted to analyze and highlight the differences between the selected CVA tools. The analysis encompassed several criteria such as coastal typology, spatial scale, dimensions included, main driver and impact targeted, inclusion of adaptive measures, as well as data inputs and outputs. The data pertaining to the selected tools was collected and organized into a binary matrix and to aid in visualizing the relationships between the multiple criteria used and the associated CVA tools, a heat map was generated using Microsoft Excel.

In the **third part**, the collected data, comparative matrix, and exclusion criteria were utilized across multiple phases of analysis. Some of the aforementioned characteristics and criteria served as exclusion criteria during the tool screening and selection process, such as coastal areas' types, spatial scale, included dimensions, and the existence of adaptive capacity. The four inclusion criteria were identified based on literature and previously identified gaps in the Egyptian context by Hemida et al. (2023). Ten assessment tools were excluded, and six were shortlisted due to better alignment with the contextual needs of the Egyptian coastal environment, and one was selected for including the physical dimension.

The **fourth part** of this study conducts a success factor analysis to systematically assess the usability of the six chosen CVA tools. This analysis aims to offer valuable guidance for the selection of the most suitable tools for implementing CVA in the specific context of Egypt. It also aims to identify tools that exhibit flexibility, allowing for the integration of additional dimensions and improvements, particularly in terms of incorporating physical data inputs. The assessment is structured around three key dimensions: user friendliness, applicability, and maturity.

III. Results

A comparative analysis of the non-exhaustive list of CVA tools gathered from a literature review was conducted. Assessment tools were categorized according to the four existing methods. Methods include indicator-based approach, index-based approach, Geographic Information Systems (GIS)-based methods, and dynamic models for coastal vulnerability assessment (Oloyede et al., 2021). Indicator and index-based methods depend on variables quantification using numerical assessments to rank coastal areas by vulnerability and rate of vulnerability increase. These rankings enable coastal managers to identify regions with higher vulnerability levels. The resulting index values are used as input data to create vulnerability maps that visually highlight areas of elevated vulnerability (Oloyede et al., 2021 & 2022). However, indicator-based methods aggregate measurements of indices or variables to create a consolidated summary indicator, representing aspects not easily measurable directly (Oloyede et al., 2022). Seven tools were analyzed with regard to indicator and index-based approaches that include the Coastal Vulnerability Index (CVI), CVI-SLR, Social Vulnerability Index (SoVI), Composite Vulnerability Index (CoVI), Multi-Scale CVI (MS-CVI), Coastal Risk Index (CoRI), and Eurosion. GIS-based methods utilize computer tools for processing and visualizing data through interactive maps, relying on

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shoreline attributes, digital land elevation, vegetation, and land use data. This method is notably user-friendly, allowing non-experts to use it easily, and it boasts a straightforward construction process. In the context of GIS-based decision support systems (DSS) methods, the study included two tools, which are the Decision Support System for Coastal Climate Change Impact Assessment (DESYCO DSS) and the THESEUS DSS (Serio et al., 2018; Oloyede et al., 2021; Ramieri et al., 2011). Dynamic models are categorized into two types: sector models, which analyze specific climate change impacts on coastal processes, and integrated assessment models (IAMs), capable of comprehensively studying multiple climate change impacts. IAMs explore diverse research approaches to complex climate change. Their effectiveness stems from addressing climate change's multidimensional nature through interdisciplinary methods, offering insight into its impact on complex systems. However, expertise related to the usage of the software might be necessary. The study analyzes seven dynamic model tools: RACE, SLAMM, FUND, SimCLIM, DIVA, RegIS, and Delft 3D. All tools were collectively evaluated based on set criteria (Oloyede et al., 2021; Gold, 1999).

The comparative analysis included the 16 previously mentioned tools from the above-illustrated methods. As shown in Table A1 in Appendix 1, the comparative analysis was represented in the form of a heat map for a matrix of binary data based on the criteria stated in the methodology part. Regarding the first criterion, coastal typology, the heat map indicated that 75% of the analyzed tools addressed various coastal types, with each type represented by at least one tool from each method. The second criterion, spatial scale, revealed that 71% of index-based and dynamic model tools focused on smaller scales, while only one GIS-based tool considered the local scale, where local scale here considers the neighborhood and city scales. The third criterion, included dimensions, indicated that nearly all tools encompassed the biophysical dimension except SoVI. Only 18% (from index-based and dynamic model tools) included the physical dimension, while 75% covered the socio-economic dimension. Additionally, 56% of the tools considered the ecological dimension in their study. The fourth criterion elucidates the main assessment drivers, predominantly tied to biophysical issues like SLR. Some tools integrated biophysical issues with socioeconomic or physical drivers, although this was less common. The fifth criterion assessed inclusion of study area's adaptive capacity in tools, with 62.5% of analyzed tools incorporating this aspect.

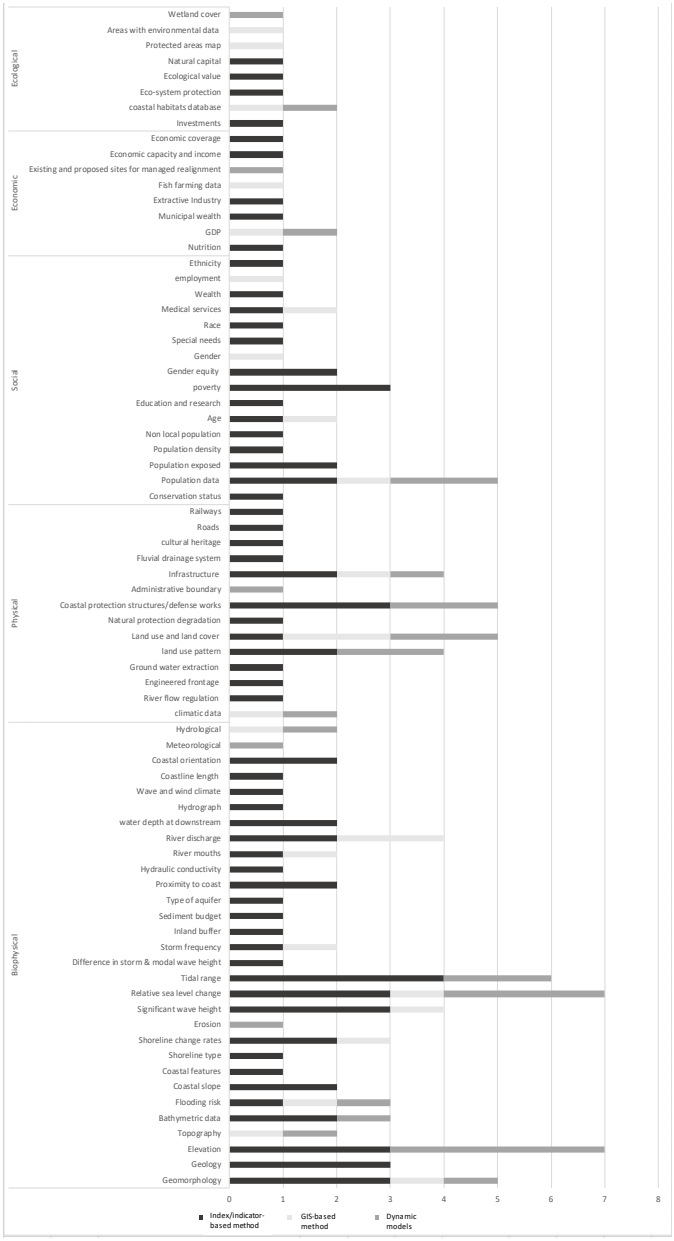

Fig. 3. Number of tools in each method using the variable
Source: Authors

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The sixth criterion analyzed data input variables, revealing in Figure 3 that biophysical and physical variables were most prevalent, with the latter primarily linked to coastal protection measures and land use patterns. Few tools emphasize economic or ecological variables. Index/indicator tools generally encompass more variables, especially common ones, compared to other tools. The researchers also noticed that GIS tools exhibit various dimensions but with limited variables each, while dynamic model tools prioritize biophysical and physical variables, offering fewer variables than index/indicator tools. They include minimal social, economic, and ecological variables. The seventh criterion indicates the study results that are mostly presented as maps and can also be in statistical or index form.

Following the application of successive layers of exclusion criteria to select tools for the Nile Delta, Table I illustrates the outcomes of the initial exclusion criteria, based on relevant local coastal classifications. The table also presents tools for assessing vulnerability across various coastal types. The Egyptian northern coastal region features diverse types, such as the low-lying Nile Delta with upper lagoons and rich wetlands. Furthermore, a significant portion of existing agricultural land is situated in proximity to the shorelines (Fishar, 2016). The diverse nature of the Nile Delta region prevented the exclusion of any tools based on this criterion.

TABLE I
CVA TOOLS FOR DIFFERENT COASTAL AREAS' TYPES

Coastal areas	Tools			Reference
	Index/ Indicator- Based	GIS-Based	Dynamic Model-Based	
Delta regions	CVI, CVI (SLR), SoVI, CoVI, CoRI, Eurosion	THESEUS-DSS,	RACE, SLAMM, FUND, SimCLIM, DIVA, Delft 3D	(Anderson, et al., 2019; Zanuttigh, et al., 2014; Moura, 2015; Ramieri, et al., 2011; Tobey, et al., 2014)
Coastal lagoons	CVI, CVI (SLR), SoVI, CoVI, CoRI, Eurosion	THESEUS-DSS,	RACE, FUND, SimCLIM, DIVA, Delft 3D	(Anderson, et al., 2019; Zanuttigh, et al., 2014; Moura, 2015; Ramieri, et al., 2011; Tobey, et al., 2014)
Coastal wetlands	CVI, CVI (SLR), SoVI, CoVI, CoRI, Eurosion	THESEUS-DSS,	RACE, SLAMM, FUND, SimCLIM, DIVA, Delft 3D	(Anderson, et al., 2019; Zanuttigh, et al., 2014; Moura, 2015; Ramieri, et al., 2011; Tobey, et al., 2014)
Coastal agricultural lands	CVI, CVI (SLR), SoVI, CoVI, CoRI, Eurosion	THESEUS-DSS,	RACE, FUND, SimCLIM, RegIS, DIVA, Delft 3D	(Anderson, et al., 2019; Zanuttigh, et al., 2014; Moura, 2015; Ramieri, et al., 2011; Tobey, et al., 2014)
Different coastline typologies (sandy, cliff, etc.)	CVI, CVI (SLR), SoVI, CoVI, MS-CVI, CoRI, Eurosion	DESYCO-DSS, THESEUS-DSS,	RACE, FUND, SimCLIM, DIVA, Delft 3D	(Mclaughlin & Cooper, 2010; Anderson, et al., 2019; Zanuttigh, et al., 2014; Moura, 2015; Ramieri, et al., 2011)

Source: Authors

Table I also highlights that the majority of the reviewed tools included in the comparative study were index- and indicator-based methods. The data also indicate that index- and indicator-based methods are applicable to various coastal areas, while MS-CVI exclusively assesses coastlines with diverse typologies. Concerning the GIS-based methods, only two tools were included: DESYCO and THESEUS and they are considered among the recent DSS tools used in the literature (Zanuttigh et al., 2014). Also, the Theseus tool only works on the coastlines with their different typologies. Concerning the dynamic models, seven tools were included in the comparative analysis, and most of the work focused on the different types of coastal areas. However, SimCLIM does not work on coastal lagoons, SLAMM only works on delta regions and coastal wetlands, and RegIS only works on coastal agricultural lands.

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According to the identified gaps by Moreira et al., (2021), few CVAs are carried out on national and local scales. Also, Hemida et al. (2023) highlighted that in the Egyptian context, the smaller scales, such as the city and neighborhood scales, were mostly recommended for future research. Therefore, filtering the tools according to the recommended study scale was considered as the second exclusion criterion. Therefore, only tools working on regional and local spatial scales were selected for consideration, and tools working only on larger scales were excluded: CoRI, Eurosion, and DIVA as shown in Table II (spatial scale part). The third exclusion criterion is based on the dimensions included in each tool. Socio-economic and physical dimensions significantly influence a community's vulnerability to natural disasters as well as its readiness for disasters (Lima & Bonetti, 2020; Kantamaneni, 2016). There is a pressing necessity to deepen one's comprehension of coastal infrastructure susceptibility due to increasing coastal stresses. Coastal infrastructure is considered an asset of paramount importance to the nation's economy (Kantamaneni, 2016). Therefore, physical and economic variables play a crucial role in determining social vulnerability and can directly affect disaster preparedness efforts. Therefore, vulnerability assessments should incorporate physical and socio-economic variables together to mitigate potential future risks (Lima & Bonetti, 2020). The selected tools were the ones that included physical, social, and economic dimensions and the rest were excluded. As shown in Table II (that included dimensions part), CVI (SLR), SoVI, CoVI, MS-CVI, DESYCO-DSS, THESEUS-DSS, SimCLIM, and RegIS were selected for the fourth exclusion criterion; however, only CoVI included the physical dimension to be evaluated with the tool. Also, if any of the above tools has the flexibility of modification, they can be used with the inclusion of the physical aspect within the tool.

The fourth exclusion criterion was the existence of adaptive capacity variables in the tools. According to the IPCC, vulnerability encompasses susceptibility, exposure, and coping as the main input variables for vulnerability assessment (Romieu et al., 2010). The absence of high-quality infrastructure can directly impact the vulnerability level of a coastal community, thus impacting the degree of the community's coping capacity. Furthermore, the presence of adaptive infrastructure is crucial for enhancing the adaptive capacity of coastal areas (Groot et al., 2020; Mycoo et al., 2021). Therefore, coping capacity variables are crucial in such assessments, but their application is infrequent due to the extensive time and effort required for data collection (Moreira et al., 2021). Two more tools were excluded according to this layer of exclusion, which are multi-scale CVI and DESYCO-DSS in Table II (adaptive capacity part).

TABLE II
TOOLS EXCLUSION ACCORDING TO SELECTED CREITEIA

Tool/ Criteria	Spatial scale						Included dimensions					Adaptive capacity
	International	Supra-regional	National	Regional	Local	Biophysical	Physical	Social	Economic	Ecological		
CVI	0.5		1	0.5	1	1	1	0	0		0	0
CVI (SLR)	0		0	0	1	1	1	0	1		1	1
SoVI	0		0	0	1	1	0	0	1		0	1
CoVI	0		0	0	1	0	1	1	1		0	1
MS-CVI	0		1	1	1	1	1	0	1		0	0
CoRI	1		1	1	0	0	1	0	1		1	1

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Eurosion	0	1	0	0	0	1	1	1	1	1	1
DESY-CO-DSS	0	0	1	1	0	1	0	1	1	1	0
THE-SEUS-DSS	1	1	1	1	1	1	0	1	1	1	1
RACE	0	0	1	1	1	1	1	0	0	0	0
SLAMM	0	0	0	1	1	1	0	0	0	1	0
FUND	1	1	1	1	0	1	0	0	1	0	1
SimCLIM	1	1	1	1	1	1	0	1	1	1	1
DIVA	1	1	1	0	0	1	0	1	1	1	1
RegIS	0	0	0	1	1	1	0	1	1	1	0.5
Delft3D	0	0	0	1	1	1	0	0	0	0	0

1 → Can be applied | 0.5 → Can be applied theoretically | 0 → Cannot be applied

Exclusion by spatial scale | Exclusion by included dimensions | Exclusion by adaptive capacity

Source: Authors

According to the previous analysis, a set of tools has been identified and considered most relevant for application in CVAs in the Egyptian context based on their main characteristics. These tools are: CVI (SLR), SoVI, and CoVI from the index-based methods; THESEUS-DSS from the GIS-based methods; and SimCLIM and RegIS from the dynamic models and the CoVI is the most recommended due to its inclusiveness concerning the dimensions, however it does not work on local scale.

IV. Discussion

Based on the previous comparative analysis, which highlighted the characteristics of the included CVA tools, and considering the applied exclusion and inclusion criteria, six tools representing 37.5% of the selected tools were shortlisted. Only one of these tools directly includes the physical dimension. To select the most fitting tool for CVA, with a focus on the physical dimension in the Egyptian context, or with high modification potential to accept the inclusion of physical variables, an additional layer of analysis was added based on the results to assess the success of each tool.

A success factor analysis was done to evaluate the suitability and usability of six selected CVA tools for adoption in coastal vulnerability assessment within the Egyptian context. This analysis is based on previous work by Meex and Verbeeck (2014), Krans *et al.* (2022), Quernheim *et al.* (2023) and Marchand *et al.* (2014). The researchers have categorized the success factor analysis into three main aspects: user friendliness, applicability, and maturity as shown in Table 3. User friendliness encompasses six criteria; (1) Expertise, that evaluates the level of knowledge required prior to utilizing the tools and (2) Guidance, that assesses the presence of guidance resources associated with the tools. This includes the availability of manuals, tutorials, open-access publications, or built-in guidance within the tool itself. (3) Ease of use (+ and – scores), that describes its ease or difficulty of use. (4) Accessibility to tool, that checks whether the tool is freely accessible, published in a journal, open-source software, or if a subscription is required for its usage. (5) Time investment (low and high), that shows the time required to use the tool and obtain results. (6) Flexibility to modification (+ and – scores), that evaluates whether the tool allows for suggested improvements, the import of different datasets, or the alteration of assessed indicators. In the applicability section, the assessment focuses on the tool's breadth of applicability and identifies any usage limitations. The degree of maturity (+ and – scores) of the tool showed if the tool was still under development. Following

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the success factor analysis and referring to Table III, the results revealed that expertise is crucial for tool usage, with most tools requiring experience, except for index or indicator-based tools. Regarding the availability of guidance, it was found that most tools provide a guide to facilitate tool usage.

In terms of ease of use, most tools were deemed user-friendly except for the THESEUS-DSS tool. Regarding accessibility, RegIS and THESEUS-DSS were theoretically available, but they no longer function due to the end of their respective research projects. However, all tools were found to be positively suited for time investment and flexibility for modification. Based on the applicability criteria, all tools were deemed applicable to any spatial scale and coastal area given the availability of data. Additionally, all tools scored positively in terms of maturity, having been tested previously. However, it is worth noting that none of the shortlisted GIS or dynamic models tools have been tested in the Egyptian context before, as per the literature. Based on the results of the success factor analysis, the researchers recommend considering the utilization of one of the following tools: CoVI or SimCLIM.

Limitations of this study pertain to the quantity of tools considered in the analysis. The constrained timeframe prompted a focus on a concise selection of tools that were pertinent and frequently referenced in recent research. The field of CVA encompasses a wide array of tools developed both locally and internationally (Rangel-Buitrrago et al., 2020). However, many of these tools are often the outcome of research projects and may not be readily accessible or widely available (Woodruff et al., 2018). The sheer volume and variety of existing tools in coastal vulnerability assessment make it impractical to collect them all, and many may have become obsolete or ceased to function over time. Furthermore, the study did not assess the practical validation of these tools in the context of Egypt, which is crucial for determining their suitability and effectiveness in real-world applications. This aspect is essential as it can impact the outcomes, considering that the tools may perform differently when adapted to the specific data requirements concerning the infrastructure and urban mobility in the coastal cities of the Egyptian context.

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TABLE III
SUCCESS FACTOR ANALYSIS FOR THE SIX SELECTED CVA TOOLS

Criteria/ Selected Tools	User-friendliness						Applicability	Degree of maturity	Link to tool
	Expertise	Guidance	Ease of use	Accessibility to tool/cost	Time investment	Flexibility to modification			
CVI (SLR)	No specific experience required (Ozyurt & Ergin, 2009).	Journal publication (Ozyurt & Ergin, 2009).	+ (Ozyurt & Ergin, 2009; Ramieri, et al., 2011)	Open access publication (Ozyurt & Ergin, 2009).	N.A.	+ (Ramieri, et al., 2011)	Depends on data availability (Ramieri, et al., 2011)	+ (Ozyurt & Ergin, 2009; Ramieri, et al., 2011)	https://etd.lib.metu.edu.tr/upload/12608146/index.pdf
SoVI	No specific experience required (Cutter, et al., 2003).	Journal publication (Cutter, et al., 2003).	+ (Cutter, et al., 2003)	Open access publication (Cutter, et al., 2003).	N.A.	- (Cutter, et al., 2003; Anderson, et al., 2019)	Depends on data availability (Cutter, et al., 2003).	+ (Cutter, et al., 2003)	https://doi.org/10.1111/1540-6237.8402002
CoVI	Requires experience in GIS and remote sensing. (Szlafsztein & Sterr, 2007)	Journal publication (Szlafsztein & Sterr, 2007).	+ (Szlafsztein & Sterr, 2007)	Open access publication (Szlafsztein & Sterr, 2007).	Low (Szlafsztein & Sterr, 2007)	+ (Szlafsztein & Sterr, 2007; Ramieri, et al., 2011)	Depends on data availability (Szlafsztein & Sterr, 2007; Ramieri, et al., 2011).	+ (Szlafsztein & Sterr, 2007)	https://doi.org/10.1007/s11852-007-0003-6
THESEUS-DSS	Requires experience (Zanuttigh, et al., 2014).	Guidance built in tool (Zanuttigh, et al., 2014).	- (Zanuttigh, et al., 2014)	Open source tool to maximize availability and uptake of the tool (Zanuttigh, et al., 2014).	Low (Zanuttigh, et al., 2014)	+ (Zanuttigh, et al., 2014)	Can be applied to any coastal area and spatial scale. And depends on data availability (Zanuttigh, et al., 2014).	+ (Zanuttigh, et al., 2014)	https://www.vliz.be/projects/theseusproject/index.php
SimCLIM	Training and Knowledge of computer is required (Abuodha & Woodroffe, 2006). However, the expertise of CLIMsystems staff are available to assist (CLIMsystems, 1993).	Manual and introductory tutorials (https://www.climsystems.com/Downloads/SimCLIMAR6/DataManual.pdf).	+ (Ramieri, et al., 2011)	There is a cost to the use of the software (Abuodha & Woodroffe, 2006).	Low (Ramieri, et al., 2011)	+ (Iyalomhe, et al., 2013)	Offers potential but requires further testing and validation. Can be applied to different spatial scales. And depends on data availability (Moura, 2015)	+ (CLIMsystems, 1993)	https://www.climsystems.com/
RegIS	Needs significant expertise (Ramieri, et al., 2011). However, the tool accommodates "*predefined scenarios screen*" that allows users with less knowledge to run the model (Holman & Harman, 2008).	Guidance built in tool and help tutorials (Holman & Harman, 2008).	+ (Ramieri, et al., 2011)	Locally feasible (Ramieri, et al., 2011)	Low (Ramieri, et al., 2011)	+ (Iyalomhe, et al., 2013).	Multiple models were being developed. So, the object-oriented approach was valuable in allowing software modularity, and therefore the ability for different research groups to iteratively develop their models autonomously, yet at the same time (Holman & Harman, 2008).	+ (Holman & Harman, 2008).	N.A.

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V. Conclusion

Based on the comprehensive analysis conducted in this research, which encompassed an examination of the existing literature, a comparative analysis of various CVA tools from index-based, indicator-based, GIS-based, and dynamic model methods, and a thorough success factor analysis, several key conclusions can be drawn. Firstly, it is evident from the literature review and comparative analysis that coastal cities, especially those in delta regions like the Nile Delta, face significant vulnerability to various natural hazards. The concentration of population and infrastructure in these areas exacerbates the socio-economic and physical vulnerability, making them highly susceptible to disasters. Secondly, the methodology employed in this research, which developed a systematic method to selecting CVA tools tailored to the Egyptian context, has provided valuable insights into the strengths and weaknesses of different tools. By applying specific inclusion and exclusion criteria, six tools were shortlisted, with one tool, CoVI, being highlighted as particularly promising due to its comprehensive inclusion of physical dimension together with social and economic dimensions. Thirdly, the success factor analysis conducted further emphasized the importance of user-friendliness, applicability, and maturity of the selected tools. While all tools showed strengths in certain aspects, such as ease of use and flexibility for modification, limitations were also identified, particularly regarding the accessibility and availability of some tools like RegIS and THESEUS-DSS.

Based on these findings, it is recommended that future CVA studies in the Egyptian context prioritize the utilization of tools like CoVI or SimCLIM, with a focus on and inclusion of the physical dimension, to address the existing gap in the literature. These tools have demonstrated suitability and effectiveness in addressing the complexities of coastal vulnerability, including the physical dimension. In conclusion, this research has contributed valuable insights into developing a systematic selection method of CVA tools for assessing coastal vulnerability in the Egyptian context or in other contexts. By addressing existing gaps in the literature and providing recommendations for future research and practical applications, this study aims to support informed decision-making and enhance resilience to climate-related hazards in vulnerable coastal regions. However, it is essential to acknowledge the limitations of this study, including the constrained timeframe and the focus on a limited number of tools. Future research should aim to address these limitations by considering a broader range of tools, especially if the adopted context has locally developed tools, and conducting practical validations in the specific context of Egypt. Additionally, ongoing monitoring and updates to the selected tools are crucial to ensure their continued relevance and effectiveness in guiding adaptation measures and resilience-building efforts in coastal cities facing the impacts of climate change.

Table IV: Comparative analysis of selected CVA tools"

Criteria / Methods & Tools		Index-based method/ Indicator-based method							GIS-based method		Dynamic model based						
											Sector models		Integrated assessment models				2 and 3 dimensional models
		CVI	CVI (SLR)	SoVI	CoVI	MS-VI	CoRI	Eurosion	DESYCO-DSS	THESEUS DSS	RACE	SLAMM	FUND	SimCLIM	DIVA	BeqiS	Delft3D
coastal typology	Delta regions	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1
	Coastal lagoons	1	0.5	1	1	0	1	1	0	1	1	0	1	1	1	0	1
	Coastal Wetlands	1	0.5	1	1	0	1	1	0	1	1	1	1	1	1	0	1
	Coastal agricultural land	1	0.5	1	1	0	1	1	0	1	1	0	1	1	1	1	1
	Different coast typologies (sandy, cliff, etc.)	1	0.5	1	1	1	1	1	1	1	1	0	1	1	1	0	1
Spatial scale	International	0.5	0	0	0	0	1	0	0	1	0	0	1	1	1	0	0
	Supra regional	1	0	0	0	1	1	1	0	1	0	0	1	1	1	0	0
	National	0.5	0	0	0	1	1	0	1	1	1	0	1	1	1	0	0
	Regional	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
	local	1	1	1	0	1	0	0	0	1	1	1	0	1	0	1	1

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Included dimensions	Biophysical		1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
	Physical		0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
	Social		0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0
	Economic		0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0
	Ecological		0	1	0	0	0	1	1	1	1	0	1	0	1	1	1	0
Main driver	Biophysical drivers	SLR	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1
		Sediment budget	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1
		Shoreline evolution	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
	Biophysical drivers	Salinity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Cyclones	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Storm surge	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1
		Flooding	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
		Wind	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		Wave	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		Drought	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Tsunami	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Hurricanes	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
		Tide	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		Erosion	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0
	Physical drivers	Failure of sea defenses	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	Socio-economic drivers	Land use change	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
		GDP growth	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0
		Population growth	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0
Adaptation measures considered			0	1	1	1	0	1	1	0	1	0	0	1	1	1	0.5	0
Data input	Biophysical variables	Geomorphology	1	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0
		Geology	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
		Elevation	1	0	0	0	1	0	1	0	0	0	1	0	1	1	1	0
		Topography	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
		Bathymetric data	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1
		Flooding risk	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0
		Coastal slope	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Coastal features	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Shoreline type	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Shoreline change rates	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
		Erosion	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Significant wave height	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0
		Relative sea level change	1	1	0	0	0	0	1	0	1	0	1	1	1	0	0	0
		Tidal range	1	1	0	0	1	0	1	0	0	0	1	0	0	0	1	0
		Difference in storm & modal wave height	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Storm frequency	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
		Inland buffer	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Sediment budget	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Type of aquifer	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Proximity to coast	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Hydraulic conductivity	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		River mouths	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
		River discharge	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0
		water depth at downstream	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Hydrograph	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Wave and wind climate	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Coastline length	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Coastal orientation	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
		Meteorological	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
		Hydrological	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
		climatic data	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
	Physical	River flow regulation	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Engineered frontage	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Ground water extraction	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		land use pattern	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1
		Land use and land cover	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1
		Natural protection degradation	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Coastal protection structures/defense works	0	1	0	1	0	0	1	0	0	1	0	0	0	0	1	0
		Administrative boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Infrastructure	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0
		Fluvial drainage system	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		cultural heritage	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Roads	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

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		Railways	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Conservation status	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Social	Population data	0	0	0	1	1	0	0	0	1	0	0	1	0	1	0	0
		Population exposed	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
		Population density	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Non local population	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Age	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
		Education and research	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		poverty	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
		Gender equity	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
		Gender	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Special needs	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Race	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Medical services	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
		Wealth	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		employment	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
		Ethnicity	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Nutrition	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Economic	GDP	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
		Municipal wealth	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Extractive Industry	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Fish farming data	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Existing and proposed sites for managed realignment	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
		Economic capacity and income	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Economic coverage	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Investments	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	Ecological	coastal habitats database	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
		Eco-system protection	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Ecological value	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Natural capital	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Protected areas map	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Areas with environmental data	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
		Wetland cover	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Government and authority		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Data output form	Tables		1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
	graphs		0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1
	Maps		1	0	0	1	1	1	0	1	1	1	1	0	1	0	1	1
	Time series projections		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	Scores, rates and statistics		0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0
	Final vulnerability index		0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Used in Egyptian context in the last 10 years (Hemida, *et al.*, 2023)			1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0

1	→ Can be applied	0.5	→ Can be applied theoretically	0	→ Cannot be applied

Table is based on (Anderson, et al., 2019; Zanuttigh, et al., 2014; Mclaughlin & Cooper, 2010; Torresan, et al., 2010; Park, et al., 2003; Ltd, 2007; Narita, et al., 2009; Moura, 2015; Ramieri, et al., 2011; Tobey, et al., 2014) (Hinkel, et al., 2010)

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VI. References

[1] P. A. Abuodha and C. D. Woodroffe, "Assessing vulnerability of coasts to climate change: A review of approaches and their application to the Australian coast," GIS for the Coastal Zone: A selection of Papers from CoastGIS 2006, 2006.

[2] E. et Ali, "Mediterranean Region. In: Climate Change 2022: Impacts, Adaptation and Vulnerability," UK and New York, NY, USA, 4, 2022.

[3] C. C. Anderson, M. Hagenlocher, F. G. Renaud, Z. Sebesvari, S. L. Cutter, and C. T. Emrich, "Comparing index-based vulnerability assessments in the Mississippi Delta: Implications of contrasting theories, indicators, and aggregation methodologies," International Journal of Disaster Risk Reduction, vol. 39, 2019, doi: 10.1016/j.ijdrr.2019.101128.

[4] L. Celliers and C. Ntombela, "Urbanisation, Coastal Development and Vulnerability, and Catchments," in The Regional State of the Coast Report: Western Indian Ocean, 2015.

[5] S. L. Cutter, B. J. Boruff, and W. L. Shirley, "Social vulnerability to environmental hazards," Soc Sci Q, vol. 84, no. 2, 2003, doi: 10.1111/1540-6237.8402002.

[6] M. El-Quilish, M. El-Ashquer, G. Dawod, and G. El Fiky, "Development of an Inundation Model for the Northern Coastal Zone of the Nile Delta Region, Egypt Using High-Resolution DEM," Arab J Sci Eng, vol. 48, no. 1, 2023, doi: 10.1007/s13369-022-07013-y.

[7] M. El-Raey, "Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise," Ocean Coast Manag, vol. 37, no. 1, 1997, doi: 10.1016/S0964-5691(97)00056-2.

[8] C. M. Finlayson, G. R. Milton, R. C. Prenctice, and N. C. Davidson, The Wetland Book II: Distribution, description, and conservation, vol. 1–3. 2018. doi: 10.1007/978-94-007-4001-3.

[9] O. E. Frihy, "Evaluation of future land-use planning initiatives to shoreline stability of Egypt's northern Nile delta," Arabian Journal of Geosciences, vol. 10, no. 5, 2017, doi: 10.1007/s12517-017-2893-4.

[10] S. Ghosh and B. Mistri, "Assessing coastal vulnerability to environmental hazards of Indian Sundarban delta using multi-criteria decision-making approaches," Ocean Coast Manag, vol. 209, 2021, doi: 10.1016/j.ocecoaman.2021.105641.

[11] C. Gold, "An Algorithmic Approach to Marine GIS. In: Marine and Coastal Geographical Information Systems."

[12] B. de Groot, W. Leendertse, and J. Arts, "Building adaptive capacity through learning in project-oriented organisations in infrastructure planning," Urban Plan, vol. 5, no. 1, 2020, doi: 10.17645/up.v5i1.2523.

[13] E. Helderop and T. H. Grubesic, "Streets, storm surge, and the frailty of urban transport systems: A grid-based approach for identifying informal street network connections to facilitate mobility," Transp Res D Transp Environ, vol. 77, 2019, doi: 10.1016/j.trd.2018.12.024.

[14] A. A. Hemida, M. Khalifa, M. Abdelsalheen, and S. Afifi, "A systematic review of coastal vulnerability assessment methods in the Egyptian context: the case study," HBRC Journal, vol. 19, no. 1, 2023, doi: 10.1080/16874048.2023.2241964.

[15] M. E. Hereher, "Coastal vulnerability assessment for Egypt's Mediterranean coast," Geomatics, Natural Hazards and Risk, vol. 6, no. 4. pp. 342–355, 2015.

[16] J. Hinkel, R. J. Nicholls, A. T. Vafeidis, R. S. J. Tol, and T. Avagianou, "Assessing risk of and adaptation to sea-level rise in the European Union: An application of DIVA," Mitig Adapt Strateg Glob Chang, vol. 15, no. 7, 2010, doi: 10.1007/s11027-010-9237-y.

[17] I. P. Holman and J. Harman, "Preliminary evaluation of the benefits of a participatory regional integrated assessment software," Climatic Change, vol. 90, no. 1–2. 2008. doi: 10.1007/s10584-008-9455-4.

[18] M. Ashraful Islam, D. Mitra, A. Dewan, and S. H. Akhter, "Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh-A geospatial approach," Ocean Coast Manag, vol. 127, 2016, doi: 10.1016/j.

ocecoaman.2016.03.012.

[19] F. Iyalomhe, J. Rizzi, S. Torresan, V. Gallina, A. Critto, and A. Marcomini, "Inventory of GIS-Based Decision Support Systems Addressing Climate Change Impacts on Coastal Waters and Related Inland Watersheds," in Climate Change - Realities, Impacts Over Ice Cap, Sea Level and Risks, 2013. doi: 10.5772/51999.

[20] T. Ji et al., "The Impact of Climate Change on Urban Transportation Resilience to Compound Extreme Events," Sustainability (Switzerland), vol. 14, no. 7. 2022. doi: 10.3390/su14073880.

[21] K. Kantamaneni, "Coastal infrastructure vulnerability: an integrated assessment model," Natural Hazards, vol. 84, no. 1, 2016, doi: 10.1007/s11069-016-2413-y.

[22] N. A. Krans, A. Ammar, P. Nymark, E. L. Willighagen, M. I. Bakker, and J. T. K. Quik, "FAIR assessment tools: evaluating use and performance," NanoImpact, vol. 27, 2022, doi: 10.1016/j.impact.2022.100402.

[23] C. O. Lima and J. Bonetti, "Bibliometric analysis of the scientific production on coastal communities' social vulnerability to climate change and to the impact of extreme events," Natural Hazards, vol. 102, no. 3. 2020. doi: 10.1007/s11069-020-03974-1.

[24] H. G. Ltd, "Risk assessment of coastal erosion," London: Ergon House. 2007.

[25] M. A. Abdrabo and M. A. Hassaan, "An integrated framework for urban resilience to climate change - Case study: Sea level rise impacts on the Nile Delta coastal urban areas," Urban Clim, vol. 14, 2015, doi: 10.1016/j.uclim.2015.09.005.

[26] F. Marchand, L. Debruyne, L. Triste, C. Gerrard, S. Padel, and L. Lauwers, "Key characteristics for tool choice in indicator-based sustainability assessment at farm level," Ecology and Society, vol. 19, no. 3, 2014, doi: 10.5751/ES-06876-190346.

[27] L. McFadden, R. J. Nicholls, A. Vafeidis, and R. S. J. Tol, "A methodology for modeling coastal space for global assessment," Journal of Coastal Research, vol. 23, no. 4. 2007. doi: 10.2112/04-0365.1.

[28] S. McLaughlin, J. Andrew, and G. Cooper, "A multi-scale coastal vulnerability index: A tool for coastal managers?," Environmental Hazards, vol. 9, no. 3, 2010, doi: 10.3763/ehaz.2010.0052.

[29] E. Mcleod et al., "Community-Based Climate Vulnerability and Adaptation Tools: A Review of Tools and Their Applications," Coastal Management, vol. 43, no. 4, 2015, doi: 10.1080/08920753.2015.1046809.

[30] E. Meex and G. Verbeeck, "The application of two sustainability assessment tools on a passive office in Flanders: a user-approach," International Journal of Sustainable Building Technology and Urban Development, vol. 5, no. 4, 2014, doi: 10.1080/2093761X.2014.948101.

[31] S. A. Mohamed, "Coastal vulnerability assessment using GIS-Based multicriteria analysis of Alexandria-northwestern Nile Delta, Egypt," Journal of African Earth Sciences, vol. 163, 2020, doi: 10.1016/j.jafrearsci.2020.103751.

[32] L. L. Moreira, M. M. De Brito, and M. Kobiyama, "Review article: A systematic review and future prospects of flood vulnerability indices," Natural Hazards and Earth System Sciences, vol. 21, no. 5. 2021. doi: 10.5194/nhess-21-1513-2021.

[33] R. P. A. Moura, "ANALYSIS OF METHODOLOGIES FOR VULNERABILITY AND RISK ASSESSMENT ON COASTAL AREAS." 2015.

[34] M. Mycoo, S. A. Robinson, C. Nguyen, C. Nisbet, and R. Tonkel, "Human Adaptation to Coastal Hazards in Greater Bridgetown, Barbados," Front Environ Sci, vol. 9, 2021, doi: 10.3389/fenvs.2021.647788.

[35] D. Narita, R. S. J. Tol, and D. Anthoff, "Economic costs of extratropical storms under climate change: An application of FUND," Journal of Environmental Planning and Management, vol. 53, no. 3, 2010, doi: 10.1080/09640561003613138.

[36] M. O. Oloyede, N. U. Benson, and A. B. Williams, "Climate change and coastal vulnerability assessment methods: A review," in IOP Conference Series: Earth and Environmental Science, 2021. doi: 10.1088/1755-1315/665/1/012069.

[37] G. Özyurt and A. Ergin, "Application of sea

level rise vulnerability assessment model to selected coastal areas of Turkey," in Journal of Coastal Research, 2009.

[38] R. A. , C. J. S. , J. R. & H. G. Park, "MODELING THE IMPACTS OF SEA-LEVEL RISE. Baltimore." MD, s.n, Baltimore, 2003.

[39] M. K. Pramanik, S. S. Biswas, B. Mondal, and R. Pal, "Coastal vulnerability assessment of the predicted sea level rise in the coastal zone of Krishna–Godavari delta region, Andhra Pradesh, east coast of India," Environ Dev Sustain, vol. 18, no. 6, 2016, doi: 10.1007/s10668-015-9708-0.

[40] M. Pregnolato, A. Ford, and R. Dawson, "Disruption and adaptation of urban transport networks from flooding," in E3S Web of Conferences, 2016. doi: 10.1051/e3sconf/20160707006.

[41] M. Pregnolato, A. Ford, V. Glenis, S. Wilkinson, and R. Dawson, "Impact of Climate Change on Disruption to Urban Transport Networks from Pluvial Flooding," Journal of Infrastructure Systems, vol. 23, no. 4, 2017, doi: 10.1061/(asce)is.1943-555x.0000372.

[42] N. Quernheim, S. Winter, L. Arnemann, S. Wolff, R. Anderl, and B. Schleich, "Concept for the Evaluation and Categorization of Sustainability Assessment Methods and Tools," in Lecture Notes in Mechanical Engineering, 2023. doi: 10.1007/978-3-031-28839-5_81.

[43] E. Ramieri, A. Barbanti, M. Picone, G. Menchini, E. Bressan, and E. Dal Forno, "Integrated plan for the sustainable management of the Lagoon of Marano and Grado," 2011. doi: 10.1051/litt/201105008.

[44] N. Rangel-Buitrago, W. J. Neal, J. Bonetti, G. Anfuso, and V. N. de Jonge, "Vulnerability assessments as a tool for the coastal and marine hazards management: An overview," Ocean Coast Manag, vol. 189, 2020, doi: 10.1016/j.ocecoaman.2020.105134.

[45] E. Romieu, T. Welle, S. Schneiderbauer, M. Pelling, and C. Vinchon, "Vulnerability assessment within climate change and natural hazard contexts: Revealing gaps and synergies through coastal applications," Sustain Sci, vol. 5, no. 2, 2010, doi: 10.1007/s11625-010-0112-2.

[46] M. López Royo, R. Ranasinghe, and J. A. Jiménez, "A Rapid, Low-Cost Approach to Coastal Vulnerability Assessment at a National Level," J Coast Res, vol. 32, no. 4, 2016, doi: 10.2112/JCOASTRES-D-14-00217.1.

[47] R. M. Abou Samra, M. El-Gammal, N. Al-Mutairi, M. M. Alsahli, and M. S. Ibrahim, "GIS-based approach to estimate sea level rise impacts on Damietta coast, Egypt," Arabian Journal of Geosciences, vol. 14, no. 6, 2021, doi: 10.1007/s12517-021-06810-3.

[48] P. Singh, V. S. P. Sinha, A. Vijhani, and N. Pahuja, "Vulnerability assessment of urban road network from urban flood," International Journal of Disaster Risk Reduction, vol. 28, 2018, doi: 10.1016/j.ijdrr.2018.03.017.

[49] C. Szlafsztein and H. Sterr, "A GIS-based vulnerability assessment of coastal natural hazards, state of Pará, Brazil," J Coast Conserv, vol. 11, no. 1, 2007, doi: 10.1007/s11852-007-0003-6.

[50] J. et al Tobey, "Coasts at Risk: An Assessment of Coastal Risks and the Role of Environmental Solutions, Rhode Island, USA," USAID/UNU-EHS/TNC/CRC, 2014.

[51] S. Torresan, E. Furlan, A. Critto, M. Michetti, and A. Marcomini, "Egypt's Coastal Vulnerability to Sea-Level Rise and Storm Surge: Present and Future Conditions," Integr Environ Assess Manag, vol. 16, no. 5, 2020, doi: 10.1002/ieam.4280.

[52] S. Torresan et al., "Risk assessment and decision support tools for the integrated evaluation of climate change impacts on coastal zones," in Modelling for Environment's Sake: Proceedings of the 5th Biennial Conference of the International Environmental Modelling and Software Society, iEMSs 2010, 2010.

[53] UN-Habitat, "State of African cities 2014: Re-imagining sustainable urban transitions. UN-Habitat, Nairobi, kenya.," 2014.

[54] M. L. Wolters and C. Kuenzer, "Vulnerability assessments of coastal river deltas - categorization and review," J Coast Conserv, vol. 19, no. 3, 2015, doi: 10.1007/s11852-015-0396-6.

[55] C. D. Woodroffe, R. J. Nicholls, Y. Saito, Z. Chen, and S. L. Goodbred, "Landscape Variability and the Response of Asian Megadeltas to Environmental Change," in Global Change and Integrated Coastal Management, 2007. doi:

10.1007/1-4020-3628-0_10.

[56] S. Woodruff, K. A. Vitro, and T. K. BenDor, "GIS and Coastal Vulnerability to Climate Change," in Comprehensive Geographic Information Systems, vol. 3, 2017. doi: 10.1016/B978-0-12-409548-9.09655-X.

[57] B. Zanuttigh et al., "THESEUS decision support system for coastal risk management," Coastal Engineering, vol. 87, 2014, doi: 10.1016/j.coastaleng.2013.11.013.

[58] CLIMsystems, "5. CLIMsystems," https://www.climsystems.com.

[59] F. De Serio, E. Armenio, M. Mossa, and A. F. Petrillo, "How to define priorities in coastal vulnerability assessment," Geosciences (Switzerland), vol. 8, no. 11, 2018, doi: 10.3390/geosciences8110415.

[60] M. O. , B. N. U. & W. A. B. Oloyede, "A Review of Coastal Vulnerability Assessment Methods," THE INTERNATIONAL JOURNAL OF CLIMATE CHANGE, vol. 14, no. 2, 2022.

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Influence of shared and innovative mobility on psychological wellbeing

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ABSTRACT

Recently, new travel options such as micromobility and shared transport systems have been introduced in many urban areas in Spain, which are intended to increase the sustainability and accessibility of cities. The Covid-19 pandemic has boosted the use of these new individual travel modes. The aim of this paper is to analyze travel behavior and wellbeing of users of these new urban solutions compared to traditional transport. Face-to-face and online surveys were carried out during the Summer of 2021 in Valencia (Spain) to collect information regarding travel behavior and wellbeing. Participants were habitual users of all urban travel modes, including those who also used motosharing, carsharing or private e-scooters. 2225 valid responses were obtained after data cleaning and validation. Satisfaction with Travel Scale (STS) is used to explore subjective wellbeing of users of new and traditional transport modes. Results show that current users of motosharing and private e-scooters were former users of public transport, while users of carsharing used to utilize more car and motosharing before. On the other hand, active transport is associated with higher satisfaction compared to new urban modes, while they provide more satisfaction than urban public transport.

Index-words: *Satisfaction with Travel, Sustainable Mobility, New Transport Solutions*

I. INTRODUCTION

New transport solutions based on shared modes and micromobility have been introduced in many urban areas, which are supposed to contribute to sustainability and accessibility of cities. However, it is still not clear how is the impact of such changes. For example, the effect of sharing mobility options on the use of conventional travel modes is not well understood yet.

On the other hand, the assessment of transport measures to promote sustainable mobility is very frequently carried out through cost-benefit related analyses. These conventional evaluation methods do not usually consider how those measures influence the quality of life and wellbeing of people. Among the dimensions that are missing, one of the most important is related to emotional/psychological aspects of people when they commute to get to work or study.

This research is part of Travelwell+ project, which aims at studying the influence of using motosharing, carsharing and private electric scooter on the psychological wellbeing of their users. This project contributes to the use of psychometric scales to gather information about wellbeing which have been scarcely applied to this purpose and some of them have not been translated to Spanish yet. In particular, this paper contributes to the validation and use of Satisfaction with Travel Scale in Spain.

In this paper, travel behavior derived from this new transport solution is analyzed first. Next, psychological wellbeing associated to the use of new transport modes is explored including car sharing, moto sharing and private e-scooters in Spain. Methodology of analysis include exploratory and descriptive measurements and Cronbach Alpha to test validity and reliability of the scales. Besides, non-parametric test U Mann-Whitney and W Wilcoxon are used to explore differences among satisfaction with new transport solutions.

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A. *Wellbeing and Travel Behavior*

The nature of wellbeing has been analyzed from two different perspectives. Firstly, wellbeing has been considered both at objective or subjective phenomenon. Subjective wellbeing (SWB) holds that an individual's perceptions and experiences are the basis for evaluations about their own life. On the other hand, the objective perspective assumes that wellbeing is configured "objectively" from the values, goals, or objectives that people have or can achieve (Nordbakke and Schwanen, 2014).

Travel behavior and wellbeing interest has increased recently. Most of the studies found in literature focus on system-wide mechanisms by which transportation can affect wellbeing (Delbosc, 2012; Reardon and Abdallah, 2013).

B. *Satisfaction with Travel Scale (STS)*

Various psychological scales have been developed to study wellbeing, however the development of specific scales in the transportation planning domain is still limited. The Satisfaction with Travel Scale (STS) is an exception. In 2010, Ettema, Gärling, Olsson and Friman proposed the application of the concept of wellbeing in the analysis of the behavior of transport users and developed an instrument for the measurement of subjective wellbeing, which included affective and cognitive elements related to daily trips.

The scale consists of nine items: six items of affective measurement, which are based on two orthogonal dimensions of core affect (valence and activation), supported by SCAS (Västfjäll et al., 2002), derived from the affect grid (Russell, 1980; Russell, 2003; Ettema et al, 2013); and three items that correspond to the dimension of cognitive assessments of travel. A 7-point Likert scale ranging from -3 to 3 is proposed to respondents to evaluate the degree of agreement with the statements included in each item.

For the measurement of the affective part, combinations of valence and activation dimensions are used: three items between positive deactivation (e.g., relaxed) and negative activation (e.g., time pressed) and three items between positive activation (e.g., alert) and negative deactivation (e.g., tired). The concept of activation or arousal refers to the degree of stimulation of an individual, due to signals from the environment, and ranges from an activation pole to a deactivation pole or quietness–excitement, while valence refers to the evaluation made by an individual about his affects in terms of positive to negative (unpleasantness–pleasantness) (Västfjäll and Gärling, 2014). The total STS score is calculated by averaging the scores qualified for each of the three dimensions of positive activation/negative deactivation, positive deactivation/negative activation, and cognitive assessment (Ettema et al., 2011, 2012, 2013; Friman et al., 2013; Olsson et al., 2013).

Some studies are found in the literature that used the STS scale to investigate the relationship between travel satisfaction and the mode of transport used (Abou-Zeid, 2009; De Vos et al., 2015; Ettema et al., 2011; Friman et al., 2013; Olsson et al., 2013; Smith, 2017). To the best of the researchers' knowledge, the STS scale has not been used in a Spanish context, which is a gap that the present study attempts to fill.

II. METHOD

A. *Questionnaire Design*

The design of the questionnaires is described as follows. Firstly, a brief introduction including the project description was presented. Next, participants were asked to identify their usual transport mode and trips characteristics.

Later, four psychometric scales to measure wellbeing were included: subjective wellbeing experienced during the trip was assessed, through the STS scale (Ettema et al., 2011) and a short form of the Positive and Negative Affect Schedule (Mackinnon et al., 1999); on the other hand, eudaimonic wellbeing was evaluated with the Exercise Self-Regulation Questionnaire

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(SRQ-E) (Levesque et al., 2007) and the adults' version of the Basic Psychological Needs Satisfaction and Frustration Scale (BPNSFS) (Chen et al., 2015). The four scales were translated and adapted into Spanish.

Lastly, participants were asked to provide details about trip attributes (frequency of use of usual mode of transport, purpose and trip duration) and sociodemographic characteristics (place of residence, sex, age, occupation, monthly income, etc.)

B. Participants Recruitment

An agreement was established with moto sharing and car sharing companies that operate in Valencia to recruit participants in the project. Those who completed the online survey could take part in a prize draw for three free rides to the value of 200 euro.

The method of recruitment of private e-scooter's users had to be different. Some repair shops were contacted to publicize the project. Leaflets were distributed among e-scooter's users while they wait for traffic light to change. Those who completed the online survey could take part in a prize draw for three checkup and maintenance.

Habitual users of traditional urban travel modes were also targeted, the distribution of the survey was carried out by email and social media. Additionally, face-to-face surveys were used to complete the quota of those modes with lower representation in the sample. A lottery consisting of five tablets was used to encourage participation.

III. RESULTS

A. Sample Distribution

2,286 individuals participated in the survey. Data cleaning process was performed to remove inconsistent or poorly answered responses, indicating a lack of effort or insufficient attention from participants. To identify and exclude such responses, the "R" "Careless" package developed by Yentes and Wilhelm (2021) was used. A total of 61 responses were eliminated from the database, resulting in a final sample size of 2,225 responses. Table I presents the distribution of the sample according to sociodemographic characteristics. 53% of the surveys were conducted through face-to-face interviews, while 47% of the surveys were completed online.

As it can be observed, gender distribution is reasonably balanced: 53% male and 47% female. Considering age, a higher participation of respondents under 35 is observed. 45.5% of the participants are employed individuals, while 26.5% are students. Nevertheless, retired, unemployed and other occupational situations are also represented in the sample.

TABLE 1. SAMPLE CHARACTERISTICS

	N	%
Female	1038	46.7%
Male	1183	53.2%
Other	4	0.2%
Age		
18-24	217	9.8%
25-34	310	13.9%
35-44	225	10.1%
45-54	146	6.6%
55-65	113	5.1%
>65	156	7.0%
Missing	19	0.9%
Occupation		
Employee	647	29.1%
Student	170	7.6%
Employee and student	108	4.9%
Retire or inactive	198	8.9%
Unemployed	45	2.0%
Missing	18	0.8%
Income		
No income	153	6.9%
1€ - 999€	187	8.4%
1000€-1999€	397	17.8%
2000€-2999€	218	9.8%
3000€ or more	81	3.6%
Missing	150	6.7%

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A. Use of New Transport Solutions

Considering shared and micro mobility users: 146 individuals are e-scooter users, 324 correspond to moto sharing users and 291 to car sharing users. As it can be observed in Table 2, traditional modes are also represented in the sample

TABLE II. MODAL SPLIT DISTRIBUTION

Mode	Sample N	Percentage
Walking	386	17.3%
Bicycle (own)	176	7.9%
Bicycle (shared)	123	5.5%
E-Scooter	146	6.6%
Urban bus	156	7.0%
Interurban bus	102	4.6%
Metro or tram	113	5.1%
Train	117	5.3%
Car	267	12.0%
Car sharing	291	13.1%
Moto sharing	324	14.6%
Other modes	24	1.1%
Total	**2225**	100%

These new transport solutions could contribute to sustainable mobility as long as their current users derive from private modes substantially. Further analyses are employed to explore this modal shift. As it can be observed in Figure 1, 26.6% of e-scooter adopters are previous users of urban bus, followed by 16.6% who used to cycle and 15.9% users of metro, tram or train and 14.5% were walking trips. Thus, more than 70% of modal shift towards e-scooter is derived from public transport and active modes. Whereas, only in 15.9% of the cases, the private car is replaced.

Motosharing customers are also former public transport users: 30% correspond to railway and 17.4% were bus passengers. Participants who used active transport modes represent a lower quota: 8% walking and 3.7% cycling. However, in this case, previous users of bikesharing represent a percentage of 9.5%. Private modes replacement is slightly higher in this case with 18% of drivers and 8.6% of moto users.

Conversely, modal shift to carsharing is derived from car drivers in first place (26.8%). Surprisingly, 17.6% current users of carsharing were previously motosharing users. This result reveals that sharing systems can be seen as competitors. This is especially true in the case of Valencia, where carsharing system is working recently. Motosharing service has been available for a few years and several companies have been operating. On the other hand, it is still relevant that the modal shift obtained from public transport is 13% and 10.6% for urban bus and railway modes, respectively. Lastly, actives modes former users represent 10.9% of cyclists (considering both owning a bike and sharing systems) and 6.7% of pedestrians.

Fig. 1. Shared and micromobility modes. Modal shift.

Later, adoption of these new mobility solution is addressed. Figure 2 shows that nearly 60% of e-scooter and motosharing users started to use these transport modes more than one year ago. Contrary to that, carsharing seems much more recent due to its novel implementation. In this case, 22% of participant's report using this mode only for one month or less, while 52% use carsharing between 1 and 6 months.

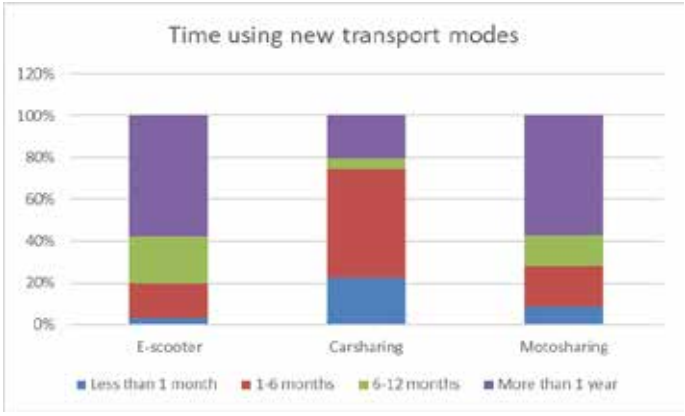

Fig. 2. Shared micromobility adoption. Time using new modes.

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Considering now frequency of use, significant differences are observed (Fig. 3). E-scooter is used every day by 73% of participants, while only 5% use this mode less 1-2 days per week. Thus, e-scooter seems to replace traditional modes for day-to-day mobility. Contrary to that, shared options are used in a more occasional base. Motosharing is used every day by 14% of respondents, and the major quota is associated with casual trips, 53% use this mode 1-2 days per week. On the other hand, 92% of carsharing users choose this mode only 1-2 days per week. Consequently, shared modes are considered as complementary options, while e-scooter might produce modal shifts.

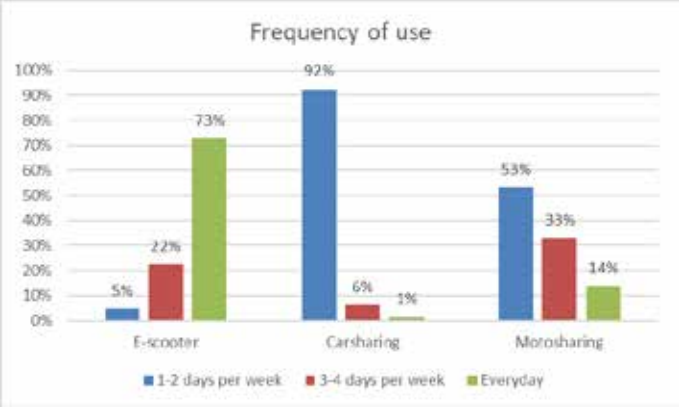

Fig. 3. Shared and micromobility modes. Frequency of use.

A. Wellbeing and New Transport Solutions

Cronbach Alpha was obtained to measure the internal consistency, or reliability of the scale. High values are obtained: positive activation (0.831), positive deactivation (0.841) and cognitive evaluation (0.864). Thus, the scale reliability is confirmed.

Differences between satisfaction associated with new transport modes (e-scooter, carsharing and motosharing) and traditional transport modes are presented next. Results of non-parametric tests U-Mann Whitney and W Wilcoxon are presented in Table III, P-values lower than 10% are considered significant. Besides, Table IV shows differences between average values of new and traditional transport modes. Thus, positive values represent a major satisfaction associated to the mode selected in relation to the rest.

Considering e-scooter first, a higher satisfaction is found for walking and cycling (both with own bicycle and shared systems) compared to e-scooter use. Next, higher positive activation is found for e-scooter use compared to urban bus, while the three dimensions are significant for interurban bus which is associated with higher satisfaction than e-scooter. On the other hand, e-scooter uses provides higher positive activation than train, while no significant differences arise for metro or tram. With respect to private vehicle, car use is associated with higher positive deactivation than e-scooter use.

Taking into account carsharing, negative results are also obtained for active modes. Thus, this new service is associated with less satisfaction than walking and cycling. Interestingly, carsharing provides more positive activation than public transport modes in general (urban bus, metro/tram and train), On the opposite, interurban bus is related to higher positive deactivation. Lastly, positive activation is found higher for carsharing than private car.

Similarly, motosharing is associated with lower satisfaction than active transport as well. Same results as those described previously for carsharing are obtained related to public transport and private car.

The comparison between other innovative transport solutions is relevant as well. E-scooter provides more satisfaction than motosharing, whereas the opposite result is found for carsharing. No differences are found between motosharing and carsharing use.

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TABLE III. U MANN-WHITNEY AND W WILCOXON TEST

Walking									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	25082.00	21599.50	21906.50	55582.5	46452.00	51288.5	58913.000	52651.00	53693.500
W Wilcoxon	35813.00	32330.50	32637.50	98068.50	88938.00	93774.50	111563	105301.00	106343.5
Z	-1.88	-4.10	-3.91	-0.12	-3.77	-1.84	-1.220337	-3.54	-3.154237
P-value	0.06	0.00	0.00	0.908	0.00	0.067	.222	0.00	.002
Bicycle (own)									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	9907.00	10206.00	9284.00	21898.50	21833.00	21308.00	23108.5	24733.50	22344
W Wilcoxon	20638.00	20937.00	20015.00	64384.50	64319.00	63794.00	75758.5	77383.50	74994
Z	-3.70	-3.34	-4.44	-2.82	-2.87	-3.24	-3.704	-2.65	-4.194
P-value	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Bicycle (shared)									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	9907.00	10206.00	9284.00	16067.50	13854.50	13622.50	16804.5	15665	14089.5
W Wilcoxon	20638.00	20937.00	20015.00	58553.50	56340.50	56108.50	69454.500	68315.000	66739.500
Z	-3.70	-3.34	-4.44	-1.65	-3.65	-3.86	-2.574	-3.513	-4.810
P-value	0.00	0.00	0.00	0.10	0.00	0.00	.010	.000	.000
E-scooter									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney				19038.00	19417.50	18537.00	21943.5	21149.000	21907
W Wilcoxon				29769.000	30148.500	29268.000	32674.5	31880.000	32638
Z				-1.78	-1.47	-2.18	-1.262	-1.851	-1.288
P-value				.075	.140	.029	0.207	.064	0.198
Urban bus									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	9412.50	10689.00	11359.50	15928.50	22406.50	19457.00	18741.000	24519.500	23075.000
W Wilcoxon	21658.50	21420.00	23605.50	28174.50	34652.50	31703.00	30987	36765.500	35321
Z	-2.62	-0.93	-0.04	-5.23	-0.23	-2.50	-4.612918	-0.532	-1.55123
P-value	0.01	0.35	0.97	0.00	0.82	0.01	.000	.594	.121
Interurban bus									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	6823.00	4972.00	5879.50	11885.000	10768.000	13744.500	13916.000	12235.500	14484.000
W Wilcoxon	11383.00	15703.00	16610.50	16445.000	53254.000	18304.500	18476.000	64885.500	67134.000
Z	-0.21	-3.73	-2.01	-2.062	-3.251	-.083	-1.428	-3.059	-.878
P-value	0.83	0.00	0.04	.039	.001	.934	.153	.002	.380
Metro / Tram									
	E-scooter			Carsharing			Motosharing		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	7551.00	7337.50	7645.50	12977	15903.00	15044	15204.000	18035.500	17876.500
W Wilcoxon	13992.00	18068.50	18376.50	19418.00	58389.00	21485.00	21645	70685.500	24317.5

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Z	-1.17	-1.53	-1.02	-3.304	-0.51	-1.333	-2.697	-0.235	-.374
P-value	0.24	0.13	0.31	0.001	0.61	0.182	.007	.814	.709
Train									
	E-scooter			**Carsharing**			**Motosharing**		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	18349.50	16653.50	17031.00	12411	16497.50	16388	14572.000	18598.500	18360.500
W Wilcoxon	50989.50	27384.50	27762.00	19314.00	58983.50	23291.00	21475	71248.500	71010.5
Z	-0.24	-1.76	-1.43	-4.303	-0.49	-0.592	-3.728	-0.302	-.505
P-value	0.81	0.08	0.15	0.00	0.62	0.554	.000	.762	.614
Car (private)									
	E-scooter			**Carsharing**			**Motosharing**		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	18349.500	16653.500	17031.000	32646.5	36178.500	35180	38002.000	40944.500	41243.000
W Wilcoxon	50989.500	27384.500	27762.000	65286.5	78664.500	67820	70642.000	93594.500	93893.000
Z	-.239	-1.764	-1.426	-2.433	-0.505	-1.051	-1.663	-.184	-.034
P-value	.811	.078	.154	0.015	.614	0.293	.096	.854	.973
Carsharing									
	E-scooter			**Carsharing**			**Motosharing**		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	19038.00	19417.50	18537.00				45313.500	46252.500	44663.000
W Wilcoxon	29769.00	30148.50	29268.00				97963.500	88738.500	97313.000
Z	-1.78	-1.47	-2.18				-.837	-.407	-1.133
P-value	0.08	0.14	0.03				.403	.684	.257
Motosharing									
	E-scooter			**Carsharing**			**Motosharing**		
Test	PA	PD	CE	PA	PD	CE	PA	PD	CE
U Mann-Whitney	21943.50	21149.00	21907.00	45313.5	46252.50	44663			
W Wilcoxon	32674.50	31880.00	32638.00	97963.5	88738.50	97313			
Z	-1.26	-1.85	-1.29	-0.84	-0.41	-1.13			
P-value	0.21	0.06	0.20	0.40	0.68	0.26			

*PA: positive activation, PD: positive deactivation, CE: cognitive evaluation

TABLE IV. AVERAGE VALUES DIFFERENCES

	Walking	Bicycle (own)	Bicycle (shared)	E-scooter	Urban bus	Interurban bus	Metro / Tram	Train	Car	Car-sharing	Moto-sha-ring
E-SCOOTER											
PA	-0.3	-0.7	-0.5		0.5	0.1	0.3	0.5	0.1	-0.3	0.9
PD	-0.7	-0.6	-0.8		-0.2	-0.8	-0.3	-0.3	-0.3	-0.2	0.6
CE	-0.5	-0.7	-0.8		0.1	-0.3	-0.1	-0.3	-0.2	-0.3	0.8
CARSHARING											
PA	0.0	-0.4	-0.3	0.3	0.8	0.3	0.5	0.7	0.3		1.1
PD	-0.4	-0.4	-0.6	0.2	0.1	-0.6	-0.1	-0.1	0.0		0.8
CE	-0.2	-0.4	-0.6	0.3	0.4	-0.1	0.2	0.0	0.1		1.0
MOTOSHARING											
PA	-0.1	-0.5	-0.4	0.2	0.7	0.2	0.4	0.6	0.2	-0.1	
PD	-0.4	-0.3	-0.5	0.3	0.1	-0.5	0.0	0.0	0.0	0.1	
CE	-0.3	-0.5	-0.7	0.2	0.2	-0.2	0.1	-0.1	0.0	-0.1	
N	384	178	123	146	156	95	113	117	255	291	324

*PA: positive activation, PD: positive deactivation, CE: cognitive evaluation

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IV. DISCUSSION AND CONCLUSION

This paper is part of Travelwell+ project, which aims at studying the influence of using motosharing, carsharing and private electric scooter on the psychological wellbeing of their users.

In this study, travel behavior of new transport modes users is explored, including modal shift from traditional modes. Next, Satisfaction with Travel Scale (STS) is used first time in Spain to analyze the differences in satisfaction between new and traditional transport modes.

Findings indicate that 70% of modal shift towards e-scooter is derived from public transport and active modes. Although this percentage is lower for carsharing and motosharing, it is still relevant. Additionally, sharing systems are seen as competitors among them. More attention should be paid to these modal shifts which derive from sustainable transport modes to new urban solutions. These implications should be considered when defining transport policies to promote sustainable transportation. On the other hand, participants who use carsharing report a frequency of use of less than two days per week. Further studies on the influence of private car owning and recent implementation of carsharing services in Spain should be made. Subsequently, results of non-parametric tests such as U-Mann Whitney and W Wilcoxon reveal significant results of satisfaction associated with daily travel with different transport modes. In general, active transportation is associated with higher satisfaction compared to the use of new transport modes. This result is observed for the three dimensions of the STS scale: positive activation, positive deactivation and cognitive evaluation. Walking and cycling (both with own or shared system bikes) provide more satisfaction than any motorized vehicle as well as public transport.

V.

E-scooter is associated with higher satisfaction compared to urban bus, while no significant results were found for the rest of public transport modes analyzed. Otherwise, for interurban buses, a higher satisfaction is found. Users could see e-scooter as a competitor mode for urban context that can replace urban bus for instance, and at the same time could be seen as a complementary mode for train or tram, railway, and interurban buses.

Next, satisfaction related to the use of public transport is lower than satisfaction produced by the use of motosharing and carsharing, especially for urban transport (urban bus and metro or tram) and train. Contrary to that, carsharing is associated with lower satisfaction compared to interurban bus. This result suggests that carsharing is valuable for users only in the urban context. In addition, the restrictions of the companies with limitations of use to specific cities could explain this result. The absence of significant results between motosharing and carsharing systems might point out that users from these modes do not use frequently both of them, or simply that the wellbeing associated to both of them is similar.

Later, carsharing and motosharing are associated with a higher satisfaction with private car while e-scooter seems to provide less satisfaction than private car. This result suggests a possible change on the tendency of owning private vehicles. The satisfaction provided by sharing systems could be higher than acquiring own cars. On the other hand, e-scooters could provide less satisfaction due to different facts, such as distance. Further research is needed to understand these new trends.

The possible competition between different sharing systems should be also addressed in further studies. Their interaction with traditional transport modes and the relations of complementarity in multimodal transport or substitution need to be explored.

In conclusion, the contribution of new mobility solutions to sustainability and wellbeing is not clear yet. The study of these factors is crucial for the development of transport policies and transport planning. For instance, the promotion of innovative transport solutions from the

public perspective should consider the effects on sustainability, quality of life, wellbeing, etc. These findings will be relevant for sustainable urban mobility plans development and transport planning in cities. The introduction of wellbeing in transport planning will contribute to healthier and more sustainable cities.

This research brings light into the application of wellbeing measures to micromobility, carsharing and motosharing users. Future work should include the validation of the scales using exploratory and confirmatory analyses and the estimation of Structural Equation Modeling.

Limitations include sample size and use of different survey strategies, including online and face-to-face interviews.

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I. References

[1] C. S. Levesque, G. C. Williams, D. Elliot, M. A. Pickering, B. Bodenhamer, and P. J. Finley, 'Validating the theoretical structure of the Treatment Self-Regulation Questionnaire (TSRQ) across three different health behaviors', *Health Educ Res*, vol. 22, no. 5, pp. 691–702, Oct. 2006, doi: 10.1093/her/cyl148.

[2] A. H. , & W. A. D. Yentes, 'Use of the satisfaction with travel scale across diverse travel modes and trip purposes', *Transp Res Part F Traffic Psychol Behav*, vol. 79, pp. 250–259, 2021.

[3] D. Västfjäll, M. Friman, T. Gärling, and M. Kleiner, 'The measurement of core affect: A Swedish self-report measure derived from the affect circumplex', *Scand J Psychol*, vol. 43, no. 1, 2002, doi: 10.1111/1467-9450.00265.

[4] V. R. Smith, 'Transportation, activity space, and subjective wellbeing: How the environment determines when travel enhances subjective well-being', *J Transp Geogr*, vol. 64, pp. 181–193, 2017.

[5] L. Reardon and S. Abdallah, 'Well-being and Transport: Taking Stock and Looking Forward', *Transp Rev*, vol. 33, no. 6, 2013, doi: 10.1080/01441647.2013.837117.

[6] J. A. Russell, 'Core Affect and the Psychological Construction of Emotion', *Psychol Rev*, vol. 110, no. 1, 2003, doi: 10.1037/0033-295X.110.1.145.

[7] J. A. Russell, 'A circumplex model of affect. Journal of Personality and Social Psychology', vol. 39, no. 6, pp. 1161–1178, 1980.

[8] L. E. , G. T. , & E. D. Olsson, 'A comparison of the satisfaction with travel scale and the day reconstruction method', *Transp Res Part F Traffic Psychol Behav*, vol. 15, no. 6, pp. 686–695, 2012.

[9] S. Nordbakke and T. Schwanen, 'Well-being and Mobility: A Theoretical Framework and Literature Review Focusing on Older People', *Mobilities*, vol. 9, no. 1. 2014. doi: 10.1080/17450101.2013.784542.

[10] D. P. MacKinnon, G. Warsi, and J. H. Dwyer, 'A Simulation Study of Mediated Effect Measures', *Multivariate Behav Res*, vol. 30, no. 1, 1995, doi: 10.1207/s15327906mbr3001_3.

[11] C. S. Levesque, G. C. Williams, D. Elliot, M. A. Pickering, B. Bodenhamer, and P. J. Finley, 'Validating the theoretical structure of the Treatment Self-Regulation Questionnaire (TSRQ) across three different health behaviors', *Health Education Research*, vol. 22, no. 5. 2007. doi: 10.1093/her/cyl148.

[12] M. Friman, S. Fujii, D. Ettema, T. Gärling, and L. E. Olsson, 'Psychometric analysis of the satisfaction with travel scale', *Transp Res Part A Policy Pract*, vol. 48, 2013, doi: 10.1016/j.tra.2012.10.012.

[13] D. Ettema, T. Gärling, L. E. Olsson, M. Friman, and S. Moerdijk, 'The road to happiness: Measuring Dutch car drivers' satisfaction with travel', *Transp Policy (Oxf)*, vol. 27, 2013, doi: 10.1016/j.tranpol.2012.12.006.

[14] D. Ettema, T. Gärling, L. Eriksson, M. Friman, L. E. Olsson, and S. Fujii, 'Satisfaction with travel and subjective well-being: Development and test of a measurement tool', *Transp Res Part F Traffic Psychol Behav*, vol. 14, no. 3, 2011, doi: 10.1016/j.trf.2010.11.002.

[15] D. Ettema, T. Gärling, L. E. Olsson, and M.

Volume 10, Issue 1, June 2024 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2024.10.1.757

Friman, 'Out-of-home activities, daily travel, and subjective well-being', *Transp Res Part A Policy Pract*, vol. 44, no. 9, 2010, doi: 10.1016/j.tra.2010.07.005.

[16] A. Delbosc, 'The role of well-being in transport policy', *Transp Policy (Oxf)*, vol. 23, 2012, doi: 10.1016/j.tranpol.2012.06.005.

[17] J. , S. T. , V. A. V. , W. F. , & M. P. De Vos, 'Travel and subjective wellbeing: A focus on findings, methods and future research needs', *Transp Rev*, vol. 35, no. 1, pp. 93–112, 2015.

[18] Y. , Z. H. , & C. X. Chen, 'The relationship between daily travel and subjective wellbeing: A comparative study of car-dependent cities and public transport-oriented cities', *Transp Res Part A Policy Pract*, vol. 74, pp. 71–85, 2015.

[19] M. Abou-Zeid, 'Impact of commuting mode choice on commuting satisfaction and wellbeing: Evidence from the Montreal metropolitan region', *Transp Res Part A Policy Pract*, vol. 43, no. 7, pp. 692–709, 2009.

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An Integrated Toolkit for Equality in Daily Urban Mobility in Saudi Arabia: Advancing Gender Mobility Indicators

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ABSTRACT

The significance of unimpeded mobility in everyday activities, including commuting, shopping, and social interactions, cannot be overstated. However, many people, particularly women, face challenges that restrict their ability to move freely because of various circumstances, such as gender-related concerns and socio-economic inequalities. The absence of a well-defined framework and comprehensive indicators for addressing gender-related mobility concerns is a notable challenge in the Kingdom of Saudi Arabia (KSA) and other similar regions. This article comprehensively analyses several mobility indicators and dimensions from diverse literature, specifically emphasizing their applicability in promoting gender equality in urban mobility within the Kingdom of Saudi Arabia (KSA). A comprehensive framework is established through rigorous analysis and comparison, taking inspiration from the "Four A's" concept introduced by the World Bank in 2020. The approach offers valuable help in navigating the complex interplay between gender dynamics and urban mobility. The comparison underscores the significance of including privacy, security, availability, and diversity of public transportation indicators in the toolkit. This inclusion is necessary to address the unique requirements, safety considerations, and cultural contexts of women when designing public transportation systems. The primary objective of these initiatives is to advance gender equality in the context of urban transportation in Saudi Arabia.

Index-words: *SDGs, Goal 5, Goal 11, Gender Equity, Urban Design, Mobility Pattern, Travel Behavior, Saudi Arabia.*

I. INTRODUCTION

About 53% of the global population lives in cities, a steadily increasing trend. Projections suggest this proportion could reach 67% by 2050. Urban travel accounts for 64% of all journeys and is expected to triple by 2050 [1]. Women comprise 50% of the world's population, occupy many jobs, and head one-third of families [2].

Population growth and rising travel demand cause mobility difficulties, including changing travel patterns and higher expectations for efficient, convenient, and dependable services. Schafer and Victor (2000) state that Goal #11 of the U.N. Sustainable Development Goals (SDGs) emphasizes safe, inclusive, and sustainable urban settings. Gender equality is a significant issue, especially in the context of the SDGs. Goal #5, "Gender Equality" [3], emphasizes women's empowerment in the SDGs. It is crucial to note that women have historically faced prejudice and inequity in urban planning and development [4], [5] and [6]. Thus, urban development must be "gender-neutral" [7], allowing equal access and services to both genders.

After introducing the SDGs in 2015, Saudi Arabia unveiled its "Saudi Arabia 2030 Vision[8], a comprehensive strategy to promote women empowerment and inclusive urban settings. Saudi Arabia was the only country to bar women from driving until September 2017. However, a royal proclamation allowed women to drive in June 2018. Of almost 15 million people, 45% are women [9]. Thus, this demographic transition impacts women's daily lives, societal contributions, and the nation's well-being, economics, and Sustainability. This development also supports Vision 2030 goals. However, Saudi women's gender-responsive daily transportation encounters are poorly understood. Women have unequal mobility chances in the country. However, empirical study on their everyday mobility experiences is scarce [10].

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This research seeks to examine and emphasise the significance of gender-responsive public transportation in Saudi Arabian cities, specifically Riyadh, Jeddah, and Dammam, where public transportation services (SAPTCO public buses & Taxi) are available. The focus is on addressing the specific needs of women. This suggests that it is important to emphasise the distinct cultural and social circumstances and requirements of women to adopt the notion of gender mobility and decrease disparities in mobility. This study analyses the influence of social and cultural norms in specific areas on the requirements for gender-based mobility. This study also analyses the current mobility indicators and dimensions in the Kingdom of Saudi Arabia (KSA). It proposes a comprehensive general toolkit for effectively resolving gender-related mobility challenges in the Kingdom of Saudi Arabia (KSA), drawing inspiration from the "Four A's" concept introduced by the World Bank. The Four A's concept evaluates public Transport's influence on individuals' well-being and social inclusivity.

II. Methodology

The present study employs an inductive analytical approach that is divided into four distinct phases. Firstly, it conducts a thorough examination of the existing body of literature on gender and urban mobility worldwide, with a particular emphasis on Saudi Arabia. This thematic analysis aims to identify the causes of gender mobility disparities on a global scale, with a specific focus on Saudi Arabia. Additionally, it seeks to extract the framework known as "The Four A's Framework," which was published by the World Bank in 2020, as an approach to addressing gender mobility issues. Furthermore, this paper investigates a variety of urban mobility indicators formulated by different international organisations and countries, with a particular emphasis on Saudi Arabia. These indicators are subsequently compared using a thematic analysis to determine the most frequently used indicators, utilising the Four A's Framework of the World Bank. This framework categorises the indicators into four areas, hence facilitating the study. Subsequently, the commonly used indicators will be employed to analyse the reasons causing gender-based mobility to ascertain the most appropriate indicator for each distinct urban mobility reason related to gender. Finally, utilising the Four A's framework of the World Bank, a gender mobility Toolkit is created for women in Saudi Arabia, taking into account the findings from the analyses mentioned above. This general toolkit includes specific modifications such as reframing, rephrasing, adding, and reducing certain indicators. The developed toolkit facilitates an understanding of the factors of gender differences in urban mobility and provides an in-depth examination of each area, with a focus on the main indicators and sub-indicators.

The analysis underscores the significance of integrating indicators about privacy, security, availability, and diversity of public transportation into the toolkit to address women's distinct requirements, safety considerations, and cultural contexts in developing public transportation systems. Additionally, this study aims to shed light on disparities in mobility patterns based on gender while also offering key concepts to effectively tackle difficulties related to gender-based mobility, privacy, and security. The primary objective of these initiatives is to advance gender equality in the context of urban transportation in Saudi Arabia.

This study is divided into four sections. The first section highlights the importance of urban mobility and its relationship with gender in Saudi Arabia. The second section provides an overview of different indicators of urban mobility. In the third section, the study examines the disparities in mobility experienced by individuals of different genders. The last section delves into the proposed gender mobility general toolkit, specifically designed to address the unique needs and challenges of gender mobility in Saudi Arabia.

III. Literature Review

A. Urban Mobility and Gender in KSA

Urban transportation systems should prioritise road user needs and promote sustainable and environmentally friendly travel [11]. Society needs sustainable urban transportation networks to improve accessibility for everybody, including women [12]. People can easily access economic and social advantages via sustainable mobility, especially public transportation [13].

The 2030 U.N. Sustainable Development Goals

(SDGs) aim to make transportation networks for the poor safe, accessible, profitable, and sustainable [14]. Scholarly discourse ignores women's public safety and gender's transportation choices and behaviours [15], [16]. Despite walking and taking public transit, women's mobility difficulties are disregarded [17], [18]. Many planning processes ignore women's neighbourhood development concerns and ideas. Instead, they prioritise street flow and asphalt paving solutions. Due to household responsibilities, women spend more time and are closer to their homes. Hence, this method fails to address road safety. Women perceive streets differently than males and devote more time to neighbourhood streets[19]. Additionally, many male decision-makers have little impact[20].

Gender and transportation research explores how planning practices perpetuate gender inequities [21], [22] and how gender determines mobility patterns [15], [23]. Gender affects travel patterns, modes, and restrictions. Travel patterns usually involve several short trips for residential, social, and occupational reasons [24], [25], [26]. However, several Middle Eastern countries, such as Saudi Arabia, have neglected urban mobility, relying heavily on private cars for daily transportation[27]. Public transit is scarce in most Saudi cities, limiting urban mobility[10]. Also, a major barrier to the use of public transit in KSA is the social status of its users, specifically foreign workers from countries such as India and other comparable nations. Many Saudi nationals view riding the SAPTCO bus as "disgraceful" because it is seen as a service for low-income individuals who are marginalised and inferior in society, as noted by [28]. Therefore, society considers it improper for women to use these types of public transportation simultaneously with men[10]. Female passengers increased their use of ride-hailing services like Careem and Uber in 2014[29]. The expected 2022 launch of a Riyadh metro system and the 2018 regulation modification allowing women to drive are projected to enhance public transportation use[29]. Before women's driving privileges, Saudi women's travel options were informal car-sharing with family, official car-sharing, private vehicle chauffeurs, contractual drivers, or taxis[30], [31]. In traditional Saudi households, women mainly used informal vehicle-sharing agreements as passengers, with male family members driving[30]. In many Saudi homes, private drivers are common[9], [31]. After updated driving regulations were implemented in 2018, women's access to and use of privately owned vehicles increased[9].

Due to legal and cultural factors, Saudi Arabia restricts women's travel and employment outside the home [32]. Women are primarily limited to domestic and caregiving activities, resulting in shorter but more frequent journeys [33]. This culture emphasises that improving women's urban mobility requires improving transportation infrastructure and services and addressing social, economic, political, and physical hurdles. These hurdles include class, gender, poverty, physical disability, and affordability [34].

The hot weather in Saudi Arabia strongly discourages users from relying on public transportation. Effective temperature regulation, particularly in extreme weather conditions such as those seen in Saudi Arabia, is of utmost importance for the female population. Regrettably, the SAPTCO bus stations lack any provisions for temperature regulation[27]. The bus stops lacked waiting rooms or shades. Waiting for the bus in hot weather, even for just five minutes, can be challenging, especially for children, women, and seniors. The bus stops should be structured in a manner that offers comfortable seating arrangements together with adequate shade to shield riders from hot weather conditions[27].

Mobility must be socially considered instead of focusing solely on transportation infrastructure to encourage freedom and independence [35]. The social components of mobility are crucial, especially for women with unique travel needs [36], [37]. Gender-responsive public transportation, including consideration of women's needs and preferences, can promote mobility and encourage active daily life [18], [38], [39]. Thus, vertical equity must be considered when considering women's travel needs in local physical environments and social and cultural norms [40], [41].

B. Reasons for Gender Mobility Differences Worldwide and in Saudi Arabia

Extensive studies have consistently demonstrated that women exhibit distinct

travel patterns compared to men[20]. Several characteristics have been identified as potential influences on gender disparities in travel behaviour. These factors include age, household size, education level, possession of a driving license, ownership of a car, income level, workplace location, and accessibility to transportation options [42], [43], [44], [45]. Additional elements, such as culture and institutions, significantly shape travel behaviour and views. Examining mobility patterns in connection to culture and home structure provides valuable insights into transportation patterns and is a viable approach for researching gender disparities [46]. This finding was supported by a study presented by Wei-Shiuen Ng and Ashley Acker at the International Transport Forum held in Paris, France. According to the authors, there is a possibility of variations in travel behaviour between developed and developing cities[47]. As an example, in the modal choices Internationally, men use cars more frequently than women [48], [49], [50], [51], [52], [53], [54]. In Saudi Arabia, a study indicated that 70.4% of women use private automobiles, 22.5% use taxis, 3.0% walk, and 2.2% use public buses. Women tend to travel less often and are more inclined to do it during non-peak hours globally due to social and cultural norms[53], [57], [60], [61], [62], [63]. In Saudi Arabia, women frequently remain at home from 10 a.m. to 5 p.m., which may result in missing out on food shopping and picking up their children. They typically rely on male family members to drive[31], [64]. Regarding security, Harassment is the main barrier that prevents women from using public transport, leading to changes in their travel habits and conduct as indicated by [69], [73], [74], [75], [76], [77], [78], [79]. In Saudi Arabia, privacy is a significant norm rooted in history, religion, and culture, which greatly affects movement and travel[31], [32], [80], [81], [82]. Female passengers do not have adequate privacy at SAPTCO bus stations, as there are no separate waiting rooms or seating for them [27]. Regarding infrastructure issues, Considering the user-friendliness of waiting areas is crucial for maintaining women's safety[73]. In Saudi Arabia, waiting rooms are crucial for using public transit due to the hot temperature, which can make it difficult for children, women, and elderly individuals to deal with the heat [27]. To explore more, a comparative analysis is undertaken in Table (3) to examine the factors contributing to gender mobility disparities globally and within Saudi Arabia. The findings underscore the significant impact of contextual factors, cultural dynamics, and societal norms on individuals' choices and behaviours related to gender mobility.

An in-depth comprehension of the complexities behind gender disparities in mobility on a worldwide scale, as well as within specific contexts like Saudi Arabia, reveals the complex relationship between cultural, social, economic, and infrastructural elements that influence travel patterns. Differences in age, education, cultural norms, and accessibility are among the factors that contribute to the observed inequalities in how men and women navigate their environments. Efforts to improve transportation in cities, influenced by frameworks such as the Sustainable Development Goals, provide chances to prioritise accessibility, safety, efficiency, and sustainability in transportation infrastructure. This, in turn, promotes gender equality and empowers women. Nevertheless, the inadequate amount of study and indicators in Arab nations, specifically in Saudi Arabia, creates a substantial void in comprehending and tackling gender mobility concerns in these settings. Incorporating gender-sensitive indicators into urban mobility assessments can help bridge the gap and promote more inclusive and equitable transportation systems. This approach addresses the specific problems experienced by women and fosters greater gender equality in transportation.

C. Urban Mobility Indicators

Various organisations and nations have devised a framework comprising dimensions and indicators aligned with the Sustainable Development Goals (SDGs) to allocate resources towards enhancing walking and public transportation infrastructure that is accessible, safe, efficient, affordable, and sustainable. One such goal is SDG 11, which focuses on attaining sustainable Transport for all. Measurements and indicators are utilised to assess, analyse, and depict urban mobility in diverse places. Indicators offer a comprehensive understanding of the condition of sustainable mobility inside a city, facilitating the design of optimal solutions and monitoring advancements [88]. In addition, the proposed measures would enable municipalities to engage in comparative

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analysis with other cities of comparable scale, facilitating knowledge exchange and mutual learning [89]. Unfortunately, the majority of the indicators included in this study are published in Western societies. This is mainly because there is insufficient research on gender mobility in Arab countries, especially within Saudi Arabian society. The purpose of this study is to emphasise the significance of addressing gender mobility in Arab countries, specifically Saudi Arabia, to achieve more gender equality and strengthen women's empowerment. This section delineates frequently employed indicators seen in diverse reports and articles (see Table I).

1. Mainstream gender in road transport, W.B., 2010[86]

This report offers valuable support to professionals in transport and gender and is funded by the Gender Action Plan (GAP) Trust Fund of the World Bank. Integrating gender perspectives into road transport projects is of great importance, as it serves as a strategy to promote economic development and environmental sustainability and address gender disparities. The study emphasises the convergence of gender and transportation policies and programmes, presenting practical approaches to address gender-related issues in road transport projects. The primary focus of the GAP programme is to enhance women's economic empowerment in World Bank Group client countries. This purpose aligns with the broader goal of fostering gender equality and empowering women, as stated in Millennium Development Goal 3 (MDG3), which ended in 2015 after the release of the SDGs. The document includes a fundamental table that outlines sample data and critical indicators for establishing benchmarks and evaluating the progress of initiatives focused on incorporating gender perspectives into road transport projects. The focus of this study is mainly directed at 20 indicators relevant to the pedestrian environment and public transit infrastructure.

1. Gender toolkit, ADB 2013[90]

The toolkit was established by the Gender and Development branch of the Asian Development Bank (ADB) to offer support to ADB officials, consultants, and government partners engaged in activities related to the transport sector. The main goal of this effort is to support the integration of gender-responsive project planning practices in the transport industry. The toolkit guides professionals in the transportation and gender field regarding integrating gender equality considerations into project design, implementation, and policy engagement. The toolkit comprises many subsectors that align with the investments made by the Asian Development Bank (ADB) in the transport sector. The subsectors encompassed within this category consist of rural roads, national highways, railways, urban transportation systems, bridges, waterborne transportation, and ports. While the suitability of various elements in the toolkit may differ, users can choose the relevant subcategories corresponding to their project's specific context. This study primarily concerns the identification of 14 indicators related to urban transport, with a particular focus on improvements in transport services and the integration of design elements responsive to gender considerations.

2. Urban Agenda, 2019[89]

This report aims to allocate resources towards improving pedestrian and public transit infrastructure, specifically emphasising accessibility, security, efficiency, affordability, and sustainability. This objective aligns with Sustainable Development Goal 11.2, which seeks to advance the accessibility of sustainable transportation choices for all individuals. The significance of transport networks that offer door-to-door accessibility is recognised by the urban agenda of the European Union (E.U.), the International Association of Public Transport (UITP), and Walk21. To accomplish this objective, a set of indicators and case studies has been developed to strengthen the walkability of urban areas and improve the accessibility of public transit (URBAN AGENDA FOR THE EU, 2019). The metrics described above are classified into four separate domains of 14 primary indicators. These metrics assess the accessibility, safety, efficiency, and affordability of pedestrian infrastructure and public transportation networks in urban areas. Implementing a hierarchical methodology in these metrics enables the acquisition and distribution of data by governmental entities, augmenting the capacity to make well-informed choices and foster progress.

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3. Smart city options: *Gender Equality and Mobility, Mind the Gap* [53]:

The publication entitled "Smart Choices for Cities" was authored by the cooperation known as CIVITAS WIKI. The primary objective of the book entitled "Gender Equality and Mobility: Mind the Gap" is to facilitate the widespread dissemination of knowledge related to the concept of sustainable urban Transport. In Europe, there is an increasing emphasis from both national and local governments on bolstering their efforts to address gender disparities in the realm of mobility and transportation. The MOBILIS project, implemented during the CIVITAS II phase as part of the broader CIVITAS programme, has established specific protocols designed to conduct a gender sensitivity audit. The project's primary aim was to enhance understanding and recognition of gender-related components inherent in policy initiatives implemented by metropolitan areas. Additionally, the study sought to assess the impacts of these measures and formulate policy recommendations for urban mobility planning. This paper primarily focuses on two key aspects, specifically the development of accessibility, safety, and comfort across various transportation modes and improving transportation service supply.

4. Saudi Arabia's "Vision 2030" program[8]:

Saudi Arabia has implemented the "Vision 2030" initiative to enhance domestic mobility. The programme, initiated in 2016, encompasses diverse social and cultural goals to generate a profound and lasting influence on the country. The Vision 2030 plan incorporates a range of initiatives and endeavours that are expressly designed to improve Transport and mobility. These projects involve implementing metro and bus networks to alleviate traffic congestion and provide transport alternatives inside urban regions such as Riyadh and Jeddah. These programmes contribute to the goal of creating sustainable and livable urban environments across Saudi Arabia. While there is no dedicated programme solely centred on mobility, the Vision 2030 initiative aims to address the crucial objective of modernising Saudi Arabia comprehensively, encompassing the matter of mobility.

Four A's framework: The concept of the Four A's was initially introduced by the World Bank in 2005 [91] and subsequently revised in 2018 [92] and 2020 [60] to facilitate scholarly investigations on the subject of mobility among women in Latin America. The Four A's technique is employed to assess the impact of public transit on well-being and social inclusion. The concept encompasses availability, affordability, acceptability, and accessibility.

Following a comprehensive examination of global urban mobility indicators, a comparative assessment was undertaken utilizing the four A's framework established by the World Bank (see Table II). This analysis aimed to identify shared indicators and determine the most commonly used across various international urban indicators. Concerning Table II, the researchers propose an extensive toolkit of urban mobility indicators that incorporates all the measures employed in these global urban mobility assessments.

TABLE I: INTERNATIONAL URBAN MOBILITY INDICATORS
source: Authors

Name of indicator	Year of issuing	Institute of issuing	Location	Number of indicators	Main aspect
Mainstream gender in road transport	2010	World Bank	World Bank group client countries	20	The integration of gender perspectives into road transport projects
Gender toolkit	2013	Gender and development branch of the Asian development bank (ADB)	Asian countries	14	Support the integration of gender-responsive project planning practices in the transport industry
Urban agenda	2019	European union (E.U.), International association of public transport (UITP) & walk21	European countries	Four domains /14 primary indicators	Allocate resources towards improving pedestrian and public transit infrastructure, specifically emphasizing accessibility, security, efficiency, affordability, and sustainability

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Smart city options: gender equality and mobility, mind the gap	2020	CIVITAS WIKI	Europe	4	To address gender disparities in mobility and transportation, with a focus on developing accessibility, safety, and comfort across various transportation modes, as well as improving transportation service supply.
Saudi Arabia's "vision 2030" program	2016	Saudi Arabia Government	Saudi Arabia	Not mentioned	Enhancing domestic mobility as part of the vision 2030 initiative

Table I I: URBAN MOBILITY INDICATORS FROM INTERNATIONAL ORGANIZATIONS, source: Authors

The Four A's of the World Bank for Gender Mobility,2020 [59]		Mainstream Gender in Road Transport, W.B.,2010[85]	Gender tool kit, ADB 2013[89]	Urban Mobility Indicators by Urban Agenda of E.U.,2019[88]	Smart choices for cities Gender equality and mobility: mind the gap! E.U.,2020[52]	Saudi Arabia 2030 vision [8]	Conclusion of common Urban Mobility Indicators
Availability	Connectivity of Public Transport	Number of improved terminals	Not Mentioned	Motorised transport alternative	Not Mentioned	Not Mentioned	Integration of Public Transport & Intermodal Terminals
		Number of Changes in women's transport mode use		Mode share walking and Public Transport			
	Coverage of Urban Public Transport	Adequate service routes		Not Mentioned			Coverage of Public Transport
		Intermediate Modes of Transport					Informal Transport
	Low Availability Issues	Changes in the frequency of transport services			Availability of P.T. during non-rush hours	Development of Public Transport	Availability of Public Transport
		Number of improved sidewalks	Kilometres of sealed and separate pedestrian	Provision of Walking space	The existence of pathways in cities	Not Mentioned	Availability of Sidewalks
Affordability	Travel Cost	Not Mentioned	Income spent on P.T./ Average cost of trips	Average income paid on Transport	Not Mentioned	Not Mentioned	Affordability
			Flexible multiple-trip tickets	Not Mentioned	Affordable, flexible fares for multi-trips		
		Set affordable fares	Not Mentioned	Number of subscription tickets	Discounted fares		
Acceptability	Quality of Urban Transport	The proportion of roads in good shape is maintained regularly and used by women.	Not Mentioned	Not Mentioned	Enhance the quality of walking & cycling paths.	Not Mentioned	Public Transport Quality
	User Comfort	Number of rest facilities	Number of waiting areas at stations and stops		Seating areas		User Comfort
		Number of women who are satisfied with new transport services provided.	The percentage of women content with new transportation services	Walking & P.T. overall Satisfaction	Not Mentioned		Satisfaction
	Security	Increased perception of Security using P.T.	Number of harassments on P.T. reported by women and girls	Perception of Safety for women.	Increase the level of Security.		Security
		Not Mentioned	Not Mentioned	Level of human activity	Not Mentioned		
		Number of lights	Number of street lighting	Availability of lighting	adequate lighting		
	Reliability	Not Mentioned	Not Mentioned	Reliability of Services	Not Mentioned		Reliability
		Pedestrian Facilities	Number of female toilets	Pedestrian Amenities			Amenities & Furniture
		Not Mentioned	Not Mentioned	Satisfaction With maps, Timetables, and Journey information	Better provision of transport information		
Accessability		Not Mentioned	Not Mentioned	Accessibility of Stations and stops to people with Reduced physical mobility.	Provide stations with lifts.	Not Mentioned	Accessibility for Impaired Groups
	Access to Transport Services	Number of improved bus stops, signals,		Population Residing <500 Meters from a P.T. Stop	Improve accessibility in vehicles, stations and stops.		Access to Public Transport
		Average travel time to formal and informal places of work and by Mode of Transport	Travel time saved (hours per day) by women	Total time spent walking or riding P.T. on daily trips	Not Mentioned		
		Number of trips made by women by mode of Transport	Number of trips made by women by way of Transport	Total number of daily trips by Walking and P.T.			
	Access to Opportunities	Changes in women's travel patterns	Not Mentioned	Several jobs and urban services are accessible within 60 minutes by P.T.		Reduce congestion to increase accessibility of jobs and services	Access to Jobs and Services
		Number of improved pedestrian crossings, safety islands	Number of pedestrian crossings	Provision of Safe crossings	Safe pedestrian crossings,	Not Mentioned	Accessibility of Pedestrians

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IV. STUDY RESULTS

A. Analyzing Urban Mobility Indicators for Gender Considerations

After reviewing global urban mobility indicators used by various organizations and countries, as outlined in Table II, this study seeks to evaluate the factors that impact gender-specific urban mobility thoroughly. The aim is to determine the most suitable indicator for each reason. The analysis presented in Table III is the foundation for developing a gendered urban mobility general toolkit. This general toolkit aims to enhance one's understanding of the unique mobility needs, safety concerns, comfort preferences, and overall views of women in their daily experiences.

B. Proposed Gender Urban Mobility General Toolkit in Saudi Arabia

The authors analysed and examined the factors contributing to gender disparities in mobility and subsequently correlated these factors with relevant indices of urban mobility, as presented in Table III. The authors have put up a general toolkit based on international urban mobility metrics, as shown in Table II, according to the analysis conducted. This general toolkit aims to tackle gender-specific requirements, perspectives, safety considerations, and cultural contexts within public transportation systems, seeking to advance gender equality in everyday mobility within the Saudi Arabian environment. The general Toolkit presented in this study draws from the Four A's framework of the World Bank while incorporating specific alterations such as reframing, rephrasing, adding, and lowering particular indicators. These adjustments have been made to better align the framework with the unique mobility requirements of different genders, as illustrated in Figure 1. The general toolkit proposes the following recommendations to mitigate the challenges faced by women in Saudi Arabia concerning their mobility.

Availability: The toolkit improves availability by dividing it into pedestrian and public transportation availability. Pedestrian Availability: The toolkit suggests including an indicator that measures the proportion of women-specific sidewalks and pedestrian zones in the urban environment. Pavements are essential for active transportation and women's mobility, especially in Saudi Arabia, where walking is rare. Sidewalks will improve pedestrian infrastructure, improving women's mobility. Public Transit Availability: The toolkit emphasises public transport availability, coverage, and integration. Additionally, it advises adding a new indicator measuring public transit diversity and range. The first indicator assesses public transportation availability using multiple sub-indicators, including stations, routes, frequency, service hours, and coverage. The proposed sub-indicators attempt to improve women's transportation access through various strategies. These strategies include increasing public transit routes and frequency, flexible service hours, and neighborhood-wide coverage. These measures would help women travel safer and more efficiently, allowing them to exploit hitherto unattainable opportunities. The second indicator assesses how well the Saudi Arabian public transport network accommodates gender mobility patterns, given the limited availability of such services. This availability will allow women to travel regardless of distance, lowering their car use. The third indicator measures public transportation system integration. This review helps women organise their complex routes, reducing their use of private vehicles and increasing public transportation. Public transportation inclusion is crucial, especially in Saudi Arabia, where women are officially barred from public transit. This indicator will improve public transportation diversity by introducing gender-specific services like "pink buses" and "pink metro." Such programs should increase female public transit use and empower women.

TABLE III: GENDER MOBILITY DIFFERENCES INTERNATIONALLY AND IN KSA, source: Authors

Gender differences in mobility	International reasons	Saudi Arabia reasons	Suggested indicators to solve those problems
Modal Choices and Preferences	The frequency of car usage is lower among women than men[48], [49], [50], [51], [52], [53], [54].	Saudi Arabian research [9] found that 70.4% of women drive private cars, 22.5 % taxis, 3.0% walk, and 2.2 % public buses.	**Availability of female-only Public Transport** **Availability of Sidewalks** **Coverage of Public Transport**
	In developed and developing nations, it is observed that women have a greater tendency to walk compared to men[48], [49], [50], [55], [56].	Even though walking is not a prevalent mode of travel in Saudi Arabia, it is still more favoured than using the public bus[27].	**Accessibility of Pedestrians** **Availability of Sidewalks**
Socio-cultural Norms and Constraints	Women tend to commute shorter distances to their workplaces and prefer establishing their enterprises closer to their residences than men. Consequently, this pattern results in a more limited scope of geographic mobility for women. [48], [49], [52], [53], [56], [57], [58].	Legal and socio-cultural norms in certain societies limit women to domestic roles, leading them to make short, frequent trips[33].	**Accessibility of Public Transport** **Access to Jobs and Services** **Availability of Public Transport** **Coverage of Public Transport**
	Moreover, numerous research has consistently demonstrated that women have a greater propensity to utilize public transit as opposed to private automobiles[48], [50], [51], [52], [54], [55], [59].	Socio-cultural factors lead to public transport being predominantly used by non-Saudi labour, making it socially unacceptable for women to use[10].	**Diversity of transportation modes** **Availability of female-only Public Transport** **Coverage of Public Transport** **Integration of Public Transport** **Privacy in transportation modes**
	Women travel less frequently and are more likely to do so during off-peak times[53], [57], [60], [61], [62], [63].	Women often stay home between 10 a.m. and 5 p.m., missing grocery shopping and kid pickups. They usually wait for male family members to drive[31], [64].	**Privacy in transportation modes** **Availability of female-only Public Transport**
	Women typically use less formal, less effective, and less expensive forms of transportation[51], [57], [58], [60], [65].	Women in Saudi Arabia have limited mobility options[10], with their choices for transit being notably restricted.	**Diversity of transportation modes** **Availability of female-only Public Transport** **Privacy**
Safety and Security Concerns	According to a survey, 61%–73% of women were more worried about Security in public transit [66]. Another study [67] found that over 60% of BRT[1] users had experienced sexual harassment. 91% of Indian women reported feeling insecure [68].	Public transportation security is essential to Saudi women. According to a study, women on SAPTCO public buses were 34.8% anxious and 34.3% concerned. Eighty per cent of women are worried about taxi safety[27].	**Security** **Privacy** **Availability of female-only Public Transport**
	Women's mobility may be restricted by their fear of travelling alone, at night, or in an unsafe environment. As a result, they may avoid or use public transit less frequently [69], [70], [71], [72].	The primary concerns for women feeling unsafe were travelling alone with unfamiliar male drivers and taxi privacy issues [27].	**Security** **Privacy** **Availability of female-only Public Transport**
	Gender-responsive public transportation use depends on individual security at bus stops [23]. At these stations, security personnel, sufficient lighting, visibility, and safety precautions are necessary to protect women[27].	The SAPTCO public bus stops and the broader infrastructure do not offer security features[27]	**Security**
	Harassment constitutes the predominant obstacle impeding women's use of public transportation, hence necessitating modifications to their travel patterns and behaviour [69], [73], [74], [75], [76], [77], [78], [79].	In Saudi Arabia, privacy is a historical, religious, and cultural norm that severely impacts mobility and travel [31], [32], [80], [81], [82]. Women lack privacy at SAPTCO bus stops, including separate waiting areas and seating[27].	**User comfort** **Privacy**

1 Bus Rapid Transit

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Infrastructure Issues	Women face a disproportionate number of mobility barriers and experience a more significant impact from time restrictions in their everyday travels[57], [60], [61].	The SAPTCO public bus operates between 3:00 p.m. and 10:00 p.m. with no morning services, which, combined with distant bus stops, challenges women's use[27].	**Availability of Public Transport** **Access to Public Transport**
	The consideration of waiting area user-friendliness holds significant importance in ensuring women's safety [73].	SAPTCO bus stops lacked necessary amenities like waiting rooms or shade, making it challenging to stay in the heat, especially for kids, women, and older people [27].	**User comfort** **Access to Public Transport**
	Accessibility elements are critical for women. These include barrier-free routes to transit stops, spatial access, and transit vehicle designs that accommodate their needs (e.g., low-floor cars, wheelchairs, pram storage, etc.)[83], [84].	The infrastructure of SAPTCO is not gender-responsive. High-floor buses, absence of storage for baby strollers/wheelchairs, and missing connecting footpaths to bus stops all pose barriers[27].	**Accessibility for Impaired Groups**
Economic Considerations	Due to the higher cost of transportation for multi-stop routes, women have indicated in multiple surveys that they spend a large percentage of their income on it[40], [60], [85], [86], [87].	Women often do not cover the cost of car purchases, but they typically handle charges related to personal drivers, operation, and maintenance[10].	**Affordability of Travel cost**

Public Transport Affordability: The toolkit examines affordability through two indicators: affordable fares and multi-trip pricing. The indicators will regulate transportation fees to make them more reasonable and ensure equal access for women and people with disabilities. Affordable multi-trip rates may encourage women to use public transportation, saving them money on car expenses.

Accessibility: the proposed toolkit restructured accessibility indicators into two groups. One category evaluates pedestrian accessibility, while the other evaluates public transit accessibility.

1. The suggested toolkit's Pedestrian Accessibility category redefines core indicators for assessing gendered accessibility perceptions. Crosswalks, pedestrian crossings, and sidewalk inclines are essential markers. These qualities are fundamental in all street designs, although they are missing in some underdeveloped nations, causing gender inaccessibility. These sub-indicators should make walking safer and more appealing for women by improving highways and pedestrian areas. This approach is expected to reduce pedestrian-vehicle accidents, enhance pedestrian safety, and boost the likelihood of pedestrians using certain streets. The programme also emphasises two sidewalk gender inclusiveness measures. These measurements consider the number of daily walking excursions and the duration of each gender's walks. These two studies highlight the need to record the time and frequency of walking trips by different genders in different communities to assess walkability. This statistic will help analyse district walkability from a gender viewpoint and examine the factors that affect it.

2. The proposed toolkit divides public transportation access into five indicators: accessibility for impaired groups, gender-based access to work and services, accessibility of stops, total number of trips by gender, and total duration. The first indicator is critical for measuring public transportation accessibility for underrepresented populations, including women and people with impairments. Women like accessibility characteristics like barrier-free routes to transit stops, spatial accessibility, and user-responsive transit vehicle design. This metric helps measure gender-based public transportation accessibility. If this issue is resolved, all genders will use public transit more. The second indicator measures gender-inclusive employment and service access within a 45-60 minute travel time. Accessibility geographical analysis can identify locations with poor transportation infrastructure, indicating areas that need development to match gender-specific mobility patterns. The third indicator was changed for gender-specific needs. Bus and light rail stations should be every 400 and 800 meters, respectively, to determine neighbourhood stop frequency. This intervention should improve transportation infrastructure, increase regional transit options, and reduce pedestrian distances. These enhancements should boost women's mobility and access to opportunities outside their immediate area. Both prior indicators have been rewritten to be more gender-specific.

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The first indicator measures how long different genders commute by public transit. The daily public transportation time allocation for each gender will be determined using these data. This indicator will also help identify concerns like poor intermodal connectivity or slow or inaccessible transit options that extend the route. The second indicator is the total number of daily public transportation trips by gender. This indicator will help assess gender use in each locality as a public transportation accessibility indicator. These indicators can help women access public transit by identifying and solving transportation issues.

Acceptability: The toolkit reduces some metrics and adds others to improve gender mobility indicators in Saudi Arabia. One of the new indicators addresses privacy, a critical issue for Saudi women using public transportation. This signal promotes privacy by providing women-only sections in public transit, waiting areas, and stations. Segregated public transportation networks are expected to increase women's use and empower them in cities. Another consideration is gender comfort on public transit. It has three sub-indicators: seating, shelter, and temperature regulation. The toolkit includes these sub-indicators. Seating and shelter availability at every public transportation station will be assessed using the first two indicators. Due to Saudi Arabia's climate, a temperature control indicator is justified. This strategy will help regulate public transportation and stop seating temperatures. The most crucial factor in daily life is gender security. This indicator has three sub-indicators: adequate lighting, natural surveillance, and active monitoring. The suggested method uses a gender-based score system to assess bus stop and sidewalk lighting accessibility in different neighbourhoods. The toolkit proposes rethinking the natural surveillance indicator from a gender perspective. This project aims to provide a scoring system to assess natural monitoring in urban thoroughfares, public transportation hubs, and pedestrian walkways. Active surveillance highlights the importance of this indicator and identifies locations where surveillance infrastructure may need development to meet gender-specific needs. This work requires checking every local route, public transportation station, and sidewalk for active surveillance.

Fig. 1. Proposed gender mobility general toolkit for KSA, source: Authors

V. DISCUSSION

The study emphasizes the importance of adopting a gendered perspective when examining urban mobility, with a specific focus on acknowledging and addressing the distinct mobility needs of women. Through an analysis of worldwide urban mobility indicators and their application to the socio-cultural milieu of Saudi Arabia, this study elucidates the multifaceted nature of mobility, encompassing not just transportation but also its intricate connections with gender roles, societal norms, and safety considerations.

The conventional approach to urban mobility indicators has typically lacked gender considerations. However, this study emphasizes the importance of acknowledging the distinct requirements, perspectives, and limitations experienced by women. The gendered perspective encompasses the pursuit of equity and the imperative to provide the safe, comfortable, and efficient mobility of half the population inside urban environments.

The need to tailor global indicators to local contexts is apparent, as the World Bank's Four A's foundational framework becomes inadequate in its one-size-fits-all approach. A customised strategy is required due to the

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distinct cultural and societal environment of Saudi Arabia, particularly concerning the roles and mobility of women. The use of markers, such as privacy, which may have varying degrees of relevance in different circumstances, emphasizes this assertion.

The toolkit offered emphasizes the necessity of including pedestrian and public transportation infrastructure. Providing sidewalks and pedestrian zones is crucial in promoting active transportation modes while implementing complete public transportation systems facilitates travel over greater distances. The adoption of this dual approach is critical to enabling the advancement of sustainable urban mobility.

Moreover, incorporating comfort-related metrics, such as temperature control, exemplifies the comprehensive perspective on mobility that emphasizes the significance of the entire travel experience, encompassing both the process and the endpoint.

Fundamentally, the research focuses not just on physical motion but also on the concept of empowerment. By acknowledging and addressing the distinct obstacles to mobility experienced by women, the researchers create opportunities for greater involvement in public spheres, economic endeavours, and social interactions. Tools like the suggested "pink buses" and "pink metro" symbolise the ongoing transition towards a more inclusive urban setting.

Although the study used a detailed methodology, it is essential to acknowledge that potential objections may emerge. Although culturally significant, the implementation of segregated transportation modes may be perceived by specific individuals as reinforcing gender disparities rather than fostering their integration. The delicate nature of striking a balance between cultural sensitivity and promoting gender equality necessitates additional research.

With the ongoing expansion of urban areas, there will be a heightened need for mobility solutions that are efficient, safe, and inclusive. The toolkit given in the study provides a framework that other countries and localities may utilize to tailor and implement according to their unique circumstances. Furthermore, the research underscores the significance of ongoing feedback and adaptability. As societal norms undergo transformation and urban dynamics experience shifts, it becomes necessary to reassess the indicators and methods in place periodically.

VI. CONCLUSION

This study critically analyses gender and urban mobility in Saudi Arabia, introducing an innovative general toolkit specifically designed for gender-specific urban mobility. This study emphasizes the importance of including a gender-focused strategy in urban transport planning, based on the World Bank's Four A's framework. Additionally, the researchers have tailored these worldwide insights to suit the specific cultural, socioeconomic, and infrastructural context of Saudi Arabia. The local application of this general toolkit is expected to significantly improve women's daily mobility by tackling persistent obstacles like privacy, security, and accessibility. The projected reforms aim to empower women by offering them safer, more comfortable, and fair access to urban mobility solutions.

The research at hand adds to the global discussion on gender equality in urban transport by highlighting the significance of adapting international frameworks to specific contexts. This study provides useful insights for places facing similar cultural and infrastructure constraints by focusing on the specific difficulties and solutions in the Saudi context. The toolkit provides a framework for incorporating gender considerations into urban planning and transport policies globally, highlighting the importance of customizing methods to local conditions to successfully tackle gender inequalities in mobility.

As cities develop, the demand for transit options that are inclusive, safe, and efficient grows more crucial. This study establishes the foundation for the next research and policy development to promote cooperation among urban planners, policymakers, and communities to enhance the inclusivity of urban settings. By acknowledging and tackling the distinct mobility obstacles experienced by women, one can progress towards a fairer and thriving urban future for everyone.

More studies are needed to apply and evaluate the gender-specific urban mobility toolkit in Saudi Arabia and in different geographical areas and cultural circumstances to customize and deploy the toolkit effectively.

Governments, urban planners, and transportation agencies in Saudi Arabia must work together to implement the toolkit. Engaging stakeholders helps integrate the toolkit's ideas into urban planning and transportation strategies. Researcher and policymaker collaboration is needed to monitor the effects of these changes and make necessary adjustments.

This research shows the need for gender-specific considerations in urban mobility design, especially in culturally diverse and dynamic Saudi Arabia. The study emphasizes the need for a personalized methodology because universal measures may not account for the myriad of cultural, social, and safety considerations that affect gender-based mobility. Including privacy, security, comfort, and accessibility, the toolkit improves urban transportation for women.

Female-inclusive urban mobility empowers women, improves economic possibilities, and fosters social cohesion. This study lays the groundwork for collaborations between scholars, policymakers, and urban designers to create universally accessible urban environments. A more inclusive and prosperous urban future can be achieved by acknowledging and addressing women's unique challenges.

References

[1] F.-J. Van Audenhove, O. Korniichuk, L. Dauby, and J. Pourbaix, "The Future of Urban Mobility 2.0: Imperatives to Shape Extended Mobility Ecosystems of Tomorrow," Jan. 2014.

[2] World Bank Group, "Population, female (% of total population) | Data." [Online]. Available: https://data.worldbank.org/indicator/SP.POP.TOTL.FE.ZS?end=2018&start=2018&view=bar

[3] UNSD and DESA, "SDG Indicators — SDG Indicators," United Nations Statistics Division, Department of Economic and Social Affairs. Accessed: Sep. 06, 2020. [Online]. Available: https://unstats.un.org/sdgs/indicators/indicators-list/

[4] R. Crompton, *Women and work in modern Britain*. New York: Oxford University Press, 2002.

[5] J. Hoff, *Law, gender and injustice : legal history of U.S. women*, New ed. New York: New York U.P., 1994.

[6] M. B. Katz, M. J. Stern, and J. J. Fader, "Women and the Paradox of Economic Inequality in the Twentieth-Century," *J Soc Hist*, vol. 39, no. 1, pp. 65–88, Sep. 2005, doi: 10.1353/jsh.2005.0107.

[7] A. Cornwall, "Whose voices? Whose choices? Reflections on gender and participatory development," *World Dev*, vol. 31, no. 8, pp. 1325–1342, Aug. 2003, doi: 10.1016/S0305-750X(03)00086-X.

[8] Saudi Arabia—Vision 2030, "The Progress & Achievements of Saudi Arabia—Vision 2030," https://www.vision2030.gov.sa/.

[9] N. Al-Qarawi and M. Kamargianni, "She Drives KSA: Phase 1 Survey Report," *Imam Abdulrahman Bin Faisal University: Dammam, Saudi Arabia.* , Sep. 2018, Accessed: Oct. 19, 2023. [Online]. Available: https://www.iau.edu.sa/sites/default/files/resources/she_drives_report_survey_results_0.pdf

[10] N. Alshabibi, "A Priminalry Determination of Factors Effecting Female Travel Demand, Pattern, and Behavior in the Kingdom of Saudi Arabia," *International Journal of Psychosocial Rehabilitation*, vol. 23, no. 1, pp. 11–20, Mar. 2019, doi: 10.37200/IJPR/V23I1/PR190208.

[11] UNESCAP, "Transport and communications bulletin for Asia and the Pacific. No. 76 : gender and transport | ESCAP." Accessed: Oct. 22, 2023. [Online]. Available: https://www.unescap.org/publications/transport-and-communications-bulletin-asia-and-pacific-no-76-gender-and-transport

[12] B. C. Richardson, "Sustainable transport: analysis frameworks," *J Transp Geogr*, vol. 13, no. 1, pp. 29–39, Mar. 2005, doi: 10.1016/J.JTRANGEO.2004.11.005.

[13] M. Ogryzek, D. Adamska-Kmieć, and A. Klimach, "Sustainable Transport: An Efficient Transportation Network—Case Study," *Sustainability*, vol. 12, no. 19, Oct. 2020, doi:

10.3390/SU12198274.

[14] U. SDGs, "@UN_Enable Full report: bit.ly/UN-report-disability-sdgs Realizing the Sustainable Development Goals by, for and with Persons with Disabilities Making cities and communities inclusive and sustainable for persons with disabilities (Goal 11) Disability-incl," 2015. Accessed: Oct. 31, 2020. [Online]. Available: https://www.un.org/development/desa/disabilities/wp-content/uploads/sites/15/2020/02/Cities-Brief-Disabilities.pdf

[15] S. Hanson, "Gender and mobility: New approaches for informing sustainability," *Gender, Place and Culture*, vol. 17, no. 1, pp. 5–23, Feb. 2010, doi: 10.1080/09663690903498225.

[16] A. Loukaitou-Sideris, "A gendered view of mobility and transport: Next steps and future directions," *Town Planning Review*, vol. 87, no. 5, pp. 547–565, Sep. 2016, doi: 10.3828/tpr.2016.38.

[17] C. Greed, "Are we still not there yet? Moving further along the gender highway," in *Integrating Gender into Transport Planning: From One to Many Tracks*, Palgrave Macmillan, 2019, pp. 25–42. doi: 10.1007/978-3-030-05042-9_2.

[18] T. P. Uteng and J. Turner, "Addressing the linkages between gender and transport in low- and middle-income countries," *Sustainability (Switzerland)*, vol. 11, no. 17, 2019, doi: 10.3390/su11174555.

[19] M.-P. Kwan, "Gender, the Home-Work Link, and Space-Time Patterns of Nonemployment Activities," *Econ Geogr*, vol. 75, no. 4, p. 370, Oct. 1999, doi: 10.2307/144477.

[20] D. Peters, "Gender and Sustainable Urban Mobility," *Global report on Human Settlements 2013*, p. 63, 2013, [Online]. Available: http://www.unhabitat.org/grhs/2013

[21] C. H. Greed, *Women and planning: creating gendered realities*. 1994. doi: 10.1016/s0264-8377(96)90012-5.

[22] M. Roberts, "Introduction: Concepts, themes and issues in a gendered approach to planning," in *Fair Shared Cities: The Impact of Gender Planning in Europe*, Taylor and Francis, 2016, pp. 1–18. doi: 10.4324/9781315581835-6.

[23] R. Law, "Beyond 'women and transport': Towards new geographies of gender and daily mobility," *Prog Hum Geogr*, vol. 23, no. 4, pp. 567–588, 1999, doi: 10.1191/030913299666161864.

[24] E. Blumenberg, "En-gendering effective planning: Spatial mismatch, low-income women, and transportation policy," *Journal of the American Planning Association*, vol. 70, no. 3, pp. 269–281, 2004, doi: 10.1080/01944360408976378.

[25] C. Miralles-Guasch, M. M. Melo, and O. Marquet, "A gender analysis of everyday mobility in urban and rural territories: from challenges to sustainability," *Gender, Place and Culture*, vol. 23, no. 3, pp. 398–417, Mar. 2016, doi: 10.1080/0966369X.2015.1013448.

[26] J. Turner and M. Grieco, "Gender and Time Poverty: The Neglected Social Policy Implications of Gendered Time, Transport and Travel," *Time Soc*, vol. 9, no. 1, pp. 129–136, Mar. 2000, doi: 10.1177/0961463X00009001007.

[27] M. A. Al-Rashid, K. M. Nahiduzzaman, S. Ahmed, T. Campisi, and N. Akgün, "Gender-Responsive Public Transportation in the Dammam Metropolitan Region, Saudi Arabia," *Sustainability*, vol. 12, no. 21, pp. 1–17, 2020, Accessed: Oct. 19, 2023. [Online]. Available: https://ideas.repec.org/a/gam/jsusta/v12y2020i21p9068-d438246.html

[28] L. Steg, "Car use: lust and must. Instrumental, symbolic and affective motives for car use," *Transp Res Part A Policy Pract*, vol. 39, no. 2–3, pp. 147–162, Feb. 2005, doi: 10.1016/J.TRA.2004.07.001.

[29] W. Saleh and A. Malibari, "Saudi women and vision 2030: Bridging the gap?," *Behavioral Sciences*, vol. 11, no. 10, p. 132, Oct. 2021, doi: 10.3390/BS11100132.

[30] M. F. Errigo and G. Tesoriere, "Urban Travel Behavior Determinants in Saudi Arabia," *TeMA: Journal of Land Use, Mobility and Environment*, vol. 0, no. 0, pp. 31–46, Jun. 2018, doi: 10.6092/1970-9870/5449.

[31] H. P. Peterson and Z. Al Kassim, "A Case Study On Perceptions Of Public Transportation In The Eastern Province Of Saudi Arabia," *Transport Problems*, vol. 15, no. 2, pp. 5–15, 2020, doi: 10.21307/TP-2020-015.

[32] M. H. Clarke, "Making transport work for women and men : challenges and opportunities in the Middle East and North Africa (MENA) region - lessons from case studies." Accessed: Oct. 22, 2023. [Online]. Available: https://documents.worldbank.

org/en/publication/documents-reports/documentdetail/220381468278678436/making-transport-work-for-women-and-men-challenges-and-opportunities-in-the-middle-east-and-north-africa-mena-region-lessons-from-case-studies

[33] X. Lu and E. I. Pas, "Socio-demographics, activity participation and travel behavior," *Transp Res Part A Policy Pract*, vol. 33, no. 1, pp. 1–18, Jan. 1999, doi: 10.1016/S0965-8564(98)00020-2.

[34] UN-HABITAT, "Mobility as Access: Equitable Urban Mobility," *United Nations Headquarters: New York, NY, USA*, 2014.

[35] K. Doughty and L. Murray, "Discourses of Mobility: Institutions, Everyday Lives and Embodiment," *Mobilities*, vol. 11, no. 2, pp. 303–322, Sep. 2014, doi: 10.1080/17450101.2014.941257.

[36] S. Iqbal, A. Woodcock, and J. Osmond, "'The effects of gender transport poverty in Karachi,'" *J Transp Geogr*, vol. 84, Apr. 2020, doi: 10.1016/j.jtrangeo.2020.102677.

[37] J. Cubells, O. Marquet, and C. Miralles-Guasch, "Gender and Age Differences in Metropolitan Car Use. Recent Gender Gap Trends in Private Transport," *Sustainability 2020, Vol. 12, Page 7286*, vol. 12, no. 18, p. 7286, Sep. 2020, doi: 10.3390/SU12187286.

[38] A. K. Das, "Gender-Responsive Public Transport," pp. 1–12, 2020, doi: 10.1007/978-3-319-71061-7_106-1.

[39] M. Maciejewska, O. Marquet, and C. Miralles-Guasch, "Changes in gendered mobility patterns in the context of the Great Recession (2007–2012)," *J Transp Geogr*, vol. 79, p. 102478, Jul. 2019, doi: 10.1016/J.JTRANGEO.2019.102478.

[40] T. Uteng, "Gender and Mobility in the Developing World," *undefined*, 2012.

[41] UN-HABITAT, "The State of Arab Cities 2012 , Challenges of Urban Transition | UN-Habitat." Accessed: Oct. 22, 2023. [Online]. Available: https://unhabitat.org/the-state-of-arab-cities-2012-challenges-of-urban-transition

[42] S. Hanson and I. Johnston, "GENDER DIFFERENCES IN WORK-TRIP LENGTH: EXPLANATIONS AND IMPLICATIONS," *http://dx.doi.org/10.2747/0272-3638.6.3.193*, vol. 6, no. 3, pp. 193–219, 1985, doi: 10.2747/0272-3638.6.3.193.

[43] M.-P. ; Kwan and A. Kotsev, "Gender differences in commute time and accessibility in Sofia, Bulgaria: a study using 3D geovisualisation on JSTOR." Accessed: Oct. 22, 2023. [Online]. Available: https://www.jstor.org/stable/43868630

[44] M. G. Boarnet and S. Sarmiento, "Can Land-use Policy Really Affect Travel Behaviour? A Study of the Link between Non-work Travel and Land-use Characteristics," *http://dx.doi.org/10.1080/0042098984538*, vol. 35, no. 7, pp. 1155–1169, Jun. 1998, doi: 10.1080/0042098984538.

[45] H. Best and M. Lanzendorf, "Division of labour and gender differences in metropolitan car use: An empirical study in Cologne, Germany," *J Transp Geogr*, vol. 13, no. 2, pp. 109–121, Jun. 2005, doi: 10.1016/J.JTRANGEO.2004.04.007.

[46] A. Bernard, A.-M. Seguin, Y. Bussiere, and A. Polacchini, "Household Structure and Mobility Patterns of Women in O-D Surveys: Methods and Results Based on the Case Studies of Montreal and Paris," *PsycEXTRA Dataset*, Jan. 2011, Accessed: Oct. 22, 2023. [Online]. Available: https://www.academia.edu/45540409/Household_Structure_and_Mobility_Patterns_of_Women_in_O_D_Surveys_Methods_and_Results_Based_on_the_Case_Studies_of_Montreal_and_Paris

[47] W.-S. Ng and A. Acker, "Understanding Urban Travel Behaviour by Gender for Efficient and Equitable Transport Policies," *International Transport Forum Discussion Papers*, Feb. 2018, doi: 10.1787/EAF64F94-EN.

[48] S. Srinivasan, "A Spatial Exploration of the Accessibility of Low-Income Women: Chengdu, China and Chennai, India," *Gendered Mobilities*, pp. 157–172, Dec. 2008, doi: 10.4324/9781315584201-17/GENDER-SOCIAL-USAGE-MOBILE-TECHNOLOGIES-INFORMATION-SOCIETY-POLICIES-EVERYDAY-PRACTICES-TOMMI-INKINEN.

[49] N. Tanzarn, "Gendered Mobilities in Developing Countries: The Case of (Urban) Ugand." Accessed: Jan. 10, 2023. [Online]. Available: https://www.taylorfrancis.com/chapters/edit/10.4324/9781315584201-13/gendered-mobilities-developing-countries-case-urban-uganda-nite-tanzarn

[50] M. Polk, "Are women potentially more accommodating than men to a sustainable transportation system in Sweden?," *Transp Res D Transp Environ*, vol. 8, no. 2, pp. 75–95, Mar.

2003, doi: 10.1016/S1361-9209(02)00034-2.

[51] Chantal DUCHÈNE, "Gender and Transport Chantal DUCHÈNE," 2011. Accessed: Nov. 18, 2020. [Online]. Available: www.internationaltransportforum.org

[52] S. Rosenbloom, "Understanding Women's and Men's Travel Patterns: The Research Challenge," *undefined*, 2006.

[53] CIVITAS, "Smart choices for cities," 2014.

[54] C. Vance and R. Iovanna, "Gender and the Automobile," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2013, no. 1, pp. 54–61, Jan. 2007, doi: 10.3141/2013-08.

[55] R. Goel, O. Oyebode, L. Foley, L. Tatah, C. Millett, and J. Woodcock, "Gender differences in active travel in major cities across the world," *Transportation (Amst)*, pp. 1–17, Jan. 2022, doi: 10.1007/S11116-021-10259-4/FIGURES/3.

[56] A. Anand and G. Tiwari, "A gendered perspective of the shelter-transport-livelihood link: The case of poor women in Delhi," *Transp Rev*, vol. 26, no. 1, pp. 63–80, Jan. 2006, doi: 10.1080/01441640500175615.

[57] M. C. Lecompte and B. S. Juan Pablo, "Transport systems and their impact con gender equity," *Transportation Research Procedia*, vol. 25, pp. 4245–4257, Jan. 2017, doi: 10.1016/J.TRPRO.2017.05.230.

[58] O. Blumen and A. Kellerman, "GENDER DIFFERENCES IN COMMUTING DISTANCE, RESIDENCE, AND EMPLOYMENT LOCATION: METROPOLITAN HAIFA 1972 AND 1983∗," *http://dx.doi.org/10.1111/j.0033-0124.1990.00054.x*, vol. 42, no. 1, pp. 54–71, 1990, doi: 10.1111/J.0033-0124.1990.00054.X.

[59] UN Habitat, "WOMEN'S SAFETY AUDITS What Works and Where?," 2008.

[60] K. Dominguez, A. L. Machado, B. Bianchi Alves, V. Raffo, S. Guerrero, and I. Portabales, *Why Does She Move?* World Bank, 2020. doi: 10.1596/33466.

[61] T. L. Brennan, "AN ANALYSIS OF TRIP BEHAVIOUR PATTERNS OF WOMEN IN DEVELOPING COUNTRIES: A CASE STUDY OF PUEBLA, MEXICO (ABSTRACT ONLY)," Jul. 1996.

[62] J. Hine and F. Mitchell, "The role of transport in social exclusion in urban Scotland: research finding," 2001.

[63] J. Hine and F. Mitchell, "Transport disadvantage and social exclusion : exclusionary mechanisms in transport in urban Scotland," 2003, Accessed: Dec. 18, 2022. [Online]. Available: https://books.google.com/books/about/Transport_Disadvantage_and_Social_Exclus.html?id=qmWwEOdwsmgC

[64] M. Nihal, "Saudi Women Driving: Women express concern over 'no hailing taxi' law." Accessed: Oct. 24, 2023. [Online]. Available: https://saudiwomendriving.blogspot.com/2013/10/women-express-concern-over-no-hailing.html

[65] A. Bhide, "Engendering the Mumbai Suburban Railway Network Study for Mumbai Rail Vikas Corporation – URK." Accessed: Feb. 07, 2023. [Online]. Available: https://urk.tiss.edu/research/engendering-the-mumbai-suburban-railway-network-study-for-mumbai-rail-vikas-corporation/

[66] H. Allen, G. Cárdenas, L. P. Pereyra, and L. Sagaris, "Ella se mueve segura. A study on women's personal safety in public transport in three Latin American cities," Mar. 2019, Accessed: Oct. 19, 2023. [Online]. Available: https://scioteca.caf.com/handle/123456789/1407

[67] M. Orozco-Fontalvo, J. Soto, A. Arévalo, and O. Oviedo-Trespalacios, "Women's perceived risk of sexual harassment in a Bus Rapid Transit (BRT) system: The case of Barranquilla, Colombia," *J Transp Health*, vol. 14, p. 100598, Sep. 2019, doi: 10.1016/J.JTH.2019.100598.

[68] S. Shah and A. Raman, "Calaméo - OLA Mobility Institute - What Do Women And Girls Want From Urban Mobility Systems?" Accessed: Oct. 19, 2023. [Online]. Available: https://www.calameo.com/books/007099207a3350f080431

[69] C. Dameria and A. H. Fuad, "Enhancing female pedestrians' safety perceptions through the permeability of building frontages (case study: blok M area)," *IOP Conf Ser Earth Environ Sci*, vol. 673, no. 1, p. 012040, Feb. 2021, doi: 10.1088/1755-1315/673/1/012040.

[70] N. Gardner, J. Cui, and E. Coiacetto, "Harassment on public transport and its impacts on women's travel behaviour," *https://doi.org/10.1080/07293682.2017.1299189*, vol. 54, no. 1, pp. 8–15, Jan. 2017, doi: 10.1080/07293682.2017.1299189.

[71] A. Lubitow, M. J. Abelson, and E. Carpenter, "Transforming mobility justice: Gendered harassment and violence on transit," *J Transp Geogr*, vol. 82, p. 102601, Jan. 2020, doi: 10.1016/J.JTRANGEO.2019.102601.

[72] K. J. Clifton and A. D. Livi, "Gender Differences in Walking Behavior, Attitudes About Walking, and Perceptions of the Environment in Three Maryland Communities." Accessed: Jan. 17, 2023. [Online]. Available: https://trid.trb.org/view/773070

[73] A. Loukaitou-Sideris and C. Fink, "Addressing Women's Fear of Victimization in Transportation Settings," *Urban Affairs Review*, vol. 44, no. 4, pp. 554–587, Mar. 2009, doi: 10.1177/1078087408322874.

[74] M. J. Smith, "Addressing the Security Needs of Women Passengers on Public Transport," *Security Journal 2008 21:1*, vol. 21, no. 1, pp. 117–133, Jan. 2008, doi: 10.1057/PALGRAVE.SJ.8350071.

[75] TTC, METRAC, and MTPF, "MOVING FORWARD: MAKING TRANSIT SAFER FOR WOMEN: A JOINT STUDY OF SECURITY ON THE RAPID TRANSIT SYSTEM RELATIVE TO SEXUAL ASSAULTS..," p. 81, 1989.

[76] A. Gekoski, J. M. Gray, J. R. Adler, and M. A. H. Horvath, "The prevalence and nature of sexual harassment and assault against women and girls on public transport: an international review," *Journal of Criminological Research, Policy and Practice*, vol. 3, no. 1. Emerald Group Publishing Ltd., pp. 3–16, 2017. doi: 10.1108/JCRPP-08-2016-0016.

[77] S. Harsment, "Statistics – The Prevalence of Street Harassment," Stop street Harassment. org. Accessed: Oct. 31, 2020. [Online]. Available: http://www.stopstreetharassment.org/resources/statistics/statistics-academic-studies/

[78] E. El Feki, S., Heilman, B. and Barker, G., *Understanding Masculinities: Results from the INTERNATIONAL MEN AND GENDER EQUALITY SURVEY (IMAGES)-MIDDLE EAST AND NORTH AFRICA*. 2017. Accessed: Sep. 04, 2020. [Online]. Available: www.promundoglobal.org

[79] B. El Deeb, "Study on Ways and Methods to Eliminate Sexual Harassment in Egypt Objectives of the Study nd a s tion k n a a Th preci Ap The Geographical Scope Distribution of the samples surveyed Geographical Scope of the Study," pp. 1–16, 2013, [Online]. Available: http://www.dgvn.de/fileadmin/user_upload/DOKUMENTE/English_Documents/Sexual-Harassment-Study-Egypt-Final-EN.pdf

[80] A. Canale, T. Campisi, G. Tesoriere, L. Sanfilippo, and A. Brignone, "The Evaluation of Home-School Itineraries to Improve Accessibility of a University Campus Trough Sustainable Transport Modes," *Communication Systems and Applications*, vol. 12250 LNCS, pp. 754–769, 2020, doi: 10.1007/978-3-030-58802-1_54.

[81] K. J. Assi, M. Shafiullah, K. M. Nahiduzzaman, and U. Mansoor, "Travel-To-School Mode Choice Modelling Employing Artificial Intelligence Techniques: A Comparative Study," *Sustainability*, vol. 11, no. 16, Aug. 2019, doi: 10.3390/SU11164484.

[82] K. J. Assi, K. M. Nahiduzzaman, N. T. Ratrout, and A. S. Aldosary, "Mode choice behavior of high school goers: Evaluating logistic regression and MLP neural networks," *Case Stud Transp Policy*, vol. 6, no. 2, pp. 225–230, Jun. 2018, doi: 10.1016/J.CSTP.2018.04.006.

[83] T. P. Uteng and T. Cresswell, "Gendered Mobilities," *Gendered Mobilities*, pp. 1–270, Jan. 2016, doi: 10.4324/9781315584201.

[84] C. Greed, "Overcoming the Factors Inhibiting the Mainstreaming of Gender into Spatial Planning Policy in the United Kingdom," *http://dx.doi.org/10.1080/00420980500060269*, vol. 42, no. 4, pp. 719–749, Apr. 2005, doi: 10.1080/00420980500060269.

[85] S. Aloul, R. Naffa, and M. Mansour, "Gender in Public Transportation – TInnGo Observatory." Accessed: Dec. 11, 2022. [Online]. Available: https://transportgenderobservatory.eu/resource/gender-in-public-transportation/

[86] World Bank, "Mainstreaming Gender in Road Transport : Operational Guidance for World Bank Staff." Washington, DC, 2010. Accessed: May 16, 2023. [Online]. Available: http://hdl.handle.net/10986/17455

[87] K. Scott and J. Babinard, "What Do Existing Household Surveys Tell Us About Gender and Transportation in Developing Countries," *undefined*, 2011.

[88] WBCSD, "Sustainable Mobility Indicators - SMP2.0." Accessed: Aug. 30, 2022. [Online]. Available: https://www.wbcsd.org/Programs/Cities-and-Mobility/Sustainable-Cities/City-Business-Collaboration/SiMPlify/Resources/

Sustainable-Mobility-Indicators-SMP2.0

[89] URBAN AGENDA FOR THE EU, "URBAN MOBILITY INDICATORS,FOR WALKING AND PUBLIC TRANSPORT," 2019, Accessed: Aug. 30, 2022. [Online]. Available: https://ec.europa.eu/futurium/en/system/files/ged/convenient-access-to-public-transport.pdf

[90] ADB, "Gender toolkit : transport : maximizing the benefits of improved mobility for all.," p. 86, 2013.

[91] A. de Avila Gomide, S. K. Leite, and J. M. Rebelo, "Public Transport and Urban Poverty: A Synthetic Index of Adequate Service." Accessed: Feb. 04, 2021. [Online]. Available: https://trid.trb.org/view/810724

[92] D. Pulido, G. Darido, R. Munoz-Raskin, and J. Moody, "The Urban Rail Development Handbook," *The Urban Rail Development Handbook*, Sep. 2018, doi: 10.1596/978-1-4648-1272-9.

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Renewable Energy in Sustainable Agricultural Production: Real Options Approach to Solar Irrigation Investment under Uncertainty

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ABSTRACT

Solar-powered irrigation system (SPIS) is a sustainable technology that utilizes renewable energy to pump water for agricultural production. Despite its environmental benefits, its adaptation is challenged by its high investment cost, particularly for small-scale farmers in most developing countries. This study aims to evaluate the attractiveness of shifting to SPIS from diesel-powered irrigation using the case of small-scale farmers in the Philippines. Considering the cost savings from adopting SPIS, this study analyzes the economic viability and optimal timing of investment under diesel price uncertainty. Results found that SPIS is economically attractive with USD 556.26/ha annual cost savings, USD 229.68/ha net present value, 12.49% internal rate of return, and a 5.58-year payback period. Considering the uncertainty in diesel prices, it is more optimal to invest immediately as waiting incurs losses. Investment decisions for SPIS are further favored by decreasing technology costs for solar PV systems, multiple utilization, cost-sharing among farmers, and negative externality of diesel. Findings provide recommendations for the widespread adoption of SPIS for more environment-friendly and sustainable production in agricultural countries.

Index-words: *Optimal Timing, Real Options, Renewable Energy, Small-scale Farmers, SPIS, Sustainable Agriculture.*

Nomenclature:

Abbreviations	
APS	**Announced pledges scenario**
BAU	**Business-as-usual**
CBA	**Cost-benefit analysis**
GBM	**Geometric Brownian motion**
GHG	Greenhouse gas
IRR	Internal rate of return
NEDA	**National Economic Development Authority**
NPV	Net present value
NZS	Net-zero emission scenario
PBP	Payback period
PV	Photovoltaics
ROA	Real options approach
SPIS	Solar-powered irrigation system
STEPS	Stated policies scenario
Symbols	
C_d	Average annual operations and maintenance costs for diesel
C_{SPIS}	Average annual operations and maintenance costs for SPIS
ε_t	Error term at period t
E_d	Negative externality of diesel combustion
I_{SPIS}	Investment cost for SPIS
J	Monte Carlo simulations
$P_{d,t}$	Price of diesel at period t
Q_d	Average annual diesel consumption
	Discount rate
ρ	Discount factor
S_t	Average annual cost savings
T_{SPIS}	Valuation period for SPIS
τ	Decision period of shifting to SPIS
μ_d	Percentage drift of diesel prices
σ_d^2	Percentage volatility of diesel prices
V_t	Option value at period t
$V_{waiting}$	Value of postponing the investment
W_t	Wiener process

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I. INTRODUCTION

The agriculture sector is both a vital contributor to global food security and a significant source of greenhouse gas (GHG) emissions from pre- and post-production activities, land use change, and farm-gate emissions [1, 2]. Currently, the agriculture sector accounts for 30 percent of total global anthropogenic emissions equivalent to 53 Gt CO_2eq [1]. Addressing the challenges of climate change urges the need to mitigate these emissions while ensuring sustainable food production to meet the needs of a growing population. Among the innovative solutions are crop and microbial genetics, electrification, and climate-smart agriculture including carbon-smart, energy-smart, weather-smart, nutrient-smart, and knowledge-smart technologies and practices [3, 4].

Another promising technology is the solar-powered irrigation system (SPIS), which can significantly reduce the GHG emissions associated with conventional diesel or electric pumps [5, 6]. SPIS utilizes solar photovoltaics (PV) to convert sunlight into electricity that powers the water pumping system to provide access to water in areas with no or limited connectivity to electricity networks or irrigation systems [7, 8]. Compared with fuel-powered generators, SPIS provides several benefits including operation safety, durability, lower operating costs, and a smaller carbon footprint [7]. While numerous countries have widely adopted SPIS, the success of this technology depends on various elements like climatic conditions, crop type, groundwater availability, government support, and the cost and availability of conventional electricity [9]. Moreover, its higher upfront cost relative to other pumps, lack of credit facilities, and technical capacity limit its widespread utilization particularly to small-scale farmers in most developing countries [5, 10]. These serve as an impetus to study the viability of SPIS as climate mitigation technology in the agriculture sector from the perspective of small-scale farmers.

Several studies analyze the viability of SPIS using various economic tools. Haffaf et al. [11] applied HOMER to design a cost-effective and sustainable solution to provide a water irrigation system based on the technical, economic, and environmental criteria. In another study, Falchetta et al. [12] devised a spatially explicit integrated modeling framework to show that over one-third of unmet crop water requirements of 19 major crops in smallholder cropland could be supplied with standalone SPIS that can be paid back by farmers within 20 years. Studies [5, 8] combined the socio-economic and environmental aspects of introducing SPIS to small-scale farmers in developing countries and found that SPIS is socially acceptable to farmers, reduces the cost of using diesel generators, is economically viable, reduces GHG emissions, and avoids air pollution. Moreover, Raza et al. [13] evaluated the socio-economic and climatic impact of PV-operated high-efficiency irrigation systems in a rural community and found that the installation of PV systems has resulted in the increased adoption of high-efficiency irrigation systems, a reduction in the high-operational costs incurred on account of old diesel-powered pumping systems, an increase in farmer's income, a reduction of GHG emissions, and savings in water.

However, these studies do not account for the uncertainties that affect investment decisions. For instance, the volatility of fossil fuel prices, CO_2 prices, technology learning, supporting policies, and social acceptance affect decisions to invest in renewable energy technologies [14-18]. On the other hand, the real options approach (ROA) overcomes these limitations by combining risks and uncertainties with management flexibility in making irreversible investments [18]. To date, there are only limited studies applying ROA to sustainable agricultural production. For instance, Jalić et al. [19] proposed a sustainable economic model for milk production using cost-benefit analysis as well as the Black–Scholes and binomial models ROA for shifting to cheese production [19]. In another study, Rocha et al. [20] analyzed whether investment projects in photovoltaic (PV) panels to produce electrical energy in a forest nursery are economically viable through binomial decision tree ROA with various managerial flexibilities such as deferral, expansion of the energy production capacity, and the abandonment of the project. Moreover, Heumesser et al. [21] applied a stochastic dynamic programming ROA to analyze a farmer's optimal investment strategy to adopt a water-efficient drip irrigation system or a sprinkler irrigation system under uncertainty about future production conditions. The ROA has not yet been applied to investment in SPIS, particularly to developing countries where small-scale farmers struggle to finance the technology due to its high investment cost. Yet, its huge potential in terms of cost savings from the volatile diesel prices has not been accounted for in previous studies.

This study bridges this gap by applying ROA to

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SPIS investment under diesel price uncertainty. Specifically, this aims to analyze the viability of shifting irrigation technology from diesel to solar using cost savings, NPV, IRR, and PBP; identify the optimal timing of investment in SPIS under diesel price uncertainty, and evaluate how solar PV costs, multiple utilization of SPIS, cost-sharing among small-scale farmers, and negative externality of diesel combustion impact the investment decisions to SPIS. This finally aims to suggest policy recommendations to support the adoption of SPIS for more inclusive, environment-friendly, and sustainable production in agricultural countries.

II. METHODOLOGY

A. Research Framework

This research applies layers of analyses to evaluate the attractiveness of shifting irrigation technology from diesel to solar PV. This includes cost-benefit analysis, real options valuation, and scenario analysis as shown in Figure 1. First, the CBA is applied to evaluate the potential costs and benefits of SPIS compared to diesel-powered irrigation systems. CBA is the systematic and analytical process of comparing benefits and costs in evaluating the desirability of a project and answering the questions as to whether a proposed project is worthwhile to undertake [22]. Among the different CBA tools, this study utilizes the net present value (NPV), internal rate of return (IRR), and payback period (PBP). These tools aim to provide an informed decision on the viability of SPIS, making sure that the expected benefits of the project outweigh the costs, as well as an overview of how long it takes to recover the cost of SPIS technology.

Fig. 1. Flowchart of the economic analysis of SPIS

The second layer of analysis supplements the CBA by incorporating flexibility in making investment decisions considering the uncertainties in SPIS technology. The real options approach (ROA), real options analysis, or real options valuation provides a competitive advantage over traditional valuation methods by capitalizing on the uncertainties and opportunities in the market, making more informed and flexible investment decisions [18]. This study applies ROA to analyze the value of flexibility to postpone the investment in SPIS over continue using a diesel-powered irrigation system. Considering the uncertainty in diesel prices, future price paths are first estimated. These prices are then incorporated in the NPV in CBA to calculate the expected NPV of SPIS for various initial prices of diesel. Then, the expected NPV of using SPIS is compared with the value of continuing diesel for irrigation to get the real option value of SPIS.

To test the robustness of the investment decisions for SPIS, several scenarios are analyzed including the business-as-usual (BAU), technology learning, SPIS cost sharing, multiple utilization of SPIS, and negative externality of diesel combustion. The BAU scenario refers to the analysis in the second layer, the real options valuation based on the historical prices of diesel, current technology cost, sole farmer utilization of SPIS, and cost savings without externalities. The technology learning scenario analyzes the investment decisions considering changes in the cost of SPIS based on climate policies. Cost sharing refers to the number of small-scale farmers sharing the costs and utilization of SPIS, while multiple utilization considers the possibility of utilizing SPIS for other purposes such as a source of electricity for home use. Finally, the negative externality scenario integrates the value of reduced GHG emissions as well as the savings from the health costs associated with the combustion of diesel fuel.

B. Real Options Valuation

This study takes the perspective of a small-scale farmer who has to decide whether to continue using diesel-powered pumps for irrigation, invest in SPIS now, or invest later. Using the fuel cost savings, shifting to SPIS now generates a net present value (NPV) as shown in Equation 1

$$NPV = \sum_{t=1}^{T_{SPIS}} \rho^t \left(S_t - C_{SPIS}\right) - I_{SPIS} \quad (1)$$

where ρ is the discount factor equal to $\frac{1}{1+r}$, r is the

discount rate, t is the valuation period, T_{SPIS} is the lifetime of SPIS, $S_t = P_{d,t}Q_d + C_d + E_d$ is the cost savings from shifting to SPIS from diesel equal to fuel price $P_{d,t}$ and quantity Q_d, the annual operations and maintenance cost C_d of using diesel-powered irrigation, and E_d is the negative externality of using diesel fuel such as the cost of GHG emissions and health costs of air pollutants from diesel combustion. On the other hand, C_{SPIS} is the annual operations and maintenance cost of SPIS and I_{SPIS} is the investment cost for SPIS. Using the NPV rule, the farmer's strategy is characterized by the decision to invest in SPIS now when NPV is positive, otherwise, continue using the diesel irrigation system as shown in Equation 2. Note that when diesel prices are low, it is more costly to invest in SPIS due to its high investment cost, hence, NPV<0.

$$\begin{aligned} &NPV \geq 0 \quad \text{invest} \\ &NPV < 0 \quad \text{postpone} \end{aligned} \tag{2}$$

Another economic tool is the Internal Rate of Return (IRR), which is the maximum interest rate or discount rate at which the project benefits equal to the investment [23]. From Equation 1, the IRR for SPIS can be calculated using Equation 3, where $= \frac{1}{1+IRR}$.

$$NPV = \sum_{t=1}^{T_{SPIS}} \rho^t (S_t - C_t) - I_{SPIS} = 0 \tag{3}$$

Moreover, the payback period (PBP) is the amount of time needed to recover the cost of the initial investment in SPIS [8]. The PBP can be calculated using Equation 4.

$$PBP = \frac{I_{SPIS}}{S_t - C_t} \tag{4}$$

Considering the uncertainty in diesel fuel prices, another option for the farmer is to defer or postpone the investment in SPIS. In line with previous studies, we assume that diesel prices are stochastic and follow a Geometric Brownian Motion (GBM) [14, 16, 24]. GBM is a continuous-time stochastic process in which the logarithm of the randomly changing quantity results in a Brownian motion with drift [25]. For diesel prices, GBM can be represented in Equation 5.

$$dP_{d,t} = \mu_d P_{d,t} dt + \sigma_d P_{d,t} dW_t \tag{5}$$

where μ_d and σ_d^2 are percentage drift and percentage volatility of diesel prices and W_t is a Wiener process or Brownian motion equal to $\varepsilon\sqrt{dt}$ such that $\varepsilon \sim N(0,1)$. Using Ito's formula, this can be solved to estimate the future prices of diesel as shown in Equation 6.

$$P_{d,t+1} = P_{d,t} \exp\left[\left(\mu_d - \frac{\sigma_d^2}{2}\right)\Delta t + \sigma_d \sqrt{\Delta t}\varepsilon_t\right] \tag{6}$$

From Equation 6, price paths for diesel can be generated from the current price and incorporated in Equation 1 to calculate the NPV. Using Monte Carlo simulations, the expected net present value, $E\{NPV\}$, for adopting SPIS can be estimated using Equation 7. This process repeats the NPV calculations in (J) multiple times under stochastic prices of diesel then, calculating the average NPV from all the iterations.

$$E\left\{NPV_j | P_{d,0}\right\} = \frac{1}{J}\sum_{j=1}^{J} NPV_j \approx E\left\{NPV | P_{d,0}\right\} \tag{7}$$

The farmer's problem is to maximize the value of adopting SPIS or continuing diesel irrigation system as described in Equation 8.

$$V_t = \max\left\{E\{NPV\},\ E\left\{\sum_{0\leq t\leq\tau} \rho^t(-S_t)\right\} | P_{d,t}\right\} \tag{8}$$

where V_t is the option value, which is the maximized value of either investing in SPIS with $E\{NPV\}$ or continuing diesel irrigation with a cost of $E\left\{\sum_{0\leq t\leq\tau} \rho^t(-S_t)\right\}$ from time t=0 to optimal timing of investment t=τ . Note that while $E\left\{\sum_{0\leq t\leq\tau} \rho^t(-S_t)\right\}$ is negative, there are initial prices of diesel $P_{d,0}$ where it is still more optimal to use diesel irrigation due to the high investment cost of SPIS (I_{SPIS}). Hence, the optimal timing of investment is characterized by the minimum period where shifting to SPIS is maximized as shown in Equation 9.

$$\tau^* = \min\{\tau | V_{t+1} = V_t\} \tag{9}$$

Finally, the optimal investment strategy using ROA is characterized by a decision to invest immediately in SPIS and postpone or delay the investment as shown in Equation 10.

$$\begin{cases} V_{\tau^*}(P_{d,t}) \leq V_0(P_{d,0}) & \text{invest} \\ V_{\tau^*}(P_{d,t}) > V_0(P_{d,0}) & \text{postpone} \end{cases} \tag{10}$$

C. *Data and Scenarios*

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This study applies the proposed ROA model for shifting irrigation technology from diesel to SPIS using the case of small farmers from the Philippines. Among the reasons for choosing the case of the Philippines are (a) it is an agricultural country with 24.5% of the economy based on agriculture, hunting, forestry, and fishing [26]; (b) irrigated agricultural land covers 61.39% of the total irrigable area provided by the National Irrigation System (44.97%), communal irrigation system (35.27%), private irrigation system (10.30%), and other national government agencies (9.4%) [27]; (c) the remaining non-irrigated land is mostly owned by small-scale farmers and is rain-fed, which are vulnerable to climate hazards [5]; and (d) diesel prices are highly volatile as the country is too dependent on imported fossil fuels, yet has a huge potential for renewable energy generation [28].

The data from this study were gathered from both primary and secondary sources. Diesel consumption was surveyed from small-scale farmers who were using diesel irrigation systems. The current price of diesel was taken from the Department of Energy, historical prices of diesel were gathered from the Energy Information Agency, investment parameters were taken from the National Economic Development Authority (NEDA), and the technology parameters were taken from the literature. The summary of data used in this study is presented in Table I.

TABLE I
LIST OF VARIABLES AND ESTIMATED PARAMETERS FOR THE PROJECT VALUATION

Parameter	Symbol	Unit	Value
Initial price of diesel	$P_{d,0}$	USD/L	1.09
Average annual diesel consumption	Q_d	L/ha/yr	74.55
Average annual operations and maintenance costs for diesel	C_d	USD/ha/yr	475
Externality cost of using diesel	E_d	USD/ha/yr	231
Average annual cost savings	S_t	USD/ha/yr	556
Average annual operations and maintenance costs for SPIS	C_{SPIS}	USD/ha/yr	140
Investment cost for SPIS	I_{SPIS}	USD	2100
Percentage drift of diesel prices	μ_d	%	0.0386
Percentage volatility of diesel prices	σ_d^2	%	0.0296
Valuation period for SPIS	T_{SPIS}	years	10
Discount rate	r	%	10
Decision period for SPIS	τ	years	10
Monte Carlo simulations	J	times	10,000

The investment cost for SPIS is USD 2100, which covers the costs of the pump and controller, solar PV panel, accessories, grounding, PV cables, and the cost of mounting such as materials (pipe, concrete, accessories) and labor costs (excavation of foundation, concreting, steal works) [5]. The SPIS technology can be utilized to irrigate 2-3 hectares of rice farms with 9 m^3/hr water output [5]. The average annual operations and maintenance cost for SPIS is USD 140. The benefits of shifting to SPIS include the energy cost savings and externality costs of using diesel. The average annual operation and maintenance for using diesel is USD 475. The average annual diesel consumption of the selected small-scale farmers is 74.55 L. Based on this value, the calculated annual cost savings for shifting to SPIS without externalities is USD 556. On the other hand, the costs of negative externalities are calculated based on the emission factors of GHG, carbon monoxide, nitrous oxides, sulfur oxides, particulate matter, and volatile organic compounds for diesel combustion [29] and the health costs of these emissions [30, 31]. The calculated annual cost of negative externalities is USD 213, which is added to the annual cost savings of shifting to SPIS with a total of USD 787.26. The NPV calculation covers a

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10-year valuation period at a 10% discount rate.

To calculate the stochastic prices of diesel, 10-year historical data were used to run the Augmented Dickey-Fuller unit root test for the stochastic process. The test result confirmed that $P_{d,t}$ follow GBM with μ_d =0.0386 and σ_d =0.0296. These parameters are then used to generate stochastic prices of diesel, as described in Equation 6. A sample simulation of price paths is shown in Figure 2.

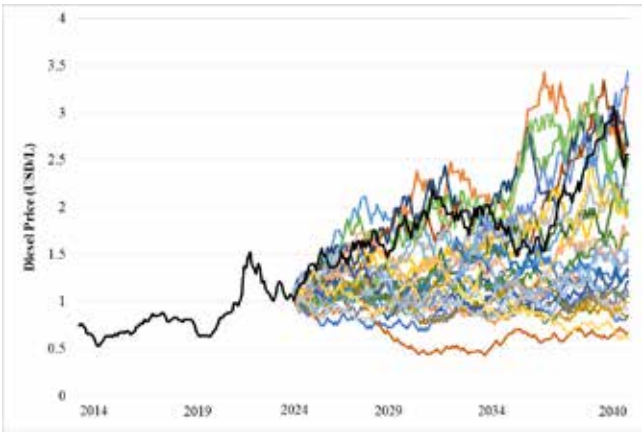

Fig. 2. Historical Diesel Prices (2014–2024) and Diesel Price Paths (2024–2040) based on Geometric Brownian Motion. (Note: curves from 2024 onwards are authors' simulations)

Given these price paths, the real options value is calculated annually by maximizing the value of either continuing the use of diesel-powered irrigation or shifting to SPIS from the initial price of diesel at $P_{d,0}$ =0 to USD 1.5/L. Then, the optimization process is repeated until the decision period $t=\tau$, which is set at 10 years. This is the period given to the investor whether to reject the project, invest immediately, or postpone the implementation of the project until its expiration date in the 10th year. The optimization results were tested for the impacts of decreasing solar PV systems (10%, 20%, and 30%), multiple utilization (additional 10%, 20%, and 30% benefits), and cost-sharing among farmers (5%, 10%, 20% reduction). Lastly, the GHG emissions and health costs of using diesel are incorporated in Equation 1 as the negative externalities of using diesel fuel.

III. RESULTS AND DISCUSSION

A. Cost Benefit Analysis of SPIS

The result of the cost-benefit analysis of shifting to SPIS from diesel-powered irrigation is presented in Table II. Based on the survey of small-scale farmers who own till 1 hectare or less rice farms, the average annual cost savings from diesel fuel and other operations and maintenance costs of using diesel-powered irrigation systems is USD 556.26 per hectare. This amount can be used to offset the high investment cost of SPIS or invest in other technologies or systems that promote sustainable farming [5]. Considering the valuation period of 10 years at a 10% discount rate, the NPV of shifting to SPIS is USD 229.68 per hectare. This implies that SPIS is economically viable and can generate USD 229.68/ha additional value by shifting to SPIS.

TABLE II
RESULT OF COST BENEFIT ANALYSIS OF SHIFTING TO SPIS FROM DIESEL IRRIGATION

Economic Indicators	Unit	Value
Annual cost savings	USD/ha/yr	556.26
Net present value	USD/ha	229.68
Internal rate of return	%	12.49
Payback period	Years	5.58

In terms of economic efficiency, the project has an IRR of 12.49%, which implies that the project generates 12.49% returns relative to the initial investment. This value also indicates that the project is feasible as it is greater than the hurdle rate set by the NEDA at 10%. Moreover, PBP shows that the investment in SPIS can be recovered in 5.58 years. While this seems long from the perspective of small-scale farmers, it should be noted that PBP is based on the cost savings from shifting to SPIS and that solar PV is exclusively utilized for irrigation purposes only. Since the technology is mobile and the system is only utilized mostly during the early stage of rice production during non-rainy season, solar PV panels can also be utilized for other purposes such as generating electricity for household use. These results support previous claims that small SPIS are profitable with 20% IRR for investment while large SPIS are moderately profitable at 10% IRR but can be improved by introducing additional uses of solar energy [32]. Meanwhile, it should be noted that these results are solely based on the cost savings from using diesel fuel. This study also considers the negative externalities of using diesel, which will be discussed in the last subsection.

B. Real Options Valuation

Considering the uncertainties in diesel prices, this study extends the cost-benefit analysis by applying real options valuation or ROA. The results of the

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valuation in the BAU scenario are summarized in Table III and presented in Figure 3.

From the figure, the blue curve represents the calculated option values at t=0 for every initial diesel price from zero to USD 1.5 per liter. Each point on the curve represents the maximized value of either shifting to SPIS or continuing the diesel-powered irrigation. It can be noticed that there are negative values on the curve showing that, at these diesel prices, cost savings can still not offset the high investment cost of SPIS. Meanwhile, option values are positive at initial diesel prices above USD 0.6058/L. This means that the optimal (minimum) price of diesel to make the investment in SPIS feasible is USD 0.6068/L. Hence, at USD 1.09/L current price of diesel, the option value is positive and investment in SPIS is feasible, which also supports the claim in the cost-benefit analysis in the previous section.

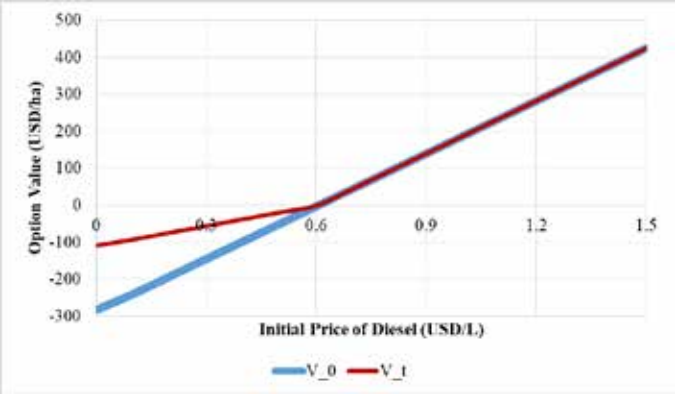

Fig. 3. Option values of shifting to SPIS in the Business-as-usual scenario

TABLE III
OPTION VALUES AT INITIAL AND TERMINAL DECISION PERIODS AND THE VALUE OF WAITING AT DIFFERENT PRICES OF DIESEL (IN USD/HA)

P_d,0	V_0	V_t	V_waiting
0	-283	-109	174
0.1	-240	-92.5	147
0.2	-192	-74.2	118
0.3	-145	-55.9	89.1
0.4	-97.6	-37.6	60
0.5	-50.2	-19.3	30.8
0.6	-2.75	-1.06	1.69
0.7	44.7	44.7	0
0.8	92.1	92.1	0
0.9	140	140	0
1	187	187	0

Note: P_d – initial price of diesel, V_0 – option value at the initial period, V_t – option value at the terminal period, V_waiting – value of waiting

On the other hand, the red curve represents the calculated option values at the terminal decision-making period (10 years) for every initial diesel price. Meanwhile, the distance between the curves represents the value of waiting to invest in SPIS. For instance, at a diesel price of USD 0.3/L, the option value in the initial period is USD -145/ha and USD -56/ha in the terminal period. This means that, at this diesel price, the value of waiting to invest is USD 89/L. It is also shown in Table 3 that the values of waiting are positive from initial diesel prices of 0 to USD 0.6/L. This explains the motivation of farmers to postpone the investment in SPIS as running irrigation using diesel is relatively cheaper than shifting to SPIS, and the cost savings cannot offset the high investment cost of SPIS. However, at the current diesel price of USD 1.09/L, the value of the option to wait is equal to zero, which implies a more optimal decision to invest immediately as postponing the investment incurs no additional value to the project. These managerial flexibilities in the decision-making process highlight the advantage of using ROA over the "now-or-never" decision rule using traditional economic valuation tools such as the NPV and IRR [16, 18].

C. *Technology Learning Scenarios*

To test the robustness of the results, this study presents three investment cases including technology learning, cost-sharing, multiple utilization of SPIS, and negative externalities of diesel.

In technology learning, four scenarios are considered: business-as-usual (BAU), stated policies scenario (STEPS), announced pledges scenario (APS), and the net-zero emission scenario (NZS). In STEPS, the global solar capacity of 220 GW is expected to double by 2030; the planned boost in the manufacturing capacity if fully realized, appears able to meet many of the deployment milestones in the APS; and further milestones in the case of solar and batteries provide what is required in the net-zero emissions by 2050 in NZS [33]. Following Wright's Law, technologies get cheaper at a consistent rate as the cumulative production of that technology increases. In the case of solar PV, the average learning rate is 20.2%. As a classic case of learning by doing, the price of technology declines when more of that technology is produced, increasing production gives the engineers the chance to learn how to improve

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the process, and more deployed technology satisfies the increasing demand leading to falling prices, and the technology becomes cost-effective [34]. Considering the different climate target scenarios, this study assumes that the learning rate within ten years of waiting to invest is 20%, 30%, and 40% for the STEPS, APS, and NZS scenarios. The results of real options valuation for shifting to SPIS at different technology learning are presented in Table IV and Figure 4.

TABLE IV
OPTION VALUES AT THE INITIAL AND TERMINAL PERIODS FOR DIFFERENT CLIMATE SCENARIOS

P_d,0	V_0	V_BAU	V_STEPS	V_APS	V_NZS
0	-283	-109	53	134	215
0.1	-240	-92	69	150	231
0.2	-192	-74	88	169	250
0.3	-145	-56	106	187	268
0.4	-98	-38	124	205	286
0.5	-50	-19	143	224	305
0.6	-3	-1	161	242	323
0.7	45	45	179	260	341
0.8	92	92	197	278	359
0.9	140	140	216	297	378
1	187	187	234	315	396

Note: P_d – initial price of diesel, V_0 – option value at the initial period in business-as-usual scenario, V_BAU – option value at the terminal period in business-as-usual scenario, V_STEP – option value at the terminal period in stated policies scenario, V_APS – option value at the terminal period in announced pledges scenario, V_NZS – option value at the terminal period in net-zero scenario

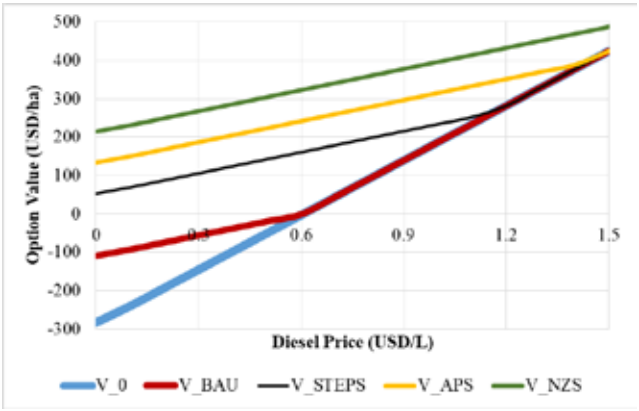

Fig. 4. Option values for shifting to SPIS at various learning rates based on climate target scenarios (BAU: business-as-usual, STEPS: stated policies scenario, APS: announced pledges scenario, NZS: net-zero emission scenario)

It can be observed that the option values at the terminal period (V_t) increased from the BAU scenario to other climate target scenarios. Compared with the BAU result, the option value in the STEPS scenario at the current diesel price (USD 1.09/L) is USD 230/ha at the initial period and USD 250/ha at the terminal period. This means that it is more optimal to postpone the investment with a value of waiting equal to USD 20/ha. In the APS and NZS, the option values at the terminal period are USD 331/ha and USD 412/ha, which result in the values of waiting equal to USD 102/ha and USD 183/ha, respectively. This implies that more stringent climate targets result in higher demand and lower prices for cleaner sources of energy like solar PV [35, 36]. On the contrary, small-scale farmers tend to wait or defer their shift of technology from diesel to SPIS until the period when solar PV is relatively cheaper than its current prices. These support previous claims on the application of real options that, while investment in solar PV is already profitable, investors can defer investment to obtain a more optimal investment value [14, 37].

D. *Cost-Sharing Scenarios*

In the case of cost-sharing, the researchers present three scenarios, where SPIS is shared by small-scale farmers. The BAU scenario is the baseline, 2S is shared by two, and 3S is shared by three small-scale farmers. In 2S and 3S scenarios, the researchers assume that the investment cost as well as operations and maintenance costs are equally shared among the farmers. Since the utilization rate is increased, the researchers assume that the capacity of the SPIS is also increased by 50% and eventually the associated costs. The results of the option valuation are shown in Table V and Figure 5.

TABLE V
OPTION VALUES AT THE INITIAL AND TERMINAL PERIODS FOR DIFFERENT COST SHARING SCENARIOS

P_d,0	V_0 (BAU)	V_t (BAU)	V_0 (2S)	V_t (2S)	V_0 (3S)	V_t (3S)
0	-283	-109	519	519	1320	1320
0.1	-240	-92.5	562	562	1363	1363
0.2	-192	-74.2	609	609	1411	1411
0.3	-145	-55.9	656	656	1458	1458
0.4	-97.6	-37.6	704	704	1505	1505
0.5	-50.2	-19.3	751	751	1553	1553
0.6	-2.75	-1.06	799	799	1600	1600
0.7	44.7	44.7	846	846	1648	1648

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0.8	92.1	92.1	894	894	1695	1695
0.9	140	140	941	941	1743	1743
1	187	187	988	988	1790	1790

Note: P_d – initial price of diesel, V_0 – option value at the initial period, V_t – option value at the terminal period, BAU – business-as-usual, 2S – SPIS shared by 2 small-scale farmers, 3S – SPIS shared by 3 small-scale farmers

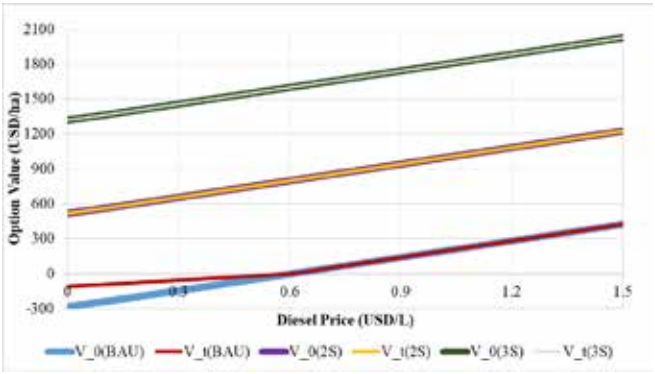

Fig. 5. Option values for shifting to SPIS at various cost-sharing scenarios (BAU: business-as-usual, 2S: shared by two farmers, 3S: shared by three farmers)

Compared with the BAU scenario, it can be observed that the option values for the 2S and 3S scenarios are all positive. This implies that even if the fuel cost is almost free, the operations and maintenance cost for diesel irrigation can already compensate for the costs of shifting to SPIS as these are shared among small-scale farmers. Another point of discussion is the significant shift of the curves upwards, which indicates that the option values for shifting to SPIS increase when the costs are shared among farmers. For instance, at the current diesel price of USD 1.09/L, the option values increase from USD 230/ha in the BAU scenario to USD 1031/ha in the 2S scenario and USD 1833/ha in the 3S scenario. These findings support the previous claim that the promotion of SPIS should also focus on the communal approach by sharing the upfront costs of SPIS thereby encouraging the technology adoption and upscaling [38]. Moreover, the option value curves for 2S and 3S are the same for the initial period (V_0) and the terminal period (V_t). These indicate that the value of waiting is equal to zero, hence, it is more optimal to invest now than postpone the investment when the cost of SPIS is shared among small-scale farmers. These also provide implications to encourage small-scale farmers to cost-share to make the SPIS more attractive than to continue using diesel-powered irrigation systems.

E. *Multiple Utilization Scenarios*

Since SPIS will only be utilized during the early months of cropping season and only during non-rainy seasons, the researchers can assume that the solar PV of SPIS can be tapped to generate renewable electricity for households. Considering the three months rainy season in the case country, this study presents multiple utilization scenarios namely, BAU: business-as-usual, 1U: one-month household utilization, 2U: two-months household utilization, and 3U: three-months utilization of solar PV for household use. For the 1U scenario, this study assumes that the solar panels have a capacity of 2.273 kW and can be utilized for six hours during the day with a 20% efficiency during rainy seasons. The current average electricity rate in the case country for household consumption is 57.38 cents/kWh. Hence, the value of cost savings for electricity consumption is added to the cost savings of using diesel irrigation. These values are equal to USD 46.95/ha/yr, USD 93.91/ha/yr, and USD 140.86/ha/yr for scenarios 1U, 2U, and 3U. The results of the options valuation are presented in Table VI and Figure 6.

TABLE VI
OPTION VALUES AT THE INITIAL AND TERMINAL PERIODS FOR DIFFERENT COST SHARING SCENARIOS

P_d,0	V_0 (BAU)	V_t (BAU)	V_0 (1U)	V_t (1U)	V_0 (2U)	V_t (2U)	V_0 (3U)	V_t (3U)
0	-283	-109	6	6	294	294	583	583
0.1	-240	-92	49	49	337	337	626	626
0.2	-192	-74	96	96	385	385	673	673
0.3	-145	-56	143	143	432	432	720	720
0.4	-98	-38	191	191	479	479	768	768
0.5	-50	-19	238	238	527	527	815	815
0.6	-3	-1	286	286	574	574	863	863
0.7	45	45	333	333	622	622	910	910

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0.8	92	92	381	381	669	669	958	958
0.9	140	140	428	428	717	717	1005	1005
1	187	187	475	475	764	764	1053	1053

Note: P_d – initial price of diesel, V_0 – option value at the initial period, V_t – option value at the terminal period, BAU – business-as-usual, 1U – one-month household utilization, 2U –2-months household utilization, and 3U –3-months utilization of solar PV for household use

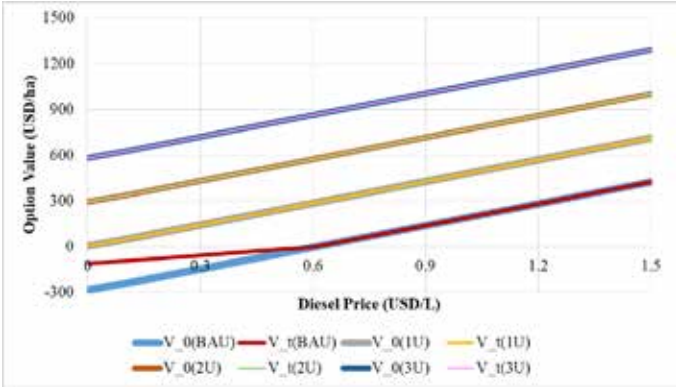

Fig. 6. Option values for shifting to SPIS at various multiple sharing scenarios (BAU: business-as-usual, 1U: one month, 2S: two months, 3S: three months utilization of solar PV for household use)

Similar to the cost-sharing scenarios, the option values for multiple-sharing scenarios are positive. This implies that the high investment cost as well as other operations and maintenance costs of SPIS can be compensated by the cost savings from diesel irrigation plus the value of electricity generated from the solar PV for household use. It can also be noticed that the curves significantly shift upwards, which indicates that the option values for shifting to SPIS increase with additional utilization of solar PV. For instance, at the current diesel price (USD 1.09/L), the option values increase from USD 230/ha in the BAU scenario to USD 518/ha in the 1U scenario, USD 518/ha in the 2U scenario, and USD 1095/ha in the 3U scenario. These results support the previous claim that while SPIS is already an economically viable option over diesel-powered irrigation, its feasibility can still be improved by introducing additional uses of solar energy such as household electricity generation [8, 32]. Furthermore, the option value curves for 1U, 2U, and 3U are the same for the initial period (V_0) and the terminal period (V_t), which indicates that the value of waiting is equal to zero. These imply that an optimal decision to invest immediately as postponement incurs no additional value to the project. These also provide implications to encourage small-scale farmers to utilize the solar PV of SPIS for other purposes such as household electricity consumption to make the SPIS more attractive than to continue using diesel-powered irrigation systems.

Finally, the findings in most real options literature that waiting or postponing the investment is a more optimal decision until the uncertainties are reduced and maximum benefits are obtained [14, 39-41]. On the contrary, in this study, the researchers showed that there are investment scenarios where it is more optimal to invest immediately as postponing the investment does not provide additional value to the project such as the cases of cost-sharing and multiple utilization scenarios.

F. Externality Cost Scenario

To further increase the attractiveness of shifting to SPIS, this study considers the negative externality of using a diesel irrigation system. This includes the GHG emissions as well as the health costs of air pollutants from diesel combustion. Among the air pollutants considered are carbon monoxide, nitrous oxides, sulfur oxides, particulate matter, and volatile organic compounds. Studies show that long and short-term exposures to these air pollutants have a different toxicological impact on humans including respiratory and cardiovascular diseases, and long-term chronic diseases [42, 43]. Replacing diesel with SPIS avoids these air pollutants from diesel combustion, thereby reducing the associated health risks and costs to farmers and the nearby communities. Moreover, shifting to SPIS also reduces the emissions of GHGs such as carbon dioxide and nitrous oxide, which absorb heat from the atmosphere and contribute to climate change [44]. Based on the average annual diesel consumption of small-scale farmers, the costs of these externalities are added to the annual cost savings from shifting to

SPIS. Table VII presents the results of the CBA with and without these externalities.

TABLE VII
COMPARISON OF COST BENEFIT ANALYSIS WITH AND WITHOUT NEGATIVE EXTERNALITIES

Economic Indicators	Unit	Without Externality	With Externality
Annual cost savings	USD/ha/yr	556.26	787.26
Net present value	USD/ha	229.68	1649.11
Internal rate of return	%	12.49	26.22%
Payback period	Years		

As shown in table V, the annual cost saving increased from USD 556 to USD 787 representing the negative externalities that are valued at USD 231/ha/yr. Consequently, this increases the NPV from USD 230/ha to USD 1649/ha, representing a significant increase in the added value of the investment. The economic efficiency of shifting to SPIS also increases from 12.49% IRR without externalities to 26.22% IRR with externalities, implying that the project generates 26.22% returns relative to the initial investment. Furthermore, the PBP reduces from 5.58 years to 3.46 years, making the shifting of technologies to SPIS more attractive than continuing diesel-powered irrigation systems. Meanwhile, these values are then integrated in the real option valuation which are shown in Table VIII and Figure 7.

TABLE VIII
OPTION VALUES AT THE INITIAL AND TERMINAL PERIODS FOR DIFFERENT CLIMATE SCENARIOS

P_d,0	V_0_BAU	V_t_BAU	V_0_E	V_t_E
0	-283	-109	1137	1137
0.1	-240	-92.5	1180	1180
0.2	-192	-74.2	1227	1227
0.3	-145	-55.9	1274	1274
0.4	-97.6	-37.6	1322	1322
0.5	-50.2	-19.3	1369	1369
0.6	-2.75	-1.06	1417	1417
0.7	44.7	44.7	1464	1464
0.8	92.1	92.1	1512	1512
0.9	140	140	1559	1559
1	187	187	1606	1606

Note: P_d – initial price of diesel, V_0_BAU – option value at the initial period in a business-as-usual scenario, V_t_BAU – option value at the terminal period in a business-as-usual scenario, V_0_E – option value at the initial period in the externality scenario, V_t_E – option value at the terminal period in the externality scenario

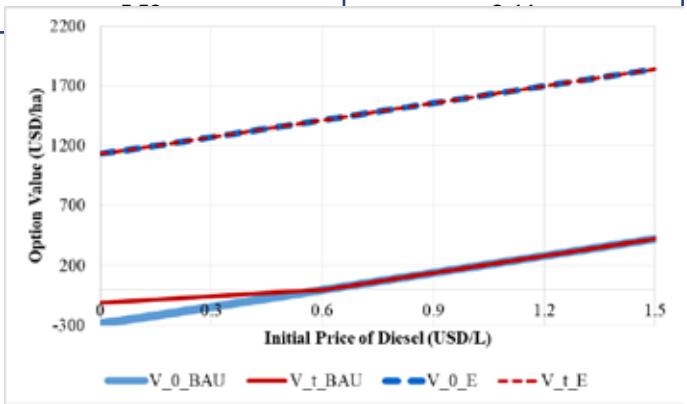

Fig. 7. Option values for shifting to SPIS integrating the negative externalities of using diesel fuel (BAU: business-as-usual without negative externality, E: with negative externality)

Results show that the option values significantly increase from the BAU scenario without negative externalities to the externality scenario. For instance, at the current price of diesel (USD 1.09/L), option values increase by 760% from USD 187/ha to USD 1606/ha. Compared with the BAU scenario, it can be observed that both V_0 and V_t in the externality scenario are the same. This implies an optimal decision to invest immediately in SPIS as postponing the investment does not give any additional value to the project. This result supports previous claims that incorporating the negative externalities of fossil fuel combustion makes alternative renewable energy technologies more attractive than continuing fossil-based technologies [16, 18].

IV. CONCLUSION

This study highlights the potential of SPIS to promote sustainable agricultural production while contributing to environmental conservation by reducing reliance on fossil fuels and mitigating greenhouse gas emissions. While the economic viability of SPIS has been extensively discussed in the literature, this study considered the uncertainty and the managerial flexibility in making investment

decisions for the SPIS. Applying the cost-benefit analysis and real options approach, this study evaluated the relative attractiveness of shifting technologies from diesel-powered irrigation to SPIS under diesel price uncertainty.

Cost-benefit analysis results showed that shifting to SPIS is economically viable with USD 556.26/ha annual cost savings, USD 229.68/ha net present value, 12.49% internal rate of return, and a 5.58-year payback period. Contrary to most real options literature, the real options valuation found that at the current price of diesel, it is more optimal to invest in SPIS immediately as waiting or postponing does not give additional value to the project. These results are further favored by technology learning, cost sharing among small-scale farmers, multiple utilization of solar PV such as electricity generation for household consumption, and negative externality of using diesel in terms of GHG emissions and health costs from fuel combustion. These findings provide several recommendations to further improve the adoption and upscaling of SPIS:

- Providing strategic incentives, supporting policies, and innovative financing mechanisms to incentivize the widespread adoption of SPIS, particularly to cover the high upfront cost of SPIS from the perspective of small-scale farmers;
- In addition to national efforts, farmer cooperatives or local government units may seek other sources of financing support from non-governmental organizations as well as international funding sources;
- Implementing efforts to achieve more stringent climate targets will decrease the cost of SPIS, making it more attractive and affordable to small-scale farmers;
- Encouraging small-scale farmers to share the technology, thereby, reducing the investment as well as operations and maintenance costs;
- Utilization of solar PV for other purposes such as electricity generation for households, particularly in rainy seasons and the latter part of the cropping season when water is abundant and irrigation is not much needed;
- Information, education, and communication of the environmental benefits of using SPIS as well as the savings from health costs of using diesel-powered irrigation systems.

Yet, the study has several limitations that can be bases for further investigation. First, the study only took the perspective of small-scale farmers. For the upscaling and widespread adoption of the technology, future studies should also consider medium- to large-scale farmers to better capture the decision-making mechanisms from various perspectives. In the real options valuation, only the diesel prices were used. Uncertainties in social acceptance, electricity rates for multiple utilization, and externalities for using fossil fuels may also be included. Lastly, this study applied the real options to defer/postpone investment. Future real options valuation may consider the option to expand/upscale SPIS, the option to switch between irrigation and electricity generation for households, and the option to abandon when governments provide irrigation systems to agricultural lands. Albeit these limitations, the real options framework proposed in this study could be a good benchmark for further analysis empowering small-scale farmers to harness the potential of renewable energy, thereby fostering a more sustainable and resilient agricultural sector for generations to come.

References

[1] "Agrifood systems and land-related emissions FAO, "Agrifood systems and land-related emissions," Nov. 2023. doi: 10.4060/cc8543en.

[2] P. C. Pandey and M. Pandey, "Highlighting the role of agriculture and geospatial technology in food security and sustainable development goals," Sustainable Development, vol. 31, no. 5, pp. 3175–3195, Oct. 2023, doi: 10.1002/sd.2600.

[3] H. Panchasara, N. Samrat, and N. Islam, "Greenhouse Gas Emissions Trends and Mitigation Measures in Australian Agriculture Sector—A Review," Agriculture, vol. 11, no. 2, p. 85, Jan. 2021, doi: 10.3390/agriculture11020085.

[4] D. L. Northrup, B. Basso, M. Q. Wang, C. L. S. Morgan, and P. N. Benfey, "Novel technologies for emission reduction complement conservation agriculture to achieve negative emissions from row-crop production," Proceedings of the National Academy of Sciences, vol. 118, no. 28, Jul. 2021, doi: 10.1073/pnas.2022666118.

[5] C. S. Guno, "Diesel to Solar Irrigation System: Economic, Environmental, and Social Acceptability Analyses by Small-Scale Farmers of Calapan, Oriental Mindoro," Journal of Human Ecology and Sustainability, vol. 2, no. 1, p. 3, Feb. 2024, doi: 10.56237/jhes23015.

[6] F. Hussain et al., "Solar Irrigation Potential, Key Issues and Challenges in Pakistan," Water (Basel), vol. 15, no. 9, p. 1727, Apr. 2023, doi: 10.3390/w15091727.

[7] N. S. Rengma, M. Yadav, and N. Kishor, "Solar photovoltaic water pumping system: A software tool development-based optimal configuration investigation for system installation location, sizing and deployment," Renewable Energy Focus, vol. 46, pp. 236–255, Sep. 2023, doi: 10.1016/j.ref.2023.07.001.

[8] C. S. Guno and C. B. Agaton, "Socio-Economic and Environmental Analyses of Solar Irrigation Systems for Sustainable Agricultural Production," Sustainability, vol. 14, no. 11, p. 6834, Jun. 2022, doi: 10.3390/su14116834.

[9] A. M. Mohammed, R. Samikannu, P. M. Kumar, I. S. K. Sailaja, V. Venkatesh, and A. Yahya, "Innovative Solutions for Water and Energy Challenges in Agriculture: A Review of Solar-Powered Irrigation Systems," in 2023 1st International Conference on Circuits, Power, and Intelligent Systems, CCPIS 2023, 2023. doi: 10.1109/CCPIS59145.2023.10291641.

[10] N. Durga et al., "Barriers to the uptake of solar-powered irrigation by smallholder farmers in sub-saharan Africa: A review," Energy Strategy Reviews, vol. 51, p. 101294, Jan. 2024, doi: 10.1016/j.esr.2024.101294.

[11] A. Haffaf, F. Lakdja, R. Meziane, and D. O. Abdeslam, "Study of economic and sustainable energy supply for water irrigation system (WIS)," Sustainable Energy, Grids and Networks, vol. 25, p. 100412, Mar. 2021, doi: 10.1016/j.segan.2020.100412.

[12] G. Falchetta, F. Semeria, M. Tuninetti, V. Giordano, S. Pachauri, and E. Byers, "Solar irrigation in sub-Saharan Africa: economic feasibility and development potential," Environmental Research Letters, vol. 18, no. 9, p. 094044, Sep. 2023, doi: 10.1088/1748-9326/acefe5.

[13] F. Raza et al., "The Socio-Economic Impact of Using Photovoltaic (PV) Energy for High-Efficiency Irrigation Systems: A Case Study," Energies (Basel), vol. 15, no. 3, p. 1198, Feb. 2022, doi: 10.3390/en15031198.

[14] C. B. Agaton, "Will a Geopolitical Conflict Accelerate Energy Transition in Oil-Importing Countries? A Case Study of the Philippines from a Real Options Perspective," Resources, vol. 11, no. 6, p. 59, Jun. 2022, doi: 10.3390/resources11060059.

[15] L. Li, S. Wang, J. Wu, and Z. Sun, "Exploring the efficacy of renewable energy support policies in uncertain environments: A real options analysis," Energy Econ, vol. 132, p. 107467, Apr. 2024, doi: 10.1016/j.eneco.2024.107467.

[16] K. I. T. Batac, A. A. Collera, R. O. Villanueva, and C. B. Agaton, "Decision Support for Investments in Sustainable Energy Sources Under Uncertainties," International Journal of Renewable Energy Development, vol. 11, no. 3, pp. 801–814, Aug. 2022, doi: 10.14710/ijred.2022.45913.

[17] À. Alonso-Travesset, D. Coppitters, H. Martín, and J. de la Hoz, "Economic and Regulatory Uncertainty in Renewable Energy System Design: A Review," Energies (Basel), vol. 16, no. 2, p. 882, Jan. 2023, doi: 10.3390/en16020882.

[18] C. B. Agaton, "Real Options Analysis of Renewable Energy Investment Scenarios in the Philippines," Renewable Energy and Sustainable Development, vol. 3, no. 3, p. 284, Dec. 2017, doi: 10.21622/resd.2017.03.3.284.

[19] N. Jalić, Č. Rozman, Ž. Vaško, and K. Pažek, "Determining the Extent of Economical Sustainability of a Case Study Milk Farm in Bosnia and Herzegovina Based on the Real

Options Model," Sustainability, vol. 14, no. 19, p. 11993, Sep. 2022, doi: 10.3390/su141911993.

[20] Q. S. Rocha, R. A. Munis, R. B. G. da Silva, E. W. Z. Aguilar, and D. Simões, "Photovoltaic Solar Energy in Forest Nurseries: A Strategic Decision Based on Real Options Analysis," Sustainability, vol. 15, no. 5, p. 3960, Feb. 2023, doi: 10.3390/su15053960.

[21] C. Heumesser, S. Fuss, J. Szolgayová, F. Strauss, and E. Schmid, "Investment in Irrigation Systems under Precipitation Uncertainty," Water Resources Management, vol. 26, no. 11, pp. 3113–3137, Sep. 2012, doi: 10.1007/s11269-012-0053-x.

[22] K. Mongkoldhumrongkul, "Techno-economic analysis of photovoltaic rooftop system on car parking area in Rayong, Thailand," Energy Reports, vol. 9, pp. 202–212, Mar. 2023, doi: 10.1016/j.egyr.2022.10.421.

[23] C. B. Agaton, C. S. Guno, R. O. Villanueva, and R. O. Villanueva, "Diesel or Electric Jeepney? A Case Study of Transport Investment in the Philippines Using the Real Options Approach," World Electric Vehicle Journal, vol. 10, no. 3, p. 51, Aug. 2019, doi: 10.3390/wevj10030051.

[24] K. Suganthi and G. Jayalalitha, "Geometric Brownian Motion in Stock Prices," J Phys Conf Ser, vol. 1377, no. 1, p. 012016, Nov. 2019, doi: 10.1088/1742-6596/1377/1/012016.

[25] L. J. Cueto, A. F. D. Frisnedi, R. B. Collera, K. I. T. Batac, and C. B. Agaton, "Digital Innovations in MSMEs during Economic Disruptions: Experiences and Challenges of Young Entrepreneurs," Adm Sci, vol. 12, no. 1, p. 8, Jan. 2022, doi: 10.3390/admsci12010008.

[26] Philippines Statistics Authority, "Agricultural Indicators System: Agricultural Structure and Resources," https://psa.gov.ph/system/files/main-publication/ais_agri_struct_resources%25202019.pdf.

[27] A. A. Collera and C. B. Agaton, "OPPORTUNITIES FOR PRODUCTION AND UTILIZATION OF GREEN HYDROGEN IN THE PHILIPPINES," International Journal of Energy Economics and Policy, vol. 11, no. 5, pp. 37–41, Aug. 2021, doi: 10.32479/ijeep.11383.

[28] EPA, "Greenhouse Gases What are the trends in greenhouse gas emissions and concentrations and their impacts on human health and the environment?," United States Environmental Protection Agency.

[29] E. S. L. de G. M. B. S. de B. and R. V. A. Schroten, " Handbook Environmental Prices," Netherlands, 2017.

[30] CE Delft, "Health impacts and costs of diesel emissions in the EU," European Public Health Alliance. (EPHA), Brussels, Belgium, 2018.

[31] Md. T. Islam and Md. E. Hossain, "Economic Feasibility of Solar Irrigation Pumps: A Study of Northern Bangladesh," International Journal of Renewable Energy Development, vol. 11, no. 1, pp. 1–13, Feb. 2022, doi: 10.14710/ijred.2022.38469.

[32] International Energy Agency, "International Energy Agency (IEA) World Energy Outlook 2022," International Energy Agency, 2022.

[33] F. Lafond et al., "How well do experience curves predict technological progress? A method for making distributional forecasts," Technol Forecast Soc Change, vol. 128, pp. 104–117, Mar. 2018, doi: 10.1016/j.techfore.2017.11.001.

[34] X. Tian, C. An, and Z. Chen, "The role of clean energy in achieving decarbonization of electricity generation, transportation, and heating sectors by 2050: A meta-analysis review," Renewable and Sustainable Energy Reviews, vol. 182, p. 113404, Aug. 2023, doi: 10.1016/j.rser.2023.113404.

[35] R. Yamashiro and A. Mori, "Combined third-party ownership and aggregation business model for the adoption of rooftop solar PV–battery systems: Implications from the case of Miyakojima Island, Japan," Energy Policy, vol. 173, p. 113392, Feb. 2023, doi: 10.1016/j.enpol.2022.113392.

[36] C. Yang, Q. Jiang, Y. Cui, and L. He, "Photovoltaic project investment based on the real options method: An analysis of the East China power grid region," Util Policy, vol. 80, p. 101473, Feb. 2023, doi: 10.1016/j.jup.2022.101473.

[37] K. Isaac and W. Joshua, "Design optimization

of communal solar powered irrigation system," Afr J Agric Res, vol. 19, no. 3, pp. 272–286, Mar. 2023, doi: 10.5897/AJAR2022.16294.

[38] M. Castellini, F. Menoncin, M. Moretto, and S. Vergalli, "Photovoltaic Smart Grids in the prosumers investment decisions: a real option model," J Econ Dyn Control, vol. 126, p. 103988, May 2021, doi: 10.1016/j.jedc.2020.103988.

[39] C. Vargas and M. Chesney, "What are you waiting to invest in grid-connected residential photovoltaics in California? A real options analysis," Journal of Sustainable Finance & Investment, vol. 13, no. 1, pp. 660–677, Jan. 2023, doi: 10.1080/20430795.2021.2016361.

[40] C. G. Ofori, G. A. Bokpin, A. Q. Q. Aboagye, and A. Afful-Dadzie, "A real options approach to investment timing decisions in utility-scale renewable energy in Ghana," Energy, vol. 235, p. 121366, Nov. 2021, doi: 10.1016/j.energy.2021.121366.

[41] M. N. K. JARKONI et al., "EFFECTS OF EXHAUST EMISSIONS FROM DIESEL ENGINE APPLICATIONS ON ENVIRONMENT AND HEALTH: A REVIEW," J Sustain Sci Manag, vol. 17, no. 1, pp. 281–301, Jan. 2022, doi: 10.46754/jssm.2022.01.019.

[42] E. Long and C. Carlsten, "Controlled human exposure to diesel exhaust: results illuminate health effects of traffic-related air pollution and inform future directions," Part Fibre Toxicol, vol. 19, no. 1, p. 11, Dec. 2022, doi: 10.1186/s12989-022-00450-5.

[43] A. Fayyazbakhsh et al., "Engine emissions with air pollutants and greenhouse gases and their control technologies," J Clean Prod, vol. 376, p. 134260, Nov. 2022, doi: 10.1016/j.jclepro.2022.134260.

[44] E. J. Mishan and E. Quah, "Brief historical background to cost-benefit analysis," in Cost-Benefit *Analysis*, 2020. doi:

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Review on Issues and Challenges to Sustainable Urban Development in the State of Uttarakhand

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ABSTRACT

State of Uttarakhand in India have gone through transitional change in the last decade. Urban population share has increased from ten percent to near about thirty percent of the total population. Due to this rapid urbanization of the state of Uttarakhand, the state is finding difficulty in attaining sustainable development. Through this study, the researchers tried to identify the major challenges and issues which are blocking the urban areas of Uttarakhand from attaining sustainable development through a systematic review framework given by Arksey and O'Malley. The framework is a six-stage methodological framework for conducting scoping studies with the sixth stage being optional. The article attempts to highlight the issues and challenges which can be evaluated by researchers, academicians and policy makers in India and the world to study, evaluate and analyze the sustainable urban development of Uttarakhand. The methodology can also be used by researchers, academicians and policy makers to identify the challenges of sustainable urban development for any hill or mountain side terrain.

Index-words: *Sustainable Development, Urban, Challenges, Uttarakhand, Himalaya.*

I. INTRODUCTION

State of Uttarakhand in India is passing through a chain of transformations on all fronts to achieve the objectives of growth that must be sustained over time. During the process of growth, the changes take place at all the fronts of development, namely social, economic, and cultural. These fast social and environmental changes have come along with stark challenges of population growth, ecological decay and unbalanced land. In addition, challenges are also with creation of affordable housing markets, stabilizing poorly resourced public sectors units, lack of jobs in both formal/informal sectors and unhygienic living conditions.

The state Uttarakhand is a state in the north of India as shown in figure 1. The state is split into two parts: Garhwal and Kumaon, with a total of 13 districts. Dehradun, the winter capital, and largest city in the state, also serves as a railhead. Bhararisain, a town in Chamoli district's Gairsain Tehsil, has been designated as Uttarakhand's summer capital. On November 9, 2000, the state of Uttaranchal became India's 27th state that was formed out of Uttar Pradesh, and in January 2007, the new state changed its name to Uttarakhand, which means "northern region," the old name for the area. The state is having 113 town and cities divided into eight municipal corporations, 25 municipal councils, 32 notified areas, nine army cantonment board and 40 census towns for administrative purposes.

Fig. 1. State of Uttarakhand (Source: veethi.com)

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Being one of the newest states of India, its urge for economic development have put up a stain on the infrastructure within cities (Prakash C, Abhinav, & Bhagwati, 2018; Colantonio & Dixon, 2011). Unplanned urban development is leading to major environmental concerns such as the depletion of forest area, loss of biodiversity, and landslides. The proportion of the urban population living in environmentally unsafe areas, below the poverty line, without access to sanitation, without access to drinking water, and without access to roads, has increased, respectively, by 20, 25, 10, 7, and 6 per ent in Uttarakhand over the past two decades (Tiwari, 2023).

It is known that urban areas must develop in a planned way where the needs of the present generation do not conflict with those of the future. The objectives of any development activity are to satisfy the needs of the population without distorting the relations between nature and society. If the needs are not reached, then the development will not be inclusive. It will result in inequality in the use of natural resources, reduced efficiency in energy system and imbalance in socio-demographic system. At the end, this will lead to emergence of crisis and reduced economic growth. These challenges are driving the policymakers to go for sustainable development.

In hilly region, climate change has created stress to urban ecosystems by increasing the rate, severity and power of extreme weather events (Durga Rao, Rao, Dadhwal, & Diwakar, 2014; Prakash C, Abhinav, & Bhagwati, 2018). Growth of an urban area or urbanization cannot slowdown, but it can be framed in a sustainable way through synergy between urban-rural land use planning. For campaign of sustainable urbanization, policymakers at various levels are looking for the optimal urban sustainability significance. The region of Uttarakhand had experienced fast urbanization during the last two decades. The process of urbanization has been unplanned, uncontrolled and unregulated (Prakash C, Abhinav, & Bhagwati, 2018; HPEC, The High Powered Expert Committee, 2011). Recently, the remote areas of the region are facing the problem of unregulated urbanization. This happened because of promotion of these areas as a tourist destination without proper land use plan. These is disrupting critical ecosystem, reduction of natural resources and increased inequalities in socio-demographic and finally resulted in decreasing drinking water availability prone to natural extreme weather events, health insecurity and increase in waste generation.

In the course of urbanization of a region, there are certain challenges that will come in front of institutions and policymakers. These challenges are employment, improving access to social infrastructure, reducing impact of pollution, natural disasters, energy conservation and other risks. In the urban area of developed countries, those who are having accessibility to basic public services are facing the issues of becoming more resourceful in the use of water and energy. They are also unable to reduce and reuse the waste generation. Cities like New York and London in particular, may have well-planned resource systems but they also have higher carbon footprints. In addition, climate change impact is increasing cities' susceptibilities. It is also putting stress on the adaptive abilities of the deprived (Nations, 2013).

Available studies of researchers on the issue of sustainable development did not give importance to the social aspect as to the economic and environmental aspects (Vallance, Perkins, & Dixon, 2011). The less attention to social aspect might be due to its intangible nature and challenge in defining its goals. Therefore, it is difficult to be executed and judged (Hikmat , Yamen , & Hadeel., 2019; Al-Dahmashawi, Hassan, Sabry, & Mahmoud, 2014). To understand the framework of development of urban areas in a sustainable urban boundary, a set of indicators, frameworks and assessment tools have been developed (Li-Yin, Jorge, Mona, & Zhang, 2011; Briassoulis, 2001). The urban indicators for understanding sustainability are critical for helping on target setting, performance assessments and enabling communiqué among the policy makers, experts and people living with urban boundary (Verbruggen & Kuik, 1991; Li-Yin, JJorge, Mona, & Zhang, 2011).

The rest of the paper is organized as follows: a brief discussion of available literature, limitations of existing literature as well as the theoretical underpinning that has been mentioned in the second section. Methodology has been presented in section three in which the deduction method has been applied to understand the issues and challenges faced by the region of Uttarakhand during the process of urbanization. Finally, findings, conclusions and policy implications of the study has been given.

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A. Issues and Challenges for Sustainable Urban Growth for the State of Uttarakhand

One of the rapid growing states in India is the Himalayan state of Uttarakhand. According to World Bank's study on the state's GSDP growth, the economy is mainly dependent on the tertiary and non-agriculture sectors. The report also highlighted that decrease in poverty in the state was the most rapid among all the states in the country after 2005. In spite of this, some of Uttarakhand's hilly districts record higher levels of poverty than its other areas. Economic inequality is an issue of the state.

Twenty four percent of the land surface of earth are either hills or mountains (UNEP, 2002) and inhabitants of twelve percent of the world's population (Huddleston, Ataman, & d'Ostiani, 2003; Prakash C, Abhinav, & Bhagwati, 2018). Macro-climate change, limits of land, ecological sensitivity, geographic remoteness and less infrastructural growth becomes a crucial issue for sustainable society for this region (Meybeck, Green, & Vörösmarty, 2001; Prakash C, Abhinav, & Bhagwati, 2018). Mountains and hilly regions are sources of a various ecosystem services, which include water sources and soils that directly affect the economy and social life of a large population both in mountains and in adjoining plains. These types of regions provide water to nearly half of the world inhabitants living along the river valleys situated far away from hilly regions (Viviroli, Dürr, Messerli, Meybeck, & Weingartner, 2007). The major rivers of the world have their origin from glaciers or mountains. The largest share of world's forests is in the mountains also which does not only start universal biodiversity hot spots, but also regulates and checks climatic circumstances and contributes towards reduction in global warming because they serve as carbon sinks. The region is also home to various indigenous people. They have progressed from diversity of cultures that comprise traditional knowledge, resource development and environmental conservation practices, agricultural and food systems, and adapting and coping mechanism to environmental changes (ICIMOD, 2010).

The natural landscape, the difficult terrain and the economy of the region were not conducive to the development of urban centres until very recently. Settlement used to be scattered with no considerable industry and even the tradition of crafts that was there was not meant for commercial transaction. The population were not able to make full exploitation of the local resources. The road and communication networks were not developed and even the number of wheeled vehicles was limited. Because of all of this, there was no urban centres in the region as late as the 20th century.

Tourism is one of the key segments of the economy for the state of Uttarakhand and can subsidize the future development in the region. It will give push for sustainable growth of the state. The growth of tourism must be inclusive (focusing on equity and wealth distribution) and sustainable (promoting domestic culture and job creation) to contribute to achieving the Sustainable Development Goals (SDGs).

Therefore, to go for sustainable urban development, first one needs to understand the challenges and issues that are impeding the sustainable growth for the urban areas of Uttarakhand.

II. LITERATURE REVIEW

In September 2000, world leaders embraced the United Nations Millennium Declaration (Nations, 2013) (United Nation General Assembly resolution 55/2). This created the platform of the beginning for the pursuit of the MDGs. An agreement was framed around the importance of human development and poverty reduction. The world touched the poverty target before 2015. In developing countries, the percent of people living on lower than $1.25 a day fell from 47 percent in 1990 to 22 percent in 2010 (Nations, 2013). There was a decrease of 700 million people of extreme poverty in 2010 compared with 1990 according to UN report. Still, results were below expectations. It is vital that the international community of institutes and policy makers to take bold and joint steps to fast-track development in achieving the Millennium Development Goals (Nations, 2013).

Sustainable development aims towards an ambitious agenda to transform the world by 2030, where everyone benefits from development efforts. Though an essentially challenging concept, it still holds a broad moral interest. The concept of sustainable development lies in an endeavour to combine global concerns on environmental issues with holistic economic issues such as inequality, job creation, climate change and building peaceful and inclusive societies.

Sustainable Urban Development must be the aim of

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all developing countries. The International Union for Conservation of Nature and Natural Resources was first to coin the term 'sustainable development' in 1980 (IUCN, 1980). Sustainable city is a city "where achievements in social, economic and physical development are made to last" was defined by The UNCHS (United Nations Conference on Human Settlement). A Sustainable city will be a city that will possess lasting supply and optimum utilization of the resources on which its growth depends and a lasting protection from environmental hazards which may impede any progress achievements.

Sustainable urban development is important because urban areas nowadays contribute significantly to the Gross Domestic Product. They contribute increasingly to export and is a rich place for capital formation. Cities offer quality education and healthcare; arts and science; technology and innovation and transport and communication.

Many cities in the world are experiencing growth in urban population. The globalization and migration of population from the rural to urban areas has hastened the process of urbanization in India. In India, the metropolitan cities like Delhi, Mumbai, Chennai and Kolkata are experiencing pressure of urban population growth. The same can be seen in hilly cities like Dehradun, Dharamshala, Darjeeling, etc. The growth of urban population has given rise to sundry of urban problems such as unemployment, housing, sanitation, safe drinking water, etc. So, there is an utmost need to study the issues and challenges for sustainable development facing the cities in Himalayan range belt.

For promotion of sustainable development, international institutions, governments at different levels, policymakers and researchers are seeking the best urban sustainability value. Study of understanding on the state of, or changes to, cities and towns in relation to better urban sustainability performance, sets of monitoring indicators, plans, policy and assessing tools, have been framed (Li-Yin, Jorge, Mona, & Zhang, 2011; Briassoulis, 2001). Identifying challenges and urban sustainability indicators helps in setting the target, assessing performance and facilitates communication between policy makers, experts and the public (Verbruggen & Kuik, 1991; Li-Yin, Jorge, Mona, & Zhang, 2011). An extensive range of urban sustainability indicators is therefore in use through the range of different cities and regions, which vary according to their particular needs, challenges and goals. However, one is getting diverse results in applying urban sustainability indicators in various situations and sometimes little gain in sustainability performance. This poor result is due to practical field conditions and not identifying correct challenges that vary from one place to other (Selman, 1999; Seabrooke & Ma, 2004). Poor selection of challenges and indicators monitoring the sustainable urbanization process is becoming an issue (Briassoulis, 2001; Li-Yin, Jorge, Mona, & Zhang, 2011; Vladimir, Annette, & Evans, 2016).

A. Theoretical Underpinning Behind Sustainable Urban Development

Rapid development of cities and towns, urban development is increasingly getting complex in nature. Physical urban forms were only taken into consideration for designing urban areas and studying its dynamics previously. At present time non-physical factors (e.g. human and society) are present and more fundamental rules are hidden for the sustainable development of cities.

Studied by researchers and policy makers, urban system is becoming more and more complex in both forms and nature. Thus, how to understand, analyze and depict such a complex dynamic system has become an urgent problem to be solved by planners and policy makers (Wensheng & Qiang, 2013).

Past research based on reductive thinking encountered great challenges in interpreting the formation of urban structure, urban spatial evolution, and laws of human activities in cities, etc., which fails to reveal deeper causes and rules of urban dynamics. By the end of 1980s, the founding of Santa Fe Institute directly facilitated and led to the emergence of complexity science. The complexity science achieved rapid development within less than 20 years and has become the focus of attention in the scientific social research field at present. On one hand, the theories of complexity science greatly change people's ideas of urban system. On the other hand, research methods of complex system particularly make powerful means available to explore urban system (Wensheng & Qiang, 2013). The view of living systems as self-organizing networks, whose components are all interconnected and interdependent, has been expressed repeatedly, in one way or another, throughout the history of philosophy and science. However, detailed models of self-organizing systems could be formulated only very recently, when the new mathematical tools

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that allowed scientists for the first time to describe and model the fundamental interconnectedness of living networks mathematically became available.

Although there is a variety of theories and no consensus has been fully reached on complexity and complex systems, some important conclusions have been approved by the scientific circle. Complex systems exist objectively and they are not determined by human knowledge. There are nonlinear interactions among microscopic individual components of complex systems and it is impossible to deduce all overall characteristics according to partial attributes. Complex systems are definitely dynamic, some novel characteristics of which spontaneously come into being during evolution. Complex systems are not intuitively presented, and openness is the fundamental condition for complex systems. Adapting to the urban dynamics is the major cause of complexity. Overall, complex systems theory is still a theoretical system remaining to be constantly improved and expanded by the concerns and efforts of scientists from different fields of all countries. The research methods of complex systems theory and complex systems have made some crucial concepts and methodologies available to study urban problems.

Many elements within an urban area such as social organizations, people flow, material flow and accumulation of historical culture, etc. are assembled, blended, fermented, and synthesized. So, a city can be regarded as a complex giant system. All complex systems have different characteristics, structures and functions. An urban system is just such a structure made up of several issues and challenges. The issues and challenges constituting cities are both in material form (including air, sunshine, soil, water, building and organisms) and in nonmaterial form such as belief, religion, thought, ideology, economy and society. There are not only a great variety of such elements, but also various connections among these elements and their sub-elements. Thus, different kinds of coupling mechanisms constitute a huge system like a city.

III. METHODOLOGY OF THE STUDY

The researchers conducted a systematic scoping review of peer-reviewed literature for this paper, with focuses on urban development and sustainability for the state of Uttarakhand (Shephard et al., 2006; Bryman, 2012). Arksey and O'Malley's systematic review framework was taken as reference for the review process (2005). The review has been into five stages. The first stage is identifying the research question, the second is to identify relevant studies, the third is selecting relevant studies, the fourth stage is to chart the data in tabular form if possible and the final stage is to collate, summarize, and report the results.

The central research question of the paper is "what are the issues and challenges for sustainable urban growth for the state of Uttarakhand". For review of the literature, particular journals were not predetermined; instead, the researchers used the following sources: EconLit (EBSCO), JSTOR, ScienceDirect and Wiley Online Library. With respect to research questions, journals and articles were searched from electronic databases with systematic review procedure. For identifying relevant studies, the first inclusion criteria were using the key terms like "sustainability", "sustainable development" and "Urban development" to search for identifying journals and articles. Terms like "social", "ecology or environment" and "economic" were also used to identify more papers. Government reports of country and the state have been considered for this study. Reports from NITIAAYOG planning and implementation body of India were especially helpful. For exclusion criteria, the reearchers specifically targeted the papers and articles relevant to the state of Uttarakhand. The flow chart given below in Figure 2 describes the process.

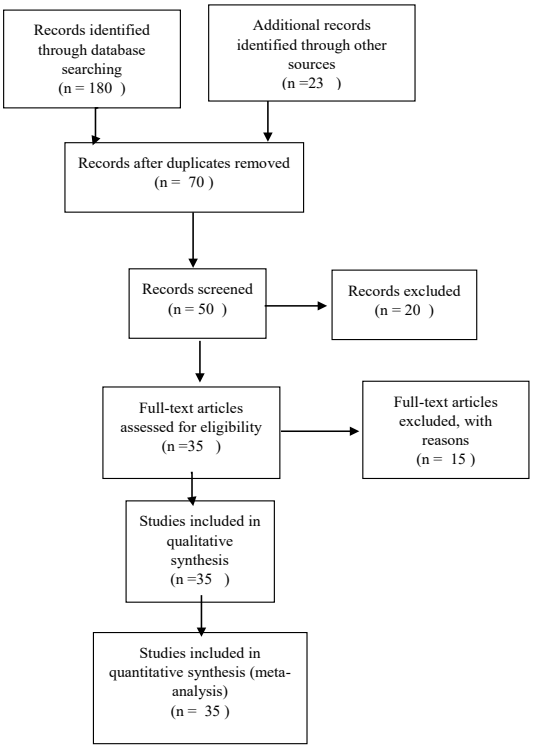

Fig. 2. Systematic review process

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Findings of the study after the systematic review process are represented in Table I.

TABLE I
MAJOR FINDINGS AFTER SYSTEMATIC REVIEWING PROCESS

SL. No	Author	Journal/Report/ Book Chapters	Key Issues and challenges identified
1	Prakash C. Tiwari, Abhinav Tiwari and Bhagwati Joshi, 2018	Journal of Urban and Regional Studies on Contemporary India	Land use patterns, Water management, Economy & employment, Environment impact, Natural resources
2	Michel Meybeck, Pamela Green and Charles Vörösmarty, 2001	Mountain Research and Development	Water resource management, Land use pattern
3	Vladimir Strezov, Annette Evans and Tim J. Evans, 2016	Sustainable Development	Economic, Social, Political
4	Govt. of India	Water and Sanitation Program	Water
5	William Seabrooke, Stanley C.W. Yeung, Florence M.F. Ma, Yong Li, 2004	Habitat International	Reconciling public and private ordering of land use, Environmental impact, Electricity, Transport, Buildings
6	Deena Mahmoud Al Dahmashawi; Doaa Kamal Eldin K. Hassan, Hanan Mostafa K. Sabry and Shaimaa Mohamed K. Mahmoud, 2014	Journal of American Science	Work & income, Education and skills, Social capital, Wellbeing
7	Harmen Verbruggen and Onno Kuik	Book Chapter	Natural resources, Economic, Social
8	Hikmat H. Ali, Yamen N. Al-Betawi and Hadeel S. Al-Qudah, 2019	International Journal of Urban Sustainable Development	Urban form and land use, Access to services, Open spaces, Transportation Availability, job Accessibility, Place to live
9	Dr. I. C. Awasthi and Dr. Bhaskar Awasthi, 2016	International Journal on Arts, Humanities, Social Sciences & Business Studies	Migration, Economy, Per capita income
10	Sandeep Tambe, Ghanashyam Kharel, M. L. Arrawatia, Himanshu Kulkarni, Kaustubh Sandeep Tambe, Ghanashyam Kharel, M. L. Arrawatia, Himanshu Kulkarni, Kaustubh Mahamuni, and Anil K. Ganeriwala, 2012	Mountain Research and Development	Ground water, Rainwater harvesting, Climate change adaptation
11	Sultan Singh Jaswal, 2014	Journal of Tourism & Hospitality	Tourism, economy, Undesirable social and cultural change:
12	Helen Briassoulis, 2001	Journal of Environmental Planning and Management	Environment, Waste management, Natural resource management, Economy, Energy Supply, Green spaces
13	Niti Aayog, 2018	Govt. of India Report	Tourism, Water management, Waste management, Economy, Air pollution, Health, Natural resources, Energy, Traffic management

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14	Li-Yin Shen, J. Jorge Ochoa, Mona N. Shah and Xiaoling Zhang, 2011	Habitat International	Transport efficiency, Economy, Policy, Governance, Land use plan, Social welfare, Waste management
15	Wilhelm Lerner	Arthur D. Little Future Lab	Multimodal transit system, Pollution
16	Abdul Bari Naik, Subita Sharma and Rajni Sharma, 2012	International Journal of Scientific and Research Publications	Energy Consumption, Education, Gender Equity, Employment, Waste management, Tourism, Local economy
17	Tara Vishwanath, Somik V. Lall, Siddarth Sharma, Nancy Lozano-Garcia, Hyong Gun Wang and David Dowal, 2013	The World Bank	Tourism, Water management, Waste management, Economy, Air pollution, Health, Natural resources, Energy, Traffic management
18	Mussorie Dehradun Development Authority, 2017	Govt. of Uttarakhand Report	Energy Consumption, Education, Transport, Gender Equity, Employment, Waste management, Tourism, Local economy
19	Ministry of Urban Development, 2014	Govt. of Uttarakhand Report	Energy Consumption, Education, Transport, Employment, Waste management, tourism, local economy
20	Ministry of Urban Development, 2014	Govt. of Uttarakhand Report	Energy Consumption, Education, Transport, Employment, Waste management, Tourism, Local economy
21	Institute For Human Development, 2018	Govt. of Uttarakhand Report	Education, Transport, Employment, Waste management, Tourism, Local economy
22	Ravi Chopra, 2014	Oxfam India	Governance, Local Economy, Climate Change
23	Pooja Singh, P.S. Chaini and M. Parida, 2014	Journal of Environmental Research and Development	Transport, Pollution, Land use
24	I. C. Awasthi and Bhaskar Awasthi, 2016	International Journal on Arts, Humanities, Social Sciences & Business Studies	Local economy, Synergy of rural and urban area, Tourism, Poverty
25	Abdul Bari Naik, Subita Sharma and Rajni Sharma, 2012	International Journal of Scientific and Research Publications	Tourism, Economy, Waste management, Social security
26	Shipra Rajesh, Suresh Jain and Prateek Sharma, 2018	Ecological Indicators	Water, Economy, Energy, Gender equality
27	Vanessa Rauland and Peter Newman, 2016	Journal of Economic Literature	Economic, Real estate, Employment
28	Debolina Kundu And Dibyendu Samanta, 2011	Economic And Political Weekly	Governance
29	Jitender Saroha, 2016	Springer (Book Chapter)	Sanitation. Water, Transportation, Employment
30	Eric Denis, Partha Mukhopadhyay And Marie-Hélène Zérah, 2012	Economic and Political Weekly	Governance, Employment
31	Harsimran Kaur and Pushplata Garg, 2019	Cities	Land use, Environment

32	Kavitha Shanmugam, Anju Baroth,Sachin Nande, Dalia M. M. Yacout, Mats Tysklind and Venkata K. K. Upadhyayula, 2019	Sustainability	Transportation, Environment
33	Pradeep Rawat, Charu Pant and Hari Nipanupud, 2016	Earth Science Informatics	Land use
34	Anoop Kumar Shukla, Chandra Shekhar Prasad Ojha, Ana Mijic, Wouter Buytaert, Shray Pathak, Rahul Dev Garg and Satyavati Shukla, 2017	Hydrology & Earth System Sciences Discussions	Land use, Water
35	Mahesh Chandra Sati and Rajendra Prasad Juyal, 2008	Mountain Research & Development	Economy, Gender

From systematic review of the various issues and challenges the researchers identified the following:

1. Degrading urban water management
2. Unplanned urban sprawl and land use
3. Inefficient public transport
4. Lack of employment opportunities and migration of population
5. Unplanned tourism development
6. Clean energy
7. Waste management
8. Urban governance

1. Degrading Urban Water Management

Zhou, Shi, Wang, Yu, & Gao in their study using GIS and remote sensing applications analyzed the river network changes of Shenzhen from 1980 to 2005. They concluded that rapid urbanization has led to ecological degradation of water sources and rivers, such as disappearance of water bodies and wetland and the outward expansion of the urban land. The same is happening to state of Uttarakhand. Nearly 65% census cities and towns in the state of Uttarakhand located on the ridges and the mountain slopes in Uttarakhand are the sources of a large number of springs, rivers and streams. These natural springs, rivers and streams do not only create sources of water supply to the towns and cities themselves, but they also provide 15–50% freshwater to the downstream rural areas of the state. The changing land use pattern and decline in forest area have disrupted the hydrological system of towns and cities in Himalaya and have also decreased ground water recharge (Ives, J.D, 1989; Prakash, Abhinav,& Bhagwati, 2018). Since, portion of the rainfall has vanished through surface runoff without recharging the groundwater reserves in urban areas, the groundwater reserve is diminishing alarmingly (Rai & Sharma, 1998; Tambe, et al., 2012; Prakash, Abhinav & Bhagwati, 2018). Some studies mentioned that the above changes had resulted into (i) Decrease of stream discharge; (ii) springs are getting dry and (iii) declining size of urban lakes (Rawat, 2009; Valdiya & Bartarya, 1991; Tiwari and Joshi, 2012a).

The hydrological investigations revealed that 25% to 41% of natural springs had dried up; 3% to 7% of wetlands were exhausted; and 11% to 47% water discharge had declined in springs and streams within and around urban areas of Shimla, Solan and Hamirpur in Himachal Pradesh and Almora, Pauri and Ranikhet towns in Uttarakhand during 1985 and 2015. Further, some researchers observed that 45% natural sources had dried, 21% had become seasonal, and stream discharge had declined by 11% in the heavily urbanized Lake Region of Nainital during 1985–2015. Consequently, 87% urban centres and 65% villages situated in the rural fringe of towns and cities in Himalaya are facing acute shortage of freshwater (Prakash, Abhinav, & Bhagwati, 2018; Tiwari and Joshi, 2012). Drinking water quality of urban lakes had degraded due to their silting and pollution. Bathymetric investigations revealed that capacity of lakes in Uttarakhand had decreased on an average by 5,494 m3 due to silt formation. It has also been observed that runoff generated by urban systems is much higher than that of forests and agricultural lands (Valdiya & Bartarya, 1991) , consequently, the deluge rate of urban areas was 35 times higher compared to flood rate of forests in the region (Rawat, 2009; Prakash, Abhinav & Bhagwati, 2018).

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According to government of India's report on water supply and sanitation for some districts in the states of Uttar Pradesh and Uttarakhand (popularly known as Swajal Project) during 1996-2003, they became a successful model to be implemented in India (Lall, 2015). The success of the project stimulated the Government of Uttarakhand to improve its coverage to other districts within the state, adopting a program approach. The project had a total budget of US$ 224 million of which the World Bank has allotted US$ 120 million credit limit (Lall, 2015). Operations started in November 2006 and concluded in June 2012. However, the benefit of the project is yet to be passed on to the population. Groundwater springs in the state, which gives support to millions of people across the state of Uttarakhand, are either increasingly parching, or becoming periodic. This causing despair to urban population of the state. According to the report published by NITIAAYOG (Report of Working Group II Sustainable Tourism in the Indian Himalayan Region, 2018), of some four million springs in the hilly region of northern India, at least thirty three percent is drying up and more than fifty percent decreased their water release.

2. Unplanned Urban Sprawl and Land Use

Negative sentiment against urban sprawl has emerged in last few years. Many researchers had concluded that key pushing forces that are changing the natural landscape and affecting ecosystem of sustainable development in the mountain regions is land use (Ives, J.D, 1989; Jandl, Borsdorf, van Miegroet, Lackner, & Psenner, 2009; Prakash, Abhinav & Bhagwati, 2018). Rapid land use changes because urban growth is creating dreadful conditions and disorder of the ecosystem services (Buytaert, Cuesta-Camacho & Tobón, 2011). Countless loss of biodiversity and interference to ecosystem in the mountains is happening due to a change in structure and functions (Borsdorf, Tappeiner & Tasser, 2010). Some literature had also identified that the urban growth and resulting land use have disrupted the hydrological regimes of Himalayan headwaters (Ives, J.D, 1989; Prakash, Abhinav & Bhagwati, 2018). The studies on middle Himalaya, Shiwaliks and Terai region have shown that the quantity of runoff from urban areas is much higher compared to the amount of overspill from other categories of land, particularly, forests and horticulture (Shukla et al., 2018). The increasing density of construction in urban areas of Himalaya is causing great depletion of underground water resources due to reduction in groundwater recharge (Tiwari and Joshi, 2015; Haigh, 2002; Rawat, 2009). In addition, if one considers land use along major transport corridors, he/she will discover that challenges lie there also. All the primary radial transport routes, particularly in cities of Dehradun, Haridwar, Roorkee and Haldwani the cities are noticeable with high-density unregulated developments. This leads to underutilization of the transport, increase in travel times, increase in pollution, and fall in the productivity of the urban economy (Smart City Dehradun, 2017).

3. Inefficient Public Transport

There has been extensive research by both government, financial and academic institutions on urbanisation trends and the need for infrastructure development as a vehicle for economic and social development. Both locally and internationally, there is an increasing realization that cities are the engines of growth and transportation acts as a backbone to social and economic development of the world.

Transport overtakes all other infrastructure concern and has the biggest impact on city competitiveness and transportation is the most serious challenge facing the city's infrastructure across cities of the world. In a survey conducted by Siemens and presented in the 'Megacity Challenges: A stakeholder perspective' 522 stakeholders were surveyed in 25 cities across world. The report concluded that there is a general consensus of the largest proportion of 85% of population which put investment requirements in the coming 5-10 years which is the highest in the transportation sector with transportation ranked much higher above housing, water, healthcare, environment etc. (Hazel, 2007).

Developed and developing cities in the world are facing the challenge of traffic congestion, increasing rate of road accidents and higher emission of greenhouse gases. In the words of Rudyard Kipling "transport is civilization". "Cities are sprawling with the 'haves' escaping to areas with better living conditions and the 'have nots' trapped and increasingly marginalized" (ADB, 2009).

Little assessed the mobility performance of 66 cities and found that most of the cities fail to meet the challenge of fulfilling urban mobility needs of growing population and that the traffic situation in most of the cities is chaotic (2011). IEA vehicle ownership trend projection shows that "India, China and other Asian countries would have a high rate of vehicle

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ownership by 2050 leading to more carbon emission and transportation issue like traffic congestion, pollution etc." (IEA, 2012)."For workers to access jobs and for businesses to access suppliers and markets, a reliable and affordable transport system is needed to enhance urban mobility. Limited transportation options can turn commuters to Indian cities into arduous treks, and many people are forced to live in substantial housing and slums too close to jobs when transport is inaccessible and unaffordable" (World Bank, 2013). "Transportation provides vital support to the economic and social development" (Hidalgo, 2013). A study on city of Dehradun showed that approximately forty eight percent of roads are being utilize for on-street parking. Pathetic Intermediate public transport named vikrams and e-rickshaws are running without proper permit or license. This is increasing the pollution level of the city. There is a notable amount of negligence in terms of transport planning for the vikrams and city buses (Smart City Dehradun, 2017). Private operator through bus and IPT is operating the existing city public transport system for the urban areas of Uttarakhand. The private buses are running on various routes having a fleet of about 100 busses. Vikram (Transport service) is the main mode of public transport in the cities and is operating from the roadside, utilizing the road ROW as terminal and causing the delay of other vehicles plying on the road (Singh, Chani, & Parida, 2014). The scenario in the other cities on the hills is far more worse. There is no proper intra- and inter-city transport. This is leading to traffic congestion and tourism, which is the main source of revenue for the state, is being affected.

4. Lack of Employment Opportunities and Migration of Population

According a report published by Govt. of Uttarakhand in 2011, the workforce participation ratio was about 34:66. Thirty three percent of the workforce is made up of main workers, while the other sixty six percent is made up of marginal and non-workers (PWC, 2016). There is an absence of enough employment opportunities in the service sector in line with the employable population of the cities and towns of Uttarakhand. Income and expenditure vary from one urban area to another. Mean per capita income of the families is Rs.2372 and mean household income is Rs.10461 (GHK International, 2007). There is also variation in population residing below poverty line (7%-40%) in the urban areas of Uttarakhand. Nearly nineteen percent of the workers migrated to cities in hope of better economic prospects as per government documents. The importance to cities is rising due to the unhappy life of villages on hills reflected in poor transport connectivity, no recreational facility, lack of drinking water, inadequate health facilities, and poor informative facilities. Besides, remote markets have further pushed the migration especially the young generation (Mamgain & Reddy, 2014).

According to Awasthi and Dev in their working paper report, many indicators of growth and development in the Uttarakhand display the below par levels of development disparities with districts (Awasthi & Dev, 2015). In the districts of the state, namely, Dehradun, Udham Singh Nagar, Roorkee and Hardwar, the economic development is healthier than the other districts in terms of economic indicators due to plain terrain (Awasthi & Awasthi, 2016). Also, change in the structure of workforce or employment is of need for successful transformation to increase the income level of population. However, due to substantial changes in the income level of the primary sector, the job scenario has not shown the expected changes over the years. Awasthi et. al also stated that in the State of Uttarakhand about forty nine percent of the working population in the primary sector is contributing about eleven percent of income, while twenty two percent in the secondary sector and twenty percent in the tertiary sector are contributing about thirty seven percent and fifty two percent of GSDP, respectively in 2011-12 (Awasthi & Dev, 2015).

Entrepreneurship base seems to have wrinkled sharply during 2004-05 to 2009-10 both for the urban area by an equal measure and the process has somewhat been prevented during 2011-12. For rural area, entrepreneurship has been the major mode of livelihoods (Awasthi & Awasthi, 2016).

5. Unplanned Tourism Development

The existing service sector focusing on tourism helps in the growth and development of a state. It takes an approach that connects as many new tourist spots as probable. The northern India hill tourism, in particular Uttarakhand, has seen growth and expansion over the last few decades in the tourism sector. The growth rate in the tourism of Uttarakhand is in line, which is to grow at an average annual rate of eight percent from 2013 to 2023 as given in the report of a government body

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(Report of Working Group II Sustainable Tourism in the Indian Himalayan Region, 2018).

All northern Indian hill and mountain states have developed tourism/eco-tourism frameworks but they have not addreseds the issues the sector is facing or can harness prospects that the change can bring. Moreover, tourism frameworks may not create synergy with the eco-tourism plan. The framework or strategic plan will vary from one state to another and it will define the scope of policy and framework formulation. Although this framework, formulates a common objective and is driven by the level of tourism development constraints in different states, the impacts of the huge tourist influx and disregard to ecology in the tourism progress trajectory of the state of Uttarakhand has led to serious apprehensions among policy makers, residents and visitors (Jaswal, 2014; Report of Working Group II Sustainable Tourism in the Indian Himalayan Region, 2018).

Tourism dependent economy works in an eco-system, which is a topographical area that includes all the living creatures whose physical environs and natural cycles help sustain them. The main tourist's attractions in the state are as follows: holy Ganga River in Haridwar, lake in Nainital and its surroundings, Gangotri and Yamunotri Glacier, and Mountains. The threat to such ecosystem is often severe as these sites are very attractive to both tourists and developers.

- Climate change: Tourism does not only affect the climate, but is also responsible for the environmental change. It can be observed by the increasing frequency of storms, disasters such as flood, land slide, sever weather events, which created a disastrous effect not only on tourism but also on the destination.

6. Clean Energy

After COP21, the major focus of the government was on sustainable development and harnessing its natural resources. All hydroelectric projects use the energy of run of water whether it is a run off river type or accumulated water type, hence every small or large hydro project fits the description of renewable sources. The main advantage of hydro power is that it is a green source of energy. There is no pollution or emissions in hydro power generation and it is basically harnessing the force of nature and using it in a manner which helps and empowers mankind. The second factor is that there is no requirement of fuel in the generation of fuel. This scenario has two aspects; first of all, there is no pollution and greenhouse gas emission from the generation, and secondly, the energy security is increased for the nation. In other types of power generation, such as thermal power, the main component which is coal is imported from another nation, hence it is dependent on the other nation and its policies. However, in case of hydro power there is no fuel requirement hence there is no dependencies on other countries. This increases the energy security of the country. This gives hydropower the title of sustainable development because it addresses the needs of today without compromising the needs of the future. Moreover, multipurpose hydroelectric project will help in flood control, irrigation purposes, navigation issue and drinking requirement (Kumar, Verma, Ghosal, & Biswas, 2018).

Hydropower potential-wise, Uttarakhand, Himachal Pradesh and Arunachal Pradesh are the top three states in India with hydropower potential of 18,175 MW, 18, 820 MW and 50,328 MW, respectively. Uttarakhand and Arunachal Pradesh have 71.85% and 93.40% potentials respectively lying unutilized. The State of Uttarakhand India is situated in Central Himalayan Region. The Himalayan glaciers feed the perennial rivers of the State, that makes it suitable for the development of hydropower projects. In Uttarakhand, out of the total hydropower potential of 18,175 MW, only 3,988 MW of capacity has been developed and 1,640 MW of capacity is in the construction phase. However, due to urbanization and economic growth, demand for electricity has been growing in the State. During 2015-16, against the energy demand of 12,889 MU, the state faced a shortage of 214 MU (deficit of 1.7%). During the year 2016-17, the State is expected to face increased energy demand of 13, 574 MU with a deficit of 336 MU (2.5%) (Mishra et al., 2018). With the State facing power shortages and with significant unutilized hydropower potential, policymakers of the state need to promote hydropower development for electricity generation being cheap and clean source of energy, which will be leading to sustainable development of the state.

7. Waste Management

Uttarakhand's urbanization is at a rate of forty percent. This is due to huge influx of fixed and

floating population. Fixed population increase is mainly observed in the plains due to natural growth and migration of population from hilly areas. Floating population makes an upward trend so as to increase of tourist footfall. With this upward trend, one can certainly see an impact on urban services including waste management. Approximate three thousand metric tons of municipal solid waste is accumulating per day. It is true that the level of waste will not come down as urbanization and tourist influx rate will not come down. Due to the fragile ecosystem of Uttarakhand, waste management is a critical issue for the future. Hundred percent waste disposal should be achieved so as to achieve sustainability.

Uttarakhand does not have organized waste management service, which includes waste collection, segregation, disposal and recycling services. Some cities in the state have waste collection mechanism but at the end, waste ends up in the open land surrounding the cities. The cities of the state are not following the mandatory responsibilities under the Solid Waste Management Rules of 2016. Waste management requires immediate control as cities of the state are being burdened up with an inefficient collection operation, lack of eco-friendly disposal mechanism and uncontrolled dumping. It is the responsibility of municipalities of Uttarakhand for looking after the services of sweeping and solid waste management. However, the service quality is poor and irregular in service. Inhabitants of economically weaker section and below poverty line are facing its harmful effect. Due to lack of awareness within the population, the inhabitants dump the waste in the open ground, street side, drains and down the hill slope. As per government data for the capital city of Uttarakhand i.e. Dehradun, eighty-five percent of population does not segregate the waste at point of source. Collection of waste is not uniform across the city. Therefore, a proper waste management plan and service is required to achieve sustainability.

8. Urban Governance

Good urban governance means transparency of system, accountability, predict issues and challenges and allows populations participation during development. The challenge in Uttarakhand is that the state's municipality bodies or corporations have limited participation in a city's development planning and infrastructure service unlike other parts of India. Para-statals or other state agencies looks after the functions of planning, urban transport, water distribution and sewage. After 74th Constitutional amendment not all eighteen functional power were given to local bodies. There is also absence of local population participation for city management.

The last decade has seen a lot of urban development in India with policies like JnNURM, AMRUT, smart city mission, etc. Many reforms were suggested and service benchmark were made available. Till now, not all reforms were implemented in the cities of Uttarakhand. Complexity of city management will increase, as cities will grow demographically and socio-economically. To handle this complexity holistic governance framework is required.

IV. CONCLUSION AND RECOMMENDATIONS FOR FUTURE POLICY DIRECTION

The policy structure for the holistic development should be inclusive as well as substantial. As happening in the other parts of the India, urbanization cannot be stopped but can be controlled. It can be in a more sustainable nature through a synergized mixed land planning on usage. Current land utilization rules and regulations need to be reframed and executed for the protected ecosystem, forests and water resources. It would also be vital to develop a balanced plan for sustainable growth in urban agglomeration zone, as it is a significant economic activity area. The unplanned urban growth in Uttarakhand is not only diminishing natural resources and disrupting the bio-system services, but also increasing the socio-economic and environmental inequality both within the towns and in their surrounding per-urban zones. Besides, the rapid and unplanned urban growth is also increasing the vulnerability of intensively changed and densely populated weak gradients to the active processes of right of way and landslides.

The prejudgment in cash flow for important economy segments is another instance where the financial institutions prefer to provide support specific to districts of plain terrain and abstain from taking unnecessary risks in the rough terrain of hilly districts. In this particular process, the crack in the economy and sustainable growth is bound to increase. As a result, one is unable to visualize the progress made towards developing employment opportunities in non-farm sectors like MSME industries for most of the urban areas. Agriculture ancillary products and services need a new policy to improve their outcome and effectiveness. Projects like carbon sequestration projects should be

promoted in the state as they will create sustainable waste management and the pollution level will come down and employment opportunities will be available. The tourism framework as outlined in the Tourism Policy of the State needs to be updated with market expectations in a given period with the development of eco-tourism sector. This will increase opportunities for local population by getting decent jobs and halt migration. Promotion of Public Private Partnership both in tourism, transport system and MSME segment is needed to bring in private investment in the state. As Uttarakhand is having a huge potential of Hydro Power generation, one needs to exploit it.

Hydroelectricity has always been one of the meters of development of the modern society. Implementation of hydro power plants can lead to various aspects that can aid in economic development and growth of society and local sociology and ecology. Throughout history, man has been harnessing the raw potential of nature to his aid; hydropower is one of the shining examples of this. By using the natural resource to its maximum potential, the researchers can ensure that proper growth and evolution of society will take place. Hydropower ensures sustainable development and a manageable future for the next generation.

This article argued that when the theory of complexity is combined with urban development, then new insights on the urban sustainable development debate arise. This sort of insight will vary geographically, and the identified challenges will also defer.

The behavior of natural and human systems in the world is complex, and so complexity is central to the urban sustainable development argument. Even though scientific research will continue to deepen one's understanding of natural systems, the complexity and non-linearity of global urban biogeochemical systems raise serious concerns about the prospects of policy approach to urban sustainable development based on predictive modelling, optimization, and finding the one right answer. The underlying complexity also allows for the emergence and persistence of many perspectives on what sustainability entails and the policies required to achieve it. The quest for a single concept of sustainable development will thus remain unsuccessful.

References

[1] (HPEC), The High Powered Expert Committee. (2011). Report on Indian Urban Infrastructure and Services. New Delhi: Ministry of Urban Development.

[2] ADB. (2009). Changing Course : A new Paradigm for Sustainable Transport. Asian Development Bank.

[3] Al-Dahmashawi, D., Hassan, D., Sabry, H., & Mahmoud, S. (2014). Incorporating social sustainability themes in the built environment. J AM Sci, 141-151.

[4] Awasthi, I. C., & Awasthi, B. (2016). Uttarakhand: Livelihood Constraints and Policy Options. International Journal on Arts, Humanities, Social Sciences & Business Studies, 1(2), 1-13.

[5] Awasthi, I. C., & Dev, N. (2015, September). Poverty and Gender Analysis of Uttarakhand:. Lucknow, Uttar Pradesh, India: Giri Institute of Development Studies.

[6] Borsdorf, A., Tappeiner, U., & Tasser, E. (2010). Mapping the Alps. In A. Borsdorf, G. Grabherr, K. Heinrich, B. Scott, & J. Stötter, Challenges for Mountain Regions, Tackling Complexity (pp. 186-191). Vienna: Bohlau.

[7] Briassoulis, H. (2001). Sustainable development and its indicators: through a (planner's) glass darkly. Journal of Environmental Planning and Management, 409-425. doi: 10.1080/09640560120046142

[8] Bryman, A. (2012). Social Research Methods. Oxford Publishers.

[9] Buytaert, W., Cuesta-Camacho, F., & Tobón, C. (2011). Potential Impacts of Climate Change on the Environmental Services of Humid Tropical Alpine Regions. Global Ecology and Biogeography, 19-33.

[10] Colantonio, A., & Dixon, T. (2011). Urban regeneration and social sustainability best

practice from European cities. London: Wiley-Blackwell.

[11] CSIS. (2011). Seizing the opportunities in Public Private Partnerships. Centre of Strategic and International Studies, www.csis.org.

[12] Durga Rao, K., Rao, V., Dadhwal, V., & Diwakar, P. (2014). Kedarnath Flash Floods: A Hydrological and Hydraulic Simulation Study. Current Science, 598-603.

[13] GHK International. (2007). City Development Plan. Dehradun: Government of Uttarakhnad.

[14] Hidalgo, D. a. (2013). Implementation of sustainable urban transport in Latin America. Research in Transportation Economics, 40, 66-77.

[15] Hikmat H., A., Yamen N., A.-B., & Hadeel S., A.-Q. (2019). Effects of urban form on social sustainability – A case study of Irbid, Jordan. International Journal of Urban Sustainable Development, 1-20. doi:10.1080/19463138.2019.1590367

[16] HPEC. (2011). Report on Indian Infrastructure & Services. High Powered Expert Committee, Ministry of Urban Development, Government of India.

[17] Huddleston, B., Ataman, E., & d'Ostiani, L. (2003). Towards a GIS-based Analysis of Mountain Environments and Population. Environment and Natural Resources, United Nations.

[18] IEA. (2012). Global Land Transport Infrstructure Requirements Estimating road and railway infrastructure capacity and costs to 2050. International Energy Agency. www.iea.org.

[19] J.D., I. (1989). Deforestation in the Himalaya: The Cause of Increased Flooding in Bangladesh and Northern India. Land Use Policy, 6, 187-193.

[20] Jandl, R., Borsdorf, A., van Miegroet, H., Lackner, R., & Psenner, R. (2009). Global Change and Sustainable Development in Mountain Regions. COST Strategic Workshop, Innsbruck University. Innsbruck: COST Strategic Workshop, Innsbruck University Press.

[21] Jaswal, S. (2014). Role of Tourism Industry in India's Development. Journal of Tourism Hospitality. doi:10.4172/2167-0269.1000126

[22] Kumar, A., Verma, S., Ghosal, A., & Biswas, S. (2018). Opportunities and Critical Success Factors for Economic Development of Uttarakhand due to Implementation of Hydro Projects. Journal of Advance Management Research, 10-15.

[23] Lall, K. (2015, 7 9). Swajal Uttarakhand. Retrieved from http://swajaluttarakhand.blogspot.com/2015/07/urwss-project-flag-bearer-of-swap-case.html

[24] Little, A. D. (2011). The Future of Urban Mobility : Towards Networked, Multimodal Cities of 2050. www.adl.com/URban_Mobility.

[25] Li-Yin, S., J. Jorge, O., Mona, N. S., & Zhang, X. (2011). The application of urban sustainability indicators - A comparison between various practices. Habitat International, 35, 17-29.

[26] Mckinsey. (2010). India's Urban Awakening : Building Inclusive Cities, Sustaining Economic Growth. Mckinsey Global institute.

[27] Meybeck, M., Green, P., & Vörösmarty, C. (2001). A New Typology for Mountains and Other Relief Classes: An Application to Global Continental Water Resources and Population Distribution. Mountain Research and Development, 34-44.

[28] Mishra, B., Nautiyal, A., Kumar, A., Pandey, D., Yaqoot, M., & Santosh, H. (2018, January). Review of Policies, Programs and Initiatives regarding Growth and Development of Hydropower in India with special reference to State of Uttarakhand. International Journal of Management Studies, 62-68. doi:10.18843/rwijms/v5i1(1)/10

[29] MoUD. (2006). National Urban Transport Policy. Ministry of Urban Development, Government of India.

[30] Nations, U. (2013). World Economic and Social Survey 2013: Sustainable Development Challenges. New York: Department of Economic and Social Affairs of the United Nations.

[31] P. Mamgain, R., & Reddy, D. (2014). OUTMIGRATION FROM HILL REGION OF UTTARAKHAND: Magnitude, Challenges and Policy Options. Hyderabad: National Institute of Rural Development and Panchayati Raj.

[32] Prakash C, T., Abhinav, T., & Bhagwati, J. (2018). Urban Growth in Himalaya: Understanding the Process and Options for Sustainable Development. Journal of Urban and Regional Studies on Contemporary India, 4(2), 15-27.

[33] PWC. (2016). Mussorie Dehradun Development Authority. Retrieved 2019, from Dehradun Smart City Proposal: https://mddaonline.in/downloads/schemes/draft_proposal.pdf

[34] Rai, S., & Sharma, E. (1998). Comparative Assessment of Runoff Characteristics under Different Land Use Patterns within a Himalayan Watershed. Hydrol Process, 12, 2235–2248.

[35] Rawat, J. (2009). Saving Himalayan Rivers: Developing Spring Sanctuaries in Headwater Regions. In B. Shah, Natural resource conservation in Uttarakhand (pp. 41-69). Haldwani: Ankit Prakshan.

[36] (2018). Report of Working Group II Sustainable Tourism in the Indian Himalayan Region. New Delhi: NITIAAYOG.

[37] Seabrooke, W., Y., & Ma, M. F. (2004). Implementing sustainable urban development at the operational level (with reference to Hong kong and Guangzhou). Habitat International, 28, 443-465.

[38] Selman, P. (1999). Three decades of environmental planning: what have we really learned? In M. K. Meadowcroft, Planning sustainability. London: Routledge.

[39] Shephard, J., Harden, A., Rees, R., Brunton, G., Garcia, J., Oliver, S., & Oakley, A. (2006). Young people and healthy eating: a systematic review of research on barriers and facilitators. Health Education Research, 239-257.

[40] Singh, P., Chani, P., & Parida, M. (2014). Assessing The Performance Of Public Transport Operation In Dehradun. Journal of Environmental Research And Development, 8(4), 1021-1025.

[41] Smart City Dehradun. (2017). MDDA. Retrieved from http://smartcities.gov.in/upload/uploadfiles/files/Annexures_Dehradun.pdf

[42] Tambe, S., Kharel, G., Arrawatia, M., Kulkarni, H., Mahamuni, K., & Ganeriwala, A. (2012). Reviving Dying Springs: Climate Change Adaptation Experiments From the Sikkim Himalaya. Mountain Research and Development, 32(1), 62-72.

[43] UNEP. (2002). United Nations Environment Programme—World Conservation Monitoring Centre. Nairobi: Mountain Watch: Environmental Change and Sustainable Development in Mountains.

[44] Valdiya, K., & Bartarya, S. (1991). Hydrological Studies of Springs in the Catchment of Gaula River, Kumaon Lesser Himalaya, India. Mountain Research and Development, 17-25.

[45] Vallance, S., Perkins, H., & Dixon, J. (2011). What is social sustainability? A clarification of concepts. Geoforum, 342-348.

[46] Verbruggen, H., & Kuik, O. (1991). Indicators of sustainable development: an overview. In H. Verbruggen, & O. Kuik, In search of indicators of sustainable development.

[47] Viviroli, D., Dürr, H., Messerli, B., Meybeck, M., & Weingartner, R. (2007). Mountains of the World, Water Towers for Humanity : Typology, Mapping, and Global Significance. Water Resource Research, 43(7), 1–13. Retrieved from http://onlinelibrary.wiley.com/ http://onlinelibrary.wiley.com/

[48] Vladimir, S., Annette, E., & Evans, T. J. (2016). Assessment of the Economic, Social and Environmental Dimensions of the Indicators for Sustainable Development. Sustainable Development. doi:10.1002/sd.1649

[49] WG 12th FYP. (2011). Recommendations of Working Group for 12th Five YEar Plan. Planning Commission, Five YEar Plan Documents, Government of India.

[50] World Bank. (2013). Urbanisation beyond Muncipal Boundaries- Nurturing Metropolitan Economies and connecting Peri-Urban Areas in India. Washington,D.C.: World Bank.

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The Commuting Behavior and Perception Correlates of Commuting Trips: A Comparative Study on the Egyptian and Migrant Populations in Cairo and Alexandria

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ABSTRACT

Recent political conflicts in the Middle East have led to a significant increase in refugees' numbers in Egypt, causing a substantial population increase in neighborhoods like Al-Rehab City and the 6th of October. The resulting semi-hybrid communities have had a notable impact on travel behavior in these areas. Due to the economic impact that is affected by this travel behavior, this study aims to investigate the commuting behaviors and preferences of individuals in Cairo and Alexandria, focusing on demographic groups such as Egyptians and migrants. The research addresses two main questions: (1) What significant variations exist in commuting characteristics between Egyptians and migrants based on their social and cultural backgrounds, and what variables influence the travel behavior of these two groups? (2) What factors relate to public transport use, that map all aspects of work/home trip choices that affect the daily commuting distances? Initially, to find the significant differences between both test groups, a questionnaire was designed and distributed through a sample of 1,810 face-to-face interviews (1,193 in Cairo and 617 in Alexandria). The questionnaire comprised 39 questions, these questions are covered in six sections that cover the following aspects: sociodemographic and household profiles, mobility habits, commuting habits and preferences, perceptions of public transportation, ridesharing, and housing. In the data analysis stage, a non-parametric statistical test "The Mann–Whitney U test" is used to determine if there is a difference between both groups according to certain variables. To examine the relationship between subjective public transport utilization and commuting trip generation, a multivariate Ordinary Least Squares (OLS) model was applied. The model application provides valuable insights for the formulation of impactful urban and mobility systems. Drawing a road map to help policymakers in enhancing public transport infrastructure to better match the preferences of commuters, ultimately fostering safer and more gratifying travel experiences.

Index-words: *Urban Transportation Planning, Travel Behavior, Commuting, Land Use Planning, Migrants, Egypt.*

I. INTRODUCTION

Traffic congestion is considered a major concern in urban areas, as it negatively affects the quality of life of the citizens. As the main approach worldwide is directed to utilize public transportation and group mobility to maintain a better sustainable environment, the private car remains the predominant mode of transportation.

After the political changes occurred in the MENA region due to wars and forced refugees that fled to the neighboring countries, such as Syrians and Sudanese, an urgent need evolved concerning

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the transportation decisions for a new population configuration. In Egypt, the presence of refugees is welcome to merge with the rest of the Egyptians freely; they are not restricted to a certain geographical location, neither gated communities nor ghettos. However, their presence with their distinct political status, social background, and economic conditions affected their travel decisions and their travel behavior.

With the new population structure, attention should be given to new users' requirements that evolves due to the new variation.

This research compares the Egyptian and migrants/refugee populations in their commuting behavior according to their perception of their physical environment. After interviewing the head of the transportation authority in Alexandria and after referring to the reports published by Transportation for Cairo in 2021 [1] for 6th of October studies done in the neighborhoods with most immigrants occupied, it was found that the public transportation dependency increased due to the accumulation of the immigrants' settlements in the mentioned areas since 2011 [2]. However, the pattern of use and the chosen mode of transportation/mobility needed more investigation to spot the change due to the user/demographic alteration according to the additions that took place in the sample population, which will help readjust the decisions concerning the transport/mobility in the study area.

In historic urban fabrics that are still standing today, the urban districts have been growing without control to meet the needs of the contemporary lifestyle leading to the formation of streets that were only meant for pedestrians and primitive transportation. Therefore, the connection between such areas and public transportation is weak and not easily accessible, and these areas suffer from major traffic problems due to the rapid motorization increase. In such cases, re-planning the streetscape and road rearranging is a must to further develop the accessibility to public transit [3].

In developed countries, some factors influence the generation of commuting trips. Firstly, the proximity and accessibility of workplaces play a role. When workplaces are together in connected urban areas, people tend to choose sustainable modes of transportation like walking, cycling, or public transportation instead of relying on long car commutes. Secondly, the way cities plan their infrastructure and design their spaces has an impact on commuting patterns. Cities that have public transport systems and pedestrian-friendly layouts encourage people to make eco choices and reduce their reliance on cars by opting for greener travel options. A case study conducted on a sector of commuters from Palestine [4] proved that the lack of awareness toward the negative impacts of single-occupancy vehicles and fuel compassion for the environment on the other hand there is a strong support from the commuters toward the developing strategies for sustainable transportation system.

According to a case study-based research about urban sprawl and travel patterns in Iran, the increase in age and the number of driving licenses in households and the use of motorized means in commuting and non-commuting travel all are correlated with the increased probability of urban sprawl in Hamedan. This shows that people on sprawled areas would pick private cars over public transit, unlike people in compacted areas. The results in Nowshahr are like those of Hamedan, linking urban sprawl with an increase in the number of cars in households and the dependency on them over public transit [5].

Economic factors also play a role. When people have high incomes, they can afford the luxury of living near their workplaces. This reduces the need for commutes. It gives them easy access to employment places [6]. Additionally, with increasing awareness, there is a growing preference for eco-commuting options such as electric vehicles and well-established public transportation networks. Commuter's choices for a transport mode are not only affected by objective factors like cost and time but also affected by subjective feelings of safety, comfort, flexibility, and convenience of different modes. When it is not hard to change the policies related to transport time and cost, it is easier to adjust some subjective feelings. [7].

Changes in culture, perceptions, and technology all contribute to how commuting has evolved. As cultural norms continue to emphasize the importance of maintaining a work-life balance and being environmentally conscious, one's attitudes towards commuting are shifting. This in turn affects the mode of transportation he/she chooses [8]. Furthermore, having a view of the safety, convenience, and affordability of transportation is also influential in encouraging people to use it instead of their private vehicles. According to a study done at the Imperial College London, using data

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from 28 world cities, about the gender differences in the perception of safety using public transportation, women are 10% more likely to feel unsafe in metros, and only 45% of women feel secure in metro stations and 55% in buses. These are averages of respondents from 28 cities, and they may differ in different contexts influenced by religion, cultural ideologies, habits, etc. of a specific city [9].

According to research by Maye Ehab, women in Egypt are suffering from a gender gap as they do not have the geographical mobility of men. However, there are other factors affecting women's commuting in Egypt, for example, women with more responsibilities have longer commutes than those who have fewer responsibilities, also married women have shorter commutes than single women [10].

Moreover, advancements in technology have introduced options, like ride-sharing services and electric scooters that provide alternatives and may reduce the frequency of driving alone [11], which already have been applied in rideshare applications like "Uber and Didi" in Egypt where they added the option of electric scooters in their ride-sharing trip options.

In a country such as India (developing country), various factors contribute to the number of trips people make for commuting. These factors include conditions, the availability of infrastructure, and urban planning. When cities experience growth and development (urban sprawl) it often leads to commutes due to increased distances between residential areas and workplaces. Insufficient public transportation options and heavy traffic congestion can also lead individuals to rely on vehicles for their commuting [12].

The Middle East is generally rated fifth out of eight regions of the whole world for transportation. However, it is rated last for environmental indicators and second-last for social indicators. The poor environmental rates are due to the high rating of pollutants and the highest land area used for transit (20%). Also, the Middle East has the second least affordable systems. The lack of consistent data also helps limit studies of sustainable mobility, and that must be improved for future developments in the area [13].

In Egypt, where the infrastructure and living conditions are still developing, several factors play a role in shaping how people commute. The expansion of areas and the population density often result in distances between residential areas and workplaces. Limited public transportation options and traffic congestion contribute to relying on vehicles or informal modes of transport, which in turn affects commuting patterns. Additionally, unfortunate economic limitations and the lack of housing near workplaces make individuals want to seek accommodation in far areas resulting in longer travel times. Moreover, in today's challenging climate, the high occurrence of a weak economy results in bad working schedules and the need for individuals to have multiple jobs. Therefore, commuting patterns become complex and diverse. [14].

The transportation infrastructure of both cities goes back to decades and even centuries, making a very complicated network of transportation, for example, the first railroads in Africa and the Middle East, and the second in the whole world after England [15]. The infrastructure of transportation, of course, goes way beyond that, especially with the latest projects focusing mainly on mobility and, supposedly, improving road conditions. All to match and satisfy the needs of the population that are formed under the influence of culture-induced behavior, leading to longer commuting time because of the culture's role in choosing a house location in Egypt.

The commuting trips in the collected data were based on the essential daily trips, which are mostly homework. Residential self-selection is the freedom of the user to choose their housing unit [16]. Extensive literature addresses the issue of residential self-selection yet the knowledge concerning residential self-selection based on population typology and the effect on their travel behavior is far from complete [17]update earlier work, include additional outcome measures, and address the methodological issue of self-selection. Methods: We computed elasticities for individual studies and pooled them to produce weighted averages. Results and conclusions: Travel variables are generally inelastic with respect to change in measures of the built environment. Of the environmental variables considered here, none has a weighted average travel elasticity of absolute magnitude greater than 0.39, and most are much less. Still, the combined effect of several such variables on travel could be quite large. Consistent with prior work, we find that vehicle miles traveled (VMT. In Egypt, the housing system is largely market-oriented. In market-oriented housing, many factors such as a lack of affordability limited

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housing options, and low accessibility, may prevent households from choosing a convenient distance between home and work and affect their travel preferences [18], [19]. It is important here to refer to the term 'spatial mismatch' that was proposed by [20], which addressed low-income households and their distant segregation from suitable job opportunities. In this aspect, he addressed black Americans as a disadvantaged minority.

As public transportation is inevitably not as accessible as the door-to-door options, it still needs improvements to be more accessible. Additionally, it is significant to encourage people to use sustainable public transportation through better service quality and safety perception as they crucially affect the perceived accessibility and ease of use leading to the connection between using the public (sustainable) transport system and achieving the comfort and ease of living desired by the users [21].

Since Kain (1968) [20], proposed the concept of "spatial mismatch", many studies have been conducted to measure the degree of spatial mismatch and its impact on employment outcomes. However, a gap is found regarding the effect of the mismatch concept on the refugees/migrants' settlements and the effect on their travel behavior [22].

This research suggests that spatial mismatch is related to residential self-selection on the one hand and commuting behavior due to users' perception on the other hand. In this regard, in the past few decades, Greater Cairo and Alexandria have experienced rapid urbanization and socio-spatial transformation. Many new settlements have been moved out to the suburbs and new gated communities emerged [23]. However, Alexandria did not go through the vast urban sprawl that Cairo faced. There are differences between both cities in terms of residential densities and distributions. Both cities had most of the immigrants/refugees choosing the suburbs and perimeter because they could not afford the high housing prices in inner cities which provide a spatial mismatch status [24]. A knowledge gap that this study covers is that data-driven travel behavior about land use as well as individuals' needs and perceptions have not been addressed in the countries in the Middle East and North Africa (MENA) region. Thus, this study is built on this gap by addressing the issue and using disaggregate, primary data collected in two large cities in Egypt, namely Cairo and Alexandria.

This paper adapts a methodology commonly used in travel behavior research. The research discusses the determination of the individual and alternative-specific variables that affect commuter's choice of a specific transportation mode. In the following sections, this paper will report on first, the reasons that control a commuter's decision to make a trip and the choice of a transport mode. Second, the strategies used to elicit the variables considered in the survey. Third, explain the methodology used to analyze the data. Fourth, finding the significant differences between the commuting characteristics of Egyptians and migrants. Finally, representing the limitations of the research and recommendations for future research.

This paper aims to give a thorough insight into transportation in Egypt in a comparative study between Egyptians and migrants, particularly in Cairo and Alexandria, to provide usable data and outcomes that help in getting closer to achieving the ultimate goal - Sustainable Urban Mobility. Also, helping the business sector associated with transportation with an insight of the market that could open the field for new opportunities or investments that would change the way transportation is used and perceived from the local point of view.

All are discussed in this paper in the following sections, respectively. The first section, Methodology, discusses the research questions and hypotheses, explains the choice of these two cities (Cairo and Alexandria) specifically, introduces their transportation infrastructure and travel behavior, discusses data collection, sample size and representativeness of the data, and discusses the analysis methods by which the data are to be put into results and be usable. The second section, Findings, includes commuting characteristics of Egyptians and migrants and shows how subjective public transport use correlates with commuting trip generation. The third section, Discussion, explains the difficulties of collecting data in both cities, and the variables that were not included in the data collection but could have been used in this research or for future research. The fourth section, Conclusion, includes a summary of the whole paper, the findings, and recommendations for planning and future research. The fifth and final section, References, is where all the sources used in the paper are stated in detail according to their mention in the paper.

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II. METHODOLOGY

A. Research Questions and Hypotheses

This study is based on two research questions (RQ): (1) Are there significant differences between the commuting characteristics of Egyptians and migrants? (2) What are the subjective public transport use correlates with commuting trip generation among Egyptians and migrants? In this study, it is hypothesized that there are significant differences between the commuting behavior and the related perceptions of Egyptians and migrant populations of Cairo and Alexandria. This might be true about the way these two sociodemographic groups use public transportation and perceive it.

B. Case Study

Cairo and Alexandria – the targeted cities of the research – are chosen to depend on and to be guided by several specific contextual factors, one of which is the diversity of their residents (ethnicity, religion, gender, etc.), so that a generic picture can be concluded with great accuracy. Another factor is the population in both cities (9.54 million in the capital Cairo in 2017, and 5.6 million in Alexandria) [25], making them a strong base to form a general and well-diversified sample to obtain maximum accuracy for the study. Also, these two cities are the ones with the most complicated network of transportation either with the formal means of transportation (buses, trams, railroads, etc.) and especially Cairo where two of the most complicated, expensive, important, and biggest transportation projects take place, which is the metro and the monorail, making the city well worth the study to draw upon and become a great source of the required data for the study. Another reason encompasses cultural attributes, geographical considerations, societal attitudes, land use patterns, and migration influx, where both cities resemble the main destination for the influx of migrants. These distinct qualities of both cities serve as a valuable case study for examining the factors that influence commuting patterns among Egyptians and migrants. By investigating the distinct qualities of these two groups, one can gain a deeper understanding of how various factors contribute to differences in the commuting behavior for both groups selected for this study.

1. Data and Variables

The dataset collected in this research was obtained from a mobility survey conducted within two prominent cities in Egypt: Cairo, and Alexandria. The time interval for data collection for the Cairo case study spanned over three months, from November 2022 to January 2023. The data for the city of Alexandria was collected during an interval of six months, which is from November 2022 to May 2023. The neighborhoods selected in Cairo and Alexandria for this study encompass three main criteria: (1) one near the city center, which is compact or located near the historical core, (2) a semi-grid iron street network, (3) and near the city boundaries with lower densities that incorporates grid-iron planning which is prepared for car use.

The criteria adopted in this study include selecting those neighborhoods which have a high concentration of migrants/refugees. For instance, in Cairo, the following neighborhoods were selected: 6th of October (Giza Governorate), El Rehab City (New Cairo), and Hadayek El Qoba (Cairo). According to Kabbani (2018), [26] those neighborhoods have a high concentration of refugees. While neighborhoods selected for Alexandria are also neighborhoods of high concentration of migrants/refugees. Selected study neighborhoods within Alexandria, namely Fouad Street in the historic downtown area, and Abu Keir, characterized as a moderately populated urban neighborhood with a middle-class demographic.

The survey results are obtained from 1,810 face-to-face interviews, 1532 Egyptian and 287 migrants. 1,193 questionnaire interviews were conducted in Cairo and 617 in Alexandria. The survey distribution process covered a wide range of various group characteristics. The surveys answered by Egyptian and emigrant respondents varied between males and females from different age groups. Although the data showed the employment state of the respondents whether they were employed, non-employed, or self-employed, the dataset had a homogeneous group of different education qualifications, high school students, undergraduate students, master's students, and Ph.D. students.

The margin of error of sample size collected for Cairo and Alexandria are 2.84% and 3.95%, respectively, according to the overall population in 2022 and the adult population of both governorates. The overall population of Cairo and Alexandria Governorates are 10,100,166, and 5,469,480, respectively [27]. The adult population is 4,720,227 in Cairo, and 2,452,602 in Alexandria according to the 2017 census [27].

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The data collected were based on a questionnaire which comprised 39 questions. These questions are covered in six sections that cover the following aspects: Sociodemographic and household profiles, mobility habits, commuting habits and preferences, perceptions of public transportation and ridesharing, and housing. Some of the questions employed in this study are: How many commute trips did you have during the past seven days? How much time do you typically spend commuting on a weekday? How long is an ideal commuting time for you per day? And how long is the maximum time are you willing to commute per day? The responses to the previously mentioned questions were in minutes. In addition to questions related to commuters' satisfaction and perception, for instance: If you commute, how satisfied are you with your commuting? And questions on perception towards public transport which measure perceived level of security. Questions on satisfaction and perception were answered using a numerical scale from 0 to 100, in which "0" is the worst, and "100" is the best.

The overall variables generated from this questionnaire are 39 variables, of which nine questions were on commuting determinants, and nine questions on perception of security. The data exploration phase initiated with the trip generation variable along with the other 12 variables. Six variables were eliminated during an iteration process in which the other six variables were considered for this study, which will be further elaborated in the analysis section.

The variables were quantified according to the methods elaborated in Table I. In the sociodemographic sections, which are composed of questions on age, gender, employment, and nationality, the nationality variable is quantified in this study as "0" for Egyptians, and "1" for migrants.

A continuous rating scale is adopted in this study, where the respondent chooses a number from 0-100 for the nine questions on the perception of security. This scale represents the level of satisfaction of the respondent, where "0" represents the lowest satisfaction level, and "100" represents the highest satisfaction level. The range utilized in this study allows respondents to make more precise decision-making. Also, it enhances the level of reliability of the adopted method [28]. Moreover, it contributes to the possibility of obtaining normally distributed data, which allows for the application of a wide range of statistical processes (i.e., Regression, t-test, ANOVA, …etc.) [29]. Specifically, it is suitable for performing statistical analysis that requires parametric data, or when sufficient variance in data is required [30]. The range adopted in this study is nlike the 5-point Likert scale which may result in little variance in data and hence may limit the potential range of statistical procedures [30]. Unlike the 5-point Likert scale which usually generates ordinal data and limits the range of statistical analyses and procedures that could be utilized [28], [30]. The descriptive statistics of the continuous variables in the study are illustrated in Table II. whereas the values of N., Mean, Std. Deviation, Minimum, and Maximum are presented.

TABLE I
STUDY VARIABLES, UNITES, TYPES, AND QUANTIFICATION METHODS

Variable	Type of variable	Quantification Method
Trip generation for commuting purposes (dependent variable to be investigated)	Continuous	The reported number of trips by the respondent during the seven days before the survey collection date.
Age	Continuous	The reported age of the respondent.
Household car ownership	Continuous	The reported number of cars owned by the household members.
Household size	Continuous	The number of household members reported by the respondent.
Time for the commuting trip on weekdays	Continuous	The reported typical number of minutes of commute time spent by the respondent during weekdays.
Ideal time for the commuting trip per day	Continuous	The reported number of minutes of the ideal commuting time according to the respondent.
Satisfaction of commuting	Continuous	The reported number is based on a numerical scale of satisfaction from 0 to 100. In which 0 is the lowest level of satisfaction, and 100 is the highest level.

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Willingness to spend time commuting (max.)	Continuous	The reported number of minutes that the respondent is willing to spend on daily commutes.
Commuting expenses per month (EGP)	Continuous	The reported expenses number of Egyptian pounds on commuting per month.
Evaluation of the quality of buses and minibuses	Continuous	The reported evaluation using a scale from 0 to 100. Where 0 is the worst quality, and 100 is the best quality.
Perceived security when using public transportation	Continuous	The reported perception using a scale from 0 to 100.
Perceived security when uniformed guards or security forces are near the PT station/stop	Continuous	The reported perception using a scale from 0 to 100.
Perceived security when the stations/stops are well-lit	Continuous	The reported perception using a scale from 0 to 100.

TABLE II
THE DESCRIPTIVE STATISTICS OF THE CONTINUOUS VARIABLES IN THE STUDY

Variable	*N*	*Mean*	*Std. Deviation*	*Minimum*	*Maximum*
Trip generation for commuting purposes during the past seven days	*1548.00*	*6.33*	*4.25*	*0.00*	*28.00*
Commuting trip time on weekdays	*1481.00*	*46.91*	*53.01*	*0.00*	*400.00*
Ideal commuting trip time per day	*1449.00*	*32.32*	*38.80*	*0.00*	*400.00*
Satisfaction of commuting	*1544.00*	*60.26*	*29.71*	*0.00*	*100.00*
Willingness to spend time commuting (max.)	*1521.00*	*53.12*	*48.71*	*0.00*	*400.00*
Commuting expenses per month	*1528.00*	*1126.56*	*1209.42*	*0.00*	*20000.00*
Nationality-Binary	*1810.00*	*0.15*	*0.36*	*0.00*	*1.00*
Age	*1409.00*	*27.51*	*9.73*	*13.00*	*78.00*
Household car ownership	*1409.00*	*1.52*	*1.28*	*0.00*	*8.00*
Household size	*1409.00*	*4.29*	*1.59*	*0.00*	*14.00*
Evaluation of the quality of buses and minibuses	*1409.00*	*43.69*	*28.39*	*0.00*	*100.00*
Perceived security when using public transportation	*1409.00*	*53.12*	*34.08*	*0.00*	*100.00*
Perceived security when uniformed guards or security forces are near the PT station/stop	*1409.00*	*67.35*	*33.23*	*0.00*	*100.00*
Perceived security when the stations/stops are well-lit	*1409.00*	*69.58*	*32.52*	*0.00*	*100.00*

TABLE III
THE RESULTS OF KOLMOGOROVE-SMIRNOV AND SHARIPO-WILK TESTS OF NORMALITY

Variable	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	P	Statistic	df	P
Trip generation for commuting purposes during the past seven days	0.207	1331	<0.001	0.878	1331	<0.001
Commuting trip time on weekdays	0.217	1331	<0.001	0.685	1331	<0.001
Ideal commuting trip time per day	0.248	1331	<0.001	0.623	1331	<0.001
Satisfaction of commuting	0.157	1331	<0.001	0.925	1331	<0.001
Willingness to spend time commuting (max.)	0.219	1331	<0.001	0.793	1331	<0.001
Commuting expenses per month	0.170	1331	<0.001	0.713	1331	<0.001

a. Analysis Methods: To solve the first research question, about finding the significant differences between the commuting characteristics of Egyptians and migrants, a nonparametric method (Mann–Whitney U) was employed since the results of the normality tests (Shapiro–Wilk (SW) and Kolmogorov–Smirnov (KS)) proved the non-normality of all the commuting variables ($p<0.001$), as presented in Table III. These results declined the null hypothesis of the normality of the commuting variables through Egyptians and migrants. The Mann–Whitney U test evaluates a null hypothesis that the probability distribution of a randomly drawn observation from the Egyptian group is the same as the probability distribution of a randomly drawn observation from the migrants' group against an alternative that those distributions are not equal. The commuting variables which are presented in Table II were input as the Mann–Whitney U test variables list, and they were grouped according to nationality-binary as Egyptians were coded "0" and migrants were coded "1".

Regarding the second research question, which inquiries about the correlation between subjective public transport use and commuting trip generation for Egyptians and migrants, a multivariate Ordinary Least Squares (OLS) model was employed for commuting trip generation as the dependent variable three times (for overall, Egyptian, and emigrant's samples). The Twelve variables presented in Table I were defined as independent variables of the model, and after running six iterations, the most efficient model was generated with the highest R^2 value. Three variables of age, household car ownership, and household size were controlled. Four subjective variables of evaluation of the quality of buses and minibuses, perceived security when using public transportation, when uniformed guards or security forces are near the public transportation (PT) station/stop, and when the stations/stops are well-lit were tested. The variables of $p<0.001$, $p<0.05$, and $0.10>p>0.05$ were taken as highly significant, significant, and marginally significant predictors, respectively. The five insignificant variables that were disregarded from the model were possession of an individual driving license, public transport use, gender, perceived security when there is surveillance by cameras, and commuting to work or study place most of the day, respectively.

2. Results

a. Commuting Characteristics of Egyptians and Migrants: The Mann-Whitney U test demonstrates intriguing results regarding the significant differences in commuting characteristics for Egyptians and migrants. As a non-parametric test, it represents the difference between the mean rank of the commuting variables across Egyptians and migrants. Table IV displays the mean rank of the commuting variables for Egyptians and migrants. In contrast, the mean rank of willingness to spend time commuting is significant ($p<0.05$) for Egyptians and migrants. At the same time, it is highly significant ($p<0.001$) for all other commuting variables among Egyptians and migrants. As illustrated in Table IV, migrants generated more commuting trips during the past seven days than Egyptians, and they are more satisfied with commuting than Egyptians. While Egyptians spend more time commuting on weekdays, their ideal commuting trip time per day is higher than migrants. They are willing to spend more time commuting than migrants, and they spend more money on commuting per month than migrants.

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TABLE IV
THE RESULTS OF THE MANN_WHITNEY U TEST FOR EGYPTIANS AND MIGRANTS

Nationality-Binary		N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	P (2-tailed)
Trip generation for commuting purposes during the past seven days	Egyptian	1299	748.59	972421.5	128071.5	972421.5	-5.252	<0.001
	Migrants	249	909.66	226504.5				
	Total	1548						
Commuting trip time on weekdays	Egyptian	1236	763.40	943557.5	123728.5	153863.5	-4.542	<0.001
	Migrants	245	628.01	153863.5				
	Total	1481						
Ideal commuting trip time per day	Egyptian	1209	746.97	903090.5	118514.5	147434.5	-4.515	<0.001
	Migrants	240	614.31	147434.5				
	Total	1449						
Satisfaction of commuting	Egyptian	1297	741.47	961692.0	119939	961692	-6.301	<0.001
	Migrants	247	935.42	231048.0				
	Total	1544						
Willingness to spend time commuting (max.)	Egyptian	1274	775.65	988184.0	138669	169297	-2.970	0.003
	Migrants	247	685.41	169297.0				
	Total	1521						
Commuting expenses per month	Egyptian	1283	787.90	1010882.0	127139	157274	-4.750	<0.001
	Migrants	245	641.93	157274.0				
	Total	1528						

b. Subjective Public Transport Use Correlates with Commute Trip Generation: Findings of the most efficient multivariate OLS model involve four significant subjective variables and three controlled variables for the three models of the overall sample, Egyptians, and migrants. The independence of subjective variables was tested using the Collinearity Statistics test, which validated the model because all the variables were independent (5>VIF>1). Furthermore, the models were validated by ANOVA – F Test which reported significant p-values ($p<0.001$) as presented in Table V. Regarding the R2-value, the OLS model for migrants works better than the other two models because the R2-value is finer. The R2 shows how much the model predicts the variability for the dependent variable. 18.7 % of the variability of the commute trip generation per week is defined by this model, and it is highly related to public transportation. This means that the subjective measures of public transportation can explain the commuting trip generation per week of migrants better than the Egyptians because they are more dependent on public transportation.

Regarding the results of the overall sample model, the evaluation of the quality of buses and minibuses, and perceived security when using public transportation are significant subjective variables ($p<0.05$). While the perceived security when uniformed guards or security forces are near the PT station/stop, and when the stations/stops are well-lit are highly significant variables ($p<0.001$). Table V indicates that the increase of one scale of evaluation of the quality of buses and minibuses is correlated with a 9.2% reduction in commuting trips per week. Unlike the perceived security when using public transportation, that scale unit is correlated with a 13.8% increase in commuting trips per week. Perceived security when uniformed guards or security forces are near the PT station/stop is highly significantly correlated positively with commuting trip generation. The increase of one unit of it is correlated with a 26.3% increase in commuting trips per week. This means that the more people feel secure because of the presence of uniformed guards or security forces near the PT station/stop, the more they commute per week, which is logical. Finally, the perceived security when the stations and stops are well-lit is highly significant negatively with the number of commuting trips per

week; its scale unit increase was correlated with a 21.1% decrease in commuting trips per week. This seems counterintuitive because the respondents' perceptions of security may be influenced by other variables. They may give a lower score to the lighting element because they believe it is less relevant than the presence of uniformed guards or security forces near the public transport station.

Finally, by comparing the results of the Egyptian and emigrant models, all the subjective public transport use variables are significant ($p<0.05$) except for the Egyptian perceived security when uniformed guards or security forces are near the PT station/stop variable, which is highly significant ($p<0.001$) and the migrants' evaluation of the quality of buses and minibuses variable which is marginally significant ($0.10>p>0.05$). This means that the main variable affecting the commuting trip generation of Egyptians is perceived security when uniformed guards or security forces are near the PT station/stop. While in the migrants' conditions, all the independent variables have the same effect on the commuting trip generation except for the evaluation of the quality of buses and minibuses variable, which has lesser impact. The model indicates that the increase of one scale of Egyptians' and migrants' perceived security when using public transportation and when uniformed guards or security forces are near the PT station/stop is correlated with 9.4%, 32.7%, 23.2%, and 49.3% increase in commuting trips per week, respectively. This means that migrants generate more commuting trips when they feel secure than Egyptians. Conversely, the increase of one scale of Egyptians' and migrants' evaluation of the quality of buses and minibuses and perceived security when the stations/stops are well-lit led to a reduction of 10.6%, 14.7%, 15.5%, and 46.5% in commuting trips per week, respectively. This indicates that migrants generate fewer commuting trips when the station is well-lit than Egyptians. All the above-mentioned results have been outlined in Table V.

TABLE V
MULTIVARIATE OLS MODEL FOR COMMUTING TRIPS GENERATION OF THE OVERALL SAMPLE, EGYPTIANS AND MIGRANTS

Independent Variable	Overall Sample			Egyptian			Migrants		
	B	β	P	B	β	P	B	β	P
(Constant)	4.337		<0.001	4.008		0	2.81		0.048
Age	0.031	0.073	0.007	0.034	0.086	0.004	0.103	0.148	0.014
Household car ownership	-0.319	-0.100	0.000	-0.21	-0.067	0.034	-0.408	-0.112	0.11
Household size	0.177	0.069	0.010	0.174	0.065	0.027	0.183	0.087	0.184
Evaluation of the quality of buses and minibuses	-0.013	-0.092	0.006	-0.015	-0.106	0.005	-0.021	-0.147	0.051
Perceived security when using public transportation	0.017	0.138	0.001	0.011	0.094	0.029	0.039	0.327	0.002
Perceived security when uniformed guards or security forces are near the PT station/stop	0.032	0.263	<0.001	0.028	0.232	<0.001	0.066	0.493	0.002
Perceived security when the stations/stops are well-lit	-0.026	-0.211	<0.001	-0.019	-0.155	0.01	-0.061	-0.465	0.001
R^2	0.063			0.049			0.187		
ANOVA - F Test P	<0.001			<0.001			<0.001		

III. DISCUSSION

A. Feedback to Previous Studies

This study examined the correlation between subjective independent variables and trip generation, as dependent variables, among Egyptians and migrants. Thus, it attempts to highlight the determinants influencing commuting trip generation. The results demonstrate some notable findings that contribute to the understanding of the commuting determinants among both groups of the study (i.e., Egyptians and migrants). As well as, shedding light on some findings which need further investigation.

One of the findings revealed that migrants generated more commuting trips (during the seven

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days before filling out the study survey) than Egyptians, which is illustrated in Figure 1. The R2 value of the OLS model for migrants denotes that the commuting trip generation is highly related to public transport. This finding is supported by several studies carried out in Canada, the USA, and Germany, which state that immigrants and non-natives use public transport more than residents [31], [32], [33].

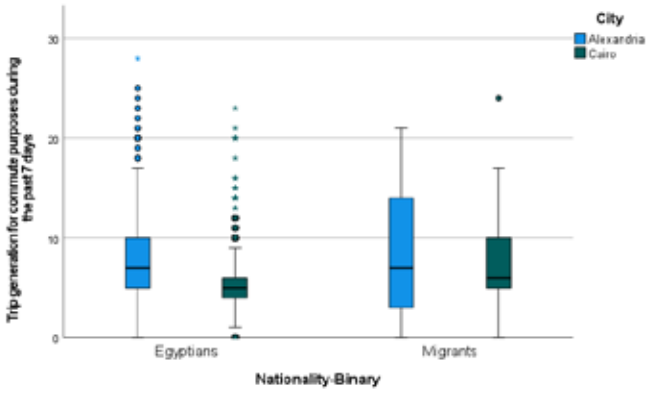

Fig. 1. Illustration of the trip generation for commute purposes for Egyptians and migrants in both cities

When comparing the results on the willingness to spend time commuting between both groups, it is found that Egyptians are more willing to spend more time than migrants. The results of a study conducted in Southern Ontario, Canada, reveal that the car-dependent-individuals have longer commuting trips [33]. Thus, the willingness to spend more time commuting expressed by Egyptians reinforces the assumption that they are considered car-dependent commuters.

Immigrants generally decide to relocate within their immediate surrounding area and tend to refrain from more extended distances. This observation suggests that natives show more willingness to commute longer distances [34]. This finding is further supported by the claim established by Kabbani (2018) that refugees, specifically Syrians, are concentrated in specific neighborhoods and cities. Additionally, they tend to reside near the location of their business [26]. This is further supported by the claim established by Casado-Díaz, Simón-Albert, and Simón (2022), [35] which states that the commuting differences between locals and non-locals are possibly a result of various factors that might include their tendency to reside in specific agglomerations. This further denotes that locals/natives have more willingness to spend more time commuting. This in turn potentially implies that spatial variations exist between local and non-local individuals regarding their willingness to trade off commuting time for other attributes such as job quality and housing affordability among commuters.

Additionally, according to the findings of this study, Egyptians spend more money on commuting than the other group. High expenditure of money on commuting by Egyptians aligns with the research findings which reveal that Egyptians are unlikely to use public transport when compared to migrants. Accordingly, this suggests that Egyptians rely on more expensive means of transport, in that case: individual means of transport (i.e. cars). Thus, this finding implies the reliance of Egyptians on cars for commuting more than any other mode, which is supported according to a comparative study carried out in Tehran and Cairo [36].

Migrants expressed a lower willingness to spend more time commuting, in contrast to the high willingness of Egyptians. Additionally, migrants are more satisfied with commuting than Egyptians. The high level of satisfaction and low level of willingness to spend time commuting of the migrants group implies a shorter commuting distance for migrants. The Findings of a previous study conducted in Canada concede with the findings of this study, which demonstrates that non-natives or immigrants commute shorter distances [33], [37].

However, there is a contrast between the findings related to shorter commuting distances and the findings reported by another study on immigrants' commuting times in Spain. The findings of the study conducted in Spain show that immigrants have more commuting time compared to locals [38]. This could be further explained by the claim established by [33] that the commuting distance for immigrants or non-natives is correlated to the number of years of their stay in the country of immigration, in which, the commuting distance of native and non-natives or immigrants converge over two decades [33], [37].

The claim established by [33] is highly considered for this study, to plan further research and investigation in the near future. Particularly in the light of the current duration of refugees/Syrian's influx to Egypt, which started in 2011-2012, which is roughly 12 years. Thus, Egypt is currently roughly in the middle of two decades interval. Thus, in less than a decade, further studies could be conducted to investigate the potential convergence of commuting time between locals and non-locals. To address this concern, the researchers plan to conduct further

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research and analysis that consider the temporal aspect of commuting distance evolution over the years for both native and non-native populations.

One of the notable results of this study is that perceived subjective variables related to public transport are positively correlated with trip generation per week. Specifically, in the case of migrants, trip generation is positively and highly correlated to perceived security in public transport and perceived security when guards are near stops. The perceived subjective variables related to public transport are presented in Figure 2. A study on immigrants in Australia revealed that immigrants usually have a positive perception towards public transit in the country of immigration [39]. This supports the findings primarily revealed by [33], [37] which highlight the role of the duration of the immigrants' stay in the country of immigration on commuting time and distance, as mentioned earlier . Contrastively, the results of perceived security when the stations and stops are well-lit are negatively and highly correlated with trip generation. This either supports or declines the results of other previous studies. Although there is a lack of studies on the correlation between commuting trip generation and station lighting factors, some studies have investigated the correlation between safety and waiting time at public transport stations, such as the study by [40]. This study opposes the negative correlation, as 18% of their study's sample approved the positive correlation between station good lighting and safety perception. On the other hand, the findings of [41], proved that individuals may not necessarily link well-lit zones with improved feelings of personal safety because well-lit areas may allow thieves to see them more easily.

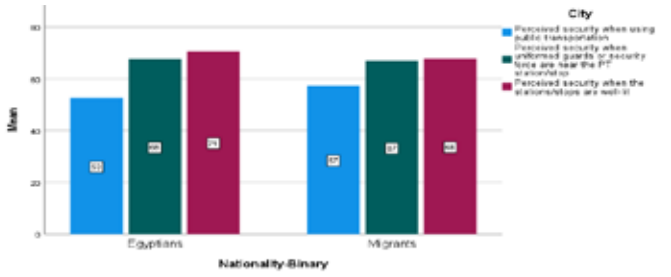

Fig. 2. The perceived subjective variables related to public transport

Given that most of the migrants group sample are Syrians, and the influx of most Syrians initiated during 2011, hence, they are currently commencing the second decade of their stay as immigrants and as underscored by the previously mentioned studies, after the second decade, non-natives' commuting determinants and perceptions are expected to shift towards longer commuting distances and negative perceptions [33], [37], [39].

a. Lessons Learned for Urban and Mobility Planning: This study shapes one's understanding of the complex relationship between trip generation, commuting determinants, and perceptions among Egyptians and migrants. The findings of this study underline the importance of continuous, efficient, and strategic investment in enhancing the quality of public transit (i.e., Buses and minibuses) in the Egyptian context and MENA region. Such investments will promote the usage of public transit and will attract a broader spectrum of users. Moreover, transport planners and policymakers' efforts should be directed to acknowledge the sense of security for all commuters, especially for public transit. This should be considered strategically to better manage the prospective change in the upcoming decades. In which perceived security towards public transit is expected to decline, thus, leading to a car-dependent mobility pattern. If sound investments are encouraged, it will shift transit mode choices towards more sustainable transport and mobility options, away from car dependency. Urban mobility and transport plans require holistic approaches in which the diverse needs of different groups of commuters should be met and, more importantly, to meet the needs of the growing population, increasing demands, and changing perceptions of the future of both Egyptians and migrants.

b. Study Limitations: Cairo city data were collected from November 2022 till January 2023, these months represent the start of a new academic year in Egypt which may present data that will differ over the other months of the year like summer months. So, the data collection is supposed to be from different seasons of the year to correctly project the actual behavior of the commuters. Moreover, a longer time frame for the data collection method means a bigger sample size, which will improve the process of forecasting the behavior of the commuters. The nature of the emigrant commuter's trip numbers and destinations will increase and decrease due to international events and the economic state of their countries. As a matter of fact, not all the variables that were intended to be applied in the survey have existed in the collected data due to expecting some difficulties in the data collection method between both cities.

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IV. CONCLUSION

The research studies Egyptian and emigrant/refugee populations in their commuting behavior according to their perception of their physical environment; Home/Work distance, the choice of mode of transportation, with a special highlight on the six variables of age, household car ownership, and household size, the role of socioeconomic characteristics, the quality of buses and mini-buses, perceived security when using public transportation were tested along with features of transport built environment in explaining commuting patterns and forecast sustainable modal splits.

Both the questionnaire and the methodology are adaptable and scalable to be used, modified, and applied in a wide range of transport modal shifting strategies. The paper concludes the effectiveness of the "Residential self-selection" and the decreased "spatial mismatch" found in the migrants in the Work/Home distance and choice and its effect on their commuting experience positively, while the Home/Work distance and choice were bounded with other socio-cultural aspects that affected their commuting experience negatively. Variables addressing the Egyptias'n and migrants' travel behavior, and modal shifts were tested and addressed by "The Mann–Whitney U test" and the multivariate Ordinary Least Squares (OLS) model.

The non-parametric statistical test "The Mann–Whitney U test" showed the difference between both groups "Egyptians and migrants", migrants have produced a higher number of commuting trips compared to Egyptians, and their satisfaction with commuting surpasses that of Egyptians. Although Egyptians invest more time in weekday commutes, their preferred daily commuting time is greater than that of migrants. Egyptians demonstrate a greater willingness to allocate time for commuting and expend more resources on commuting expenses each month compared to migrants, Due to the high costs associated with changing residency in Egypt, Egyptians often find it challenging to easily relocate. Consequently, their regular home-to-work commuting typically incurs higher expenses compared to migrants, who look for accommodation close to their workplace.

To explore the correlation between subjective public transport usage and the generation of commuting trips among both Egyptians and migrants, a multivariate Ordinary Least Squares (OLS) model was employed. The model was executed three times, encompassing the overall sample, the Egyptian-specific subset, and the migrants-specific subset, with commute trip generation serving as the dependent variable. When comparing the models for Egyptians and migrants, all subjective variables related to public transport usage are statistically significant. However, the Egyptian perceived security when uniformed guards or security forces are near the public transport station/stop variable is highly significant, while the migrants' evaluation of the quality of buses and minibuses variable is marginally significant. The model suggests that a one-scale increase in both Egyptians' and migrants' perceived security when using public transportation, and when uniformed guards or security forces are near the station/stop, is associated with a high percentage increase in weekly commuting trips, respectively.

The findings indicate that migrants tend to generate more commuting trips when they perceive a higher level of security compared to Egyptians. Additionally, the results suggest that migrants generate fewer commuting trips when the public transport station is well-lit, in contrast to Egyptians.

Due to the acceptance of Egyptian society for all nationalities to merge into the culture and live as they still in their home, the expansion of the migrants' population extended all over the 27 governorates of Egypt, which will require an extensive effort to cover all these governorates to have more accurate results. Future research will be required to cover the North and the south of Egypt, also a longer time frame will be required, which means the survey has to be collected during a full year, to measure accurately the behavior of each group during the peak seasons and off seasons.

In future research, it is recommended to have a larger sample size and access to governmental big data to maintain accuracy, save time, and help the researchers use more powerful parametric tools to analyze the data, which will have higher precision in the commuter's behavior forecasting process. Furthermore, it is recommended that forthcoming studies consider the geographical context of neighborhoods when examining the correlates of commuting behavior for Egyptians and migrants. Such an approach will enhance one's understanding of how neighborhood characteristics impact the variables of commuting behavior, thereby informing recommendations for urban and mobility planning initiatives.

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http://dx.doi.org/10.21622/RESD.2024.10.1.768

References

[1] A. Hegazy and S. Abu Hendy, "Sustainable Urban Mobility Plan in 6th of October," : https://transportforcairo.com/wp-content/uploads/2021/10/6O_SUMP_P1_Final_Report_v1.2_En.pdf.

[2] Syria Refugee, "Syria Refugee Crisis Explained," https://www.unrefugees.org/news/syria-refugee-crisis-explained/.

[3] O. Hassan, E. A. K. Mohamed, A. Hassan, M. Shaheen, and W. Bekheet, "Sustainable urban development of mobility and streetscape in historic city quarters, an ancient street in Alexandria - Egypt, as a case study," Alexandria Engineering Journal, vol. 78, pp. 378–389, Sep. 2023, doi: 10.1016/j.aej.2023.07.065.

[4] S. Abu-Eisheh, W. Kuckshinrichs, and A. Dwaikat, "Strategic Planning for Sustainable Transportation in Developing Countries: The Role of Vehicles," Transportation Research Procedia, vol. 48, pp. 3019–3036, 2020, doi: 10.1016/j.trpro.2020.08.184.

[5] M. Mehriar, H. Masoumi, and I. Mohino, "Urban Sprawl, Socioeconomic Features, and Travel Patterns in Middle East Countries: A Case Study in Iran," Sustainability, vol. 12, no. 22, p. 9620, Nov. 2020, doi: 10.3390/su12229620.

[6] K. A. Small and E. T. Verhoef, The economics of urban transportation. 2007. doi: 10.4324/9780203642306.

[7] Y. Yang, C. Wang, W. Liu, and P. Zhou, "Understanding the determinants of travel mode choice of residents and its carbon mitigation potential," Energy Policy, vol. 115, pp. 486–493, Apr. 2018, doi: 10.1016/j.enpol.2018.01.033.

[8] P. G. Røe, "Qualitative research on intra-urban travel: an alternative approach," J Transp Geogr, vol. 8, no. 2, pp. 99–106, Jun. 2000, doi: 10.1016/S0966-6923(99)00039-3.

[9] L. A. B. Ouali, D. J. Graham, A. Barron, and M. Trompet, "Gender Differences in the Perception of Safety in Public Transport," J R Stat Soc Ser A Stat Soc, vol. 183, no. 3, pp. 737–769, Jun. 2020, doi: 10.1111/rssa.12558.

[10] M. Ehab, "THE COMMUTING GENDER GAP AND FEMALES' LABOR SUPPLY AND EARNINGS IN THE EGYPTIAN LABOR MARKET," in Economic Research Forum, 2018.

[11] J. Urry, "The 'System' of Automobility," Theory Cult Soc, vol. 21, no. 4–5, pp. 25–39, Oct. 2004, doi: 10.1177/0263276404046059.

[12] R. V. Ponnaluri, "Sustainable Bus Rapid Transit initiatives in India: The role of decisive leadership and strong institutions," Transp Policy (Oxf), vol. 18, no. 1, pp. 269–275, Jan. 2011, doi: 10.1016/j.tranpol.2010.08.010.

[13] C. De Gruyter, G. Currie, and G. Rose, "Sustainability Measures of Urban Public Transport in Cities: A World Review and Focus on the Asia/Middle East Region," Sustainability, vol. 9, no. 1, p. 43, Dec. 2016, doi: 10.3390/su9010043.

[14] D. Sims, "Understanding Cairo: the logic of a city out of control," Choice Reviews Online, vol. 49, no. 04, 2011, doi: 10.5860/choice.49-2329.

[15] "Egyptian National Railways," https://www.enr.gov.eg/En/ENR.aspx?ID=2.

[16] T. Lin, D. Wang, and X. Guan, "The built environment, travel attitude, and travel behavior: Residential self-selection or residential determination?," J Transp Geogr, vol. 65, pp. 111–122, Dec. 2017, doi: 10.1016/j.jtrangeo.2017.10.004.

[17] R. Ewing and R. Cervero, "Travel and the Built Environment," Journal of the American Planning Association, vol. 76, no. 3, pp. 265–294, Jun. 2010, doi: 10.1080/01944361003766766.

[18] P. Næss, "Residential location affects travel behavior—but how and why? The case of Copenhagen metropolitan area," Prog Plann, vol. 63, no. 2, pp. 167–257, Feb. 2005, doi: 10.1016/j.progress.2004.07.004.

[19] T. Schwanen and P. L. Mokhtarian, "What if you live in the wrong neighborhood? The impact of residential neighborhood type dissonance on distance traveled," Transp Res D Transp Environ, vol. 10, no. 2, pp. 127–151, Mar. 2005, doi: 10.1016/j.trd.2004.11.002.

[20] J. F. Kain, "Housing segregation, negro employment, and metropolitan decentralization," Quarterly Journal of Economics, vol. 82, no. 2, 1968, doi: 10.2307/1885893.

[21] M. Friman, K. Lättman, and L. E. Olsson, "Public Transport Quality, Safety, and Perceived Accessibility," Sustainability, vol. 12, no. 9, p. 3563, Apr. 2020, doi: 10.3390/su12093563.

[22] Y. Li, S. Geertman, P. Hooimeijer, Y. Lin, and H. Yang, "Do migrants and locals differ in commuting behavior? A case study of Xiamen, China," Transp Policy (Oxf), vol. 108, pp. 1–10, Jul. 2021, doi: 10.1016/j.tranpol.2021.04.020.

[23] D. Lin, A. Allan, and J. Cui, "The impacts of urban spatial structure and socio-economic factors on patterns of commuting: a review," International Journal of Urban Sciences, vol. 19, no. 2, pp. 238–255, May 2015, doi: 10.1080/12265934.2015.1016092.

[24] Y. Fan, "The Planners' War against Spatial Mismatch," J Plan Lit, vol. 27, no. 2, pp. 153–169, May 2012, doi: 10.1177/0885412211431984.

[25] UN DESA, "World Population Prospects - Population Division," World Population Prospects: 2023 Revision. Accessed: Aug. 12, 2023. Available: https://population.un.org/wpp/

[26] R. Kabbani, "Entrepreneurship and the integration of refugees and migrants: A case study of Syrian refugees in Egypt."

[27] "CAPMAS," Accessed: Aug. 12, 2023, https://www.capmas.gov.eg/.

[28] L. Hadjiiski, H.-P. Chan, B. Sahiner, M. A. Helvie, and M. A. Roubidoux, "Quasi-Continuous and Discrete Confidence Rating Scales for Observer Performance Studies," Acad Radiol, vol. 14, no. 1, pp. 38–48, Jan. 2007, doi: 10.1016/j.acra.2006.09.048.

[29] F. Funke and U.-D. Reips, "Why Semantic Differentials in Web-Based Research Should Be Made from Visual Analogue Scales and Not from 5-Point Scales," Field methods, vol. 24, no. 3, pp. 310–327, Aug. 2012, doi: 10.1177/1525822X12444061.

[30] S. Y. Y. Chyung, I. Swanson, K. Roberts, and A. Hankinson, "Evidence-Based Survey Design: The Use of Continuous Rating Scales in Surveys," Performance Improvement, vol. 57, no. 5, pp. 38–48, May 2018, doi: 10.1002/pfi.21763.

[31] E. Blumenberg and A. Evans, "Planning for Demographic Diversity: The Case of Immigrants and Public Transit," J Public Trans, vol. 13, no. 2, pp. 23–45, Jun. 2010, doi: 10.5038/2375-0901.13.2.2.

[32] J. Welsch, K. Conrad, and D. Wittowsky, "Exploring immigrants travel behaviour: empirical findings from Offenbach am Main, Germany," Transportation (Amst), vol. 45, no. 3, pp. 733–750, May 2018, doi: 10.1007/s11116-016-9748-9.

[33] K. Bruce Newbold, D. M. Scott, and C. Burke, "Immigrant status and commute distance: an exploratory study based on the greater Golden Horseshoe," Transportation (Amst), vol. 44, no. 1, pp. 181–198, Jan. 2017, doi: 10.1007/s11116-015-9633-y.

[34] I. Geis, "Foreign countries, foreign customs: an analysis of short-distance mobility of new immigrants in the Rhine-Main region in Germany," European Transport Research Review, vol. 11, no. 1, 2019, doi: 10.1186/s12544-019-0360-x.

[35] J. M. Casado-Díaz, R. Simón-Albert, and H. Simón, "Reassessing the commuting penalty for immigrants: new evidence from Spain," Transportation (Amst), vol. 49, no. 4, pp. 1099–1132, Aug. 2022, doi: 10.1007/s11116-021-10204-5.

[36] H. Mostofi, H. Masoumi, and H.-L. Dienel, "The Relationship between Regular Use of Ridesourcing and Frequency of Public Transport Use in the MENA Region (Tehran and Cairo)," Sustainability, vol. 12, no. 19, p. 8134, Oct. 2020, doi: 10.3390/su12198134.

[37] V. Preston, S. McLafferty, and M. Maciejewska, "Gender, Immigration and Commuting in Metropolitan Canada," Tijdschrift voor Economische en Sociale Geografie, vol. 113, no. 4, pp. 348–364, Sep. 2022, doi: 10.1111/tesg.12521.

Volume 10, Issue 1, June 2024 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2024.10.1.768

[38] M. Blázquez, C. Llano, and J. Moral, "Commuting times: Is there any penalty for immigrants?," Urban Studies, vol. 47, no. 8, 2010, doi: 10.1177/0042098009356127.

[39] R. Shafi, A. Delbosc, and G. Rose, "The role of culture and evolving attitudes in travel behaviour assimilation among south asian immigrants in Melbourne, Australia," Transportation (Amst), vol. 50, no. 4, pp. 1261–1287, Aug. 2023, doi: 10.1007/s11116-022-10277-w.

[40] S. Chowdhury and B. van Wee, "Examining women's perception of safety during waiting times at public transport terminals," Transp Policy (Oxf), vol. 94, pp. 102–108, Aug. 2020, doi: 10.1016/j.tranpol.2020.05.009.

[41] M. S. H. and A. S. S. Atkins, "The influence of street lighting on crime and fear of crime. in Crime Prevention Unit paper," Home Office, Crime Prevention Unit, vol. 28. Home Office, Crime Prevention Unit, London, 1991.

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Modeling the Kinetics of Pyrolysis of Date Seeds Using Artificial Neural Networks

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ABSTRACT

Ground date seeds were subjected to thermal analysis in a stream of Nitrogen at four different heating rates (5, 10, 15 and 20oC.min-1) and their TG – DTG patterns were obtained. Two peaks showed up for the degradation of lignocellulosic components. Three iso-conversional methods were used to obtain the activation energy of these steps: the Flynn-Wall-Ozawa (FWO), the Kissinger-Asahira-Sunoze (KAS) and the Friedmann methods. The results show that the values of activation energy for the first step of degradation varied from 113.76 to 117.80 kJ.mol-1, depending on the calculation method. For the second step, the corresponding values were 130.99, 123.07 and 127.52 kJ.mol-1. At the end of the second peak, biochar was formed that went on cracking off its more volatile constituents at higher temperatures. An artificial Neural Network simulation was carried out for the first degradation step. The values obtained from that simulation for conversion – temperature curves and for biochar content were in excellent agreement with the corresponding experimental figures. However, the simulated values obtained for activation energy at different conversion levels were higher.

Index-words: *Activation energy, ANN Simulation, Conversion, Date seeds, Percent biochar, Pyrolysis.*

I. INTRODUCTION

Substituting fossil fuels by waste in many industrial fields has become an increasingly common practice in the last two decades to alleviate some of the effects of the continuous depletion of fossil fuel type [1, 2]. A typical example is the partial use of some agricultural waste in the firing process in the cement industry [3, 4]. In this context, biorefineries using agricultural and food waste are considered a sustainable energy source [5].

On the other hand, pyrolysis of vegetable and food waste has proved to be a rich source of gaseous, and liquid and solid products that possess many uses, among which is substituting fossil fuels. Slow pyrolysis of agricultural waste at heating rates not exceeding 80°C.min^{-1} results in the formation of biochar, which possesses an elevated calorific value [6 – 8], besides exhibiting a large surface area for use as adsorbent in wastewater treatment [9 – 11]. Faster pyrolysis at rates reaching 1000°C.min^{-1} normally yields biooil rather than solid biochar., which is largely used as a promising substitute for conventional fuels [12, 13] and as cosmetic material [14]. The production of bio-oil can be enhanced using flash pyrolysis at heating rates exceeding 1000°C. min^{-1} [15, 16].

Research involving disclosure of the mechanism of slow pyrolysis of agricultural waste has yielded abundant literature in which most authors agreed on a common mechanism of waste degradation [17 – 21]. This consists of elimination of moisture followed by devolatilization of lignocellulosic material (Hemi-cellulose, cellulose, and lignin) and ends at a temperature ~400°C by forming biochar. At higher temperatures, the final elimination of lignin takes place as well as cracking of the formed biochar. The kinetics of such devolatilization reactions have been followed up by thermal analysis. This technique involves either following up the change in weight with time at constant temperature, or heating at constant heating rates. The former method can only be used whenever the conditions of reaction are isothermal [22, 23] which is hardly the case in pyrolysis reactions. That is why kinetics of these processes are commonly studied at constant heating rates usually using non – model kinetic techniques, the most common of which were the Flynn – Wall

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– Ozawa (FWO), the Kissinger – Asahira – Sunose (KAS) and the Friedman techniques. These models yield the value of activation energy of the reactions occurring on pyrolysis without generally specifying the controlling step [24 – 29]. On the other hand, model fitting methods that disclose the reaction's controlling step have only been successfully used whenever the reaction was well – defined [28, 27], which is not usually the case in pyrolyzing agricultural waste [30, 31]. Nevertheless, whenever the most used model fitting method, namely the Coats – Redfern model, was used most devolatilization reactions of lignocellulosic components turned out to follow first order kinetics [32, 33].

Attempts to model the degradation of agricultural waste using mathematical analysis were limited owing to the complexity of the reactions thereof. Using a kinetic analysis of simultaneous reactions, Sheth and Babu [34] studied the pyrolysis of wood and obtained model results which reasonably agree with experimental outcome. A similar approach was recently presented by Bieniek et al. on studying the pyrolysis of brewery spent grain and medium-density fiberboard [35]. On the other hand, several researchers have used simulation techniques, such as ANN (Artificial Neural Networks), to model the degradation kinetics of different types of biomasses [36 – 39].

In particular, the kinetics of pyrolysis of date seeds were investigated by Aly et al. [40]. They used several model and non-model methods to evaluate the activation energy of degradation of lignocellulosic components and obtained values of activation energy ranging from 135 to 160 kJ.mol^{-1}depending on the technique used in calculations. On the other hand, Raza et al. [41] used the Coats – Redfern technique to obtain a value of activation energy ranging from 170 to 190 kJ.mol^{-1}, depending on the heating rate used, a result close to that obtained by Aly et al. [40].

In the present paper, the kinetic parameters of the pyrolysis of date seeds were determined using three different iso-conversional methods, and the results were compared to those obtained using Artificial Neural Networks (ANN) modelling. The use of ANN simulation is a step towards further use of that simulation technique to predict the different outcomes of degradation of agricultural waste since no mathematical tool can easily deal with the kinetics of the complex reactions occurring thereof.

II. MATERIALS AND METHODS

A. Raw Material

The sole raw material used in this investigation consists of date seeds (Zaghloul type) collected from the local market in Cairo, Egypt. These were ground and screened between sieves 16 (0.792 mm) and 20 (0.635 mm) as per ASTM C136-01 [42], with an average particle size = 0.714 mm. The ash content of the ground powder was determined by heating samples of powder to 1000°C. An average ash content of 0.62% was obtained.

B. Thermal Analysis

This was conducted at four different heating rates (5, 10, 15 and 20°C.min^{-1}) using about 15 mg of ground material, dried overnight in a muffle dryer at 80°C. Nitrogen was admitted to the apparatus (Universal V4.5A TA Instruments) at the rate of 50mg.min^{-1}. Conversion in the main step of the devolatilization of lignocellulosic components was calculated using the expression:

$$\alpha = \frac{m_0 - m}{m_0 - m_f} \qquad \backslash \quad (1)$$

Where:

- m_0 represents the initial mass before decomposition.
- m represents the mass after any time along the decomposition reaction.
- m_f represents the final mass left after decomposition.

C. Calculation Models

As previously pointed out, non–model techniques are more reliable in determining the kinetic parameters of degradation of lignocellulosic materials. For that reason, three methods were chosen to that aim.

1. Flynn – Wall – Ozawa (FWO) method

This method relies on integrating the basic kinetic equation:

$$\frac{d\alpha}{dt} = A\, e^{-\frac{E}{RT}} f(\alpha) \qquad (2)$$

Where:

- A is a pre-exponential factor (s^{-1})
- E is the activation energy for reaction (J.mol^{-1})
- R is the general gas constant (J.mol^{-1}K^{-1})
- T is the temperature (K)

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$f(\alpha)$ is a function of conversion that depends on the rate controlling step.

Considering the rate of heating to be $\beta = \frac{dT}{dt}$ °C.min^{-1}, Equation (2) can be written as:

$$\frac{d\alpha}{dT} = \frac{A}{\beta} e^{-\frac{E}{RT}} f(\alpha) \quad (3)$$

Separation of variables and integrating, the following expression is obtained:

$$\frac{A}{\beta} \int e^{-\frac{E}{RT}} dT = \int \frac{d\alpha}{f(\alpha)} \quad (4)$$

The LHS cannot be integrated analytically, and requires expanding the integrand into an infinite series, of which only the first terms are kept. The final expression takes the form:

$$\log \beta = \ln \frac{A f(\alpha)}{\frac{d\alpha}{dT}} - \frac{E}{0.4567RT}, \quad (5)$$

Hence, a plot of $\log \beta$ against $1/T$ should yield, for each value of conversion α, a straight line of slope $\frac{E}{0.4567R}$ from which the activation energy can be calculated, at each value of α.

2. Kissinger – Asahira – Sunoze (KAS) method

This method is a generalization of the classical Kissinger method [43]. The original method was based on DTG peak having an inflection point of the $\alpha - T$ curve. It was later modified to suit any conversion, and not necessarily that at inflection.

The final kinetic equation takes the form:

$$\ln \frac{\beta}{T_\alpha^2} = -\frac{E}{RT_\alpha} + \ln \frac{R.A(\alpha)}{E.g(\alpha)} \quad (6)$$

Here, T_α is the temperature corresponding to a conversion = α and $g(\alpha)$ is a kinetic function related to $f(\alpha)$ by the expression:

$$g(\alpha) = \int \frac{d\alpha}{f(\alpha)} \quad (7)$$

Equation 6 reveals that a plot of $\ln \frac{\beta}{T_\alpha^2}$ against $1/T$ will produce straight lines, for different values of α, of slope = $-E/R$, , from which the value of E is obtained.

3. Friedman method

The merit of that method is that it involves neither assumptions nor serious approximations, as it deals with the basic kinetic equation 3, by rewriting it in the form:

$$\ln \beta \frac{d\alpha}{dT} = \ln A f(\alpha) - \frac{E}{RT} \quad (8)$$

The values of $\frac{d\alpha}{dT}$ can be obtained from the $\alpha - T$ plot by calculating $\frac{\Delta\alpha}{\Delta T}$ at small conversion intervals (0.05) and a plot of $\ln \beta \frac{\Delta\alpha}{\Delta T}$ against $1/T$ will yield straight lines, at each value of α, of slope = $-E/R$, from which the value of E can be determined.

This method can also be used to validate a rate controlling step using the concept of kinetic compensation according to which a plot of $\ln A$ against E, for different values of conversion, should yield a straight line [44]. To obtain the value of $\ln A$, the intercepts of the $1/T$ - $\ln \beta \frac{\Delta\alpha}{\Delta T}$ plots are first determined at each conversion level. Their values = $\ln A f(\alpha)$. Next, a kinetic function $f(\alpha)$ is assumed from table I.

The reliability of the different iso-conversional methods used in the calculation of the kinetic parameters in degradation reactions has been the subject of much dispute, although most authors prefer using the Friedman method over the two other techniques. This is since it relies on using the basic kinetic equation (2) without making any serious assumptions. Also, it allows for the determination of the most probable controlling step of the reaction [46].

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TABLE I
THE FUNCTION $f(a)$ FOR DIFFEENT RATE CONTROLLING STEPS [45]

Desig-nation	Controlling step	f (a)
A	Crystallization and grain growth (Avrami-Erofeev)	$2(1-\alpha).\left[\ln(1-\alpha)\right]^{\frac{m-1}{m}}$
F0	Zero order reaction	0
F1	First order reaction	$1-\alpha$
Fn	nth order reaction (n ≠ 1)	$(1-\alpha)^n$
R2	Cylindrical: Reaction at interface (Shrinking cylinder)	$2(1-\alpha)^{\frac{1}{2}}$
R3	Spherical: Surface reaction at interface (Shrinking sphere)	$3(1-\alpha)^{\frac{2}{3}}$
D1	One dimensional diffusion	$\frac{1}{2\alpha}$
D2	Two-dimensional diffusion	$-\ln(1-\alpha)$
D3	Three-dimensional diffusion (Thin ash layer – Jander equation)	$\frac{3(1-\alpha)^{\frac{2}{3}}}{2-(1-\alpha)^{\frac{1}{3}}}$
D4	Spherical: diffusion through ash (Ginstling – Brounstein equation)	$\frac{1}{2\left[(1-\alpha)^{-\frac{1}{3}}-1\right]}$

Usually, the determination coefficients (R^2) for the plot of $\ln A$ against E is obtained for probable expressions of $f(\alpha)$, the highest value corresponding to the most probable controlling mechanism.

In general. The Friedman method is often preferred to the two other techniques since it relies on little or no assumptions, besides disclosing the most probable controlling step of the reaction.

D. Modelling Using Artificial Neural Networks (ANN)

Neural networks were used to predict the conversion, biochar yield and activation energy based on the input variables such as biomass type, heating rate, temperature, and residence time. Neural networks can also capture the non-linear and complex relationships between the input and output variables, which are often difficult to describe by conventional models [47].

In the present work, MATLAB codes for pyrolysis of biomass have been used. The conventional steps of neural networks modelling were followed [48]:

- **Collection of data**: This step consisted of gathering as much data as possible from the literature dealing with the pyrolysis of vegetable waste. This included the effect of time and/or temperature on conversion to biochar, its final yield and its composition, and the activation energy of degradation.
- **Modelling**: For pyrolysis modeling, a feedforward network was used, which is the simplest and most common type. It possesses an input layer, one or more hidden layers, and an output layer. The input layer receives the input variables, the hidden layers perform the computations, and the output layer produces the output variables.
- **Training:** This step is necessary to adjust the network weights and biases, which are the parameters that determine the network output. The learning algorithm is the method that updates the network parameters based on the error function, which measures the difference between the network output and the desired output. In the present work, backpropagation was used, which calculates the error gradient for each network parameter and updates them in the opposite direction of the gradient.
- **Validation:** This is carried out by determining statistical parameters such as root mean squared error, correlation coefficient (R), determination coefficient (R^2), etc. In the present work, the determination coefficient has been used as it measures to what extent variation of output variables relate to variation in input variables.

III. Results and Discussion

The chosen case was that corresponding to the ground material pyrolyzed at a heating rate = 10°C. min^{-1}.

A. TG – DTG Results

The TG (Thermogravimetry) – DTG (Differential Thermogravimetry) curves for a specimen of powder pyrolyzed in Nitrogen at a heating rate of 10°C.min^{-1} are shown in Figure 1. There is a sharp DTG peak at 316.04°C corresponding to the devolatilization of hemicellulose and cellulose and partly lignin, as is the case for the pyrolysis of most lignocellulosic

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materials [21,49]. The full devolatilization of lignin ends at about 400°C, whereby biochar is formed associated with a second DTG peak at 369.31°C. This was assessed by heating 50 g of the material in presence of Nitrogen in a muffle furnace at the same heating rate after which heating was stopped. Figure 2 displays an image of the resulting biochar.

B. Conversion – Temperature Curves for the First Degradation Step

From the spreadsheet obtained for TG data, it was possible to calculate the conversion at different temperatures corresponding to the first DTG peak at all four heating rates. Figure 3 shows the curves obtained for conversion of ground date seeds for the first decomposition step, corresponding to the first DTG peak in Figure 1.

C. Determination of Kinetic Parameters for the First Degradation Step

As previously pointed out, determination of the kinetic parameters was carried out using three different non–model methods. The results are reviewed in the following sections.

1. Application of the FWO method

When values of $\log \beta$ against $1/T$ were plotted for different conversion levels, straight lines were obtained, as evidenced from Figure 4.

From the slopes of the lines, it was possible to evaluate the activation energy at each conversion. The values and the corresponding values obtained by the two other methods are listed in Table III. The average activation energy = 116.06 kJ.mol^{-1}.

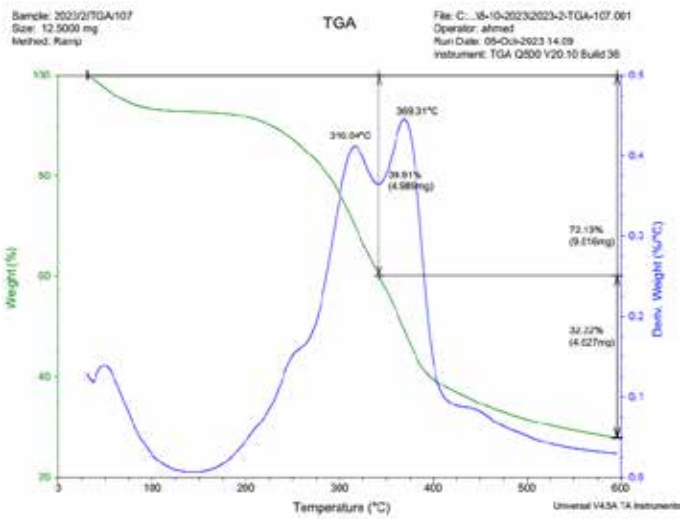

Fig. 1. Thermal analysis curves of ground date seeds at 10°C. min^{-1}

$\ln A$ against E. A

≈ 0.7.

Fig. 2. Biochar prepared by firing in Nitrogen to 600°C

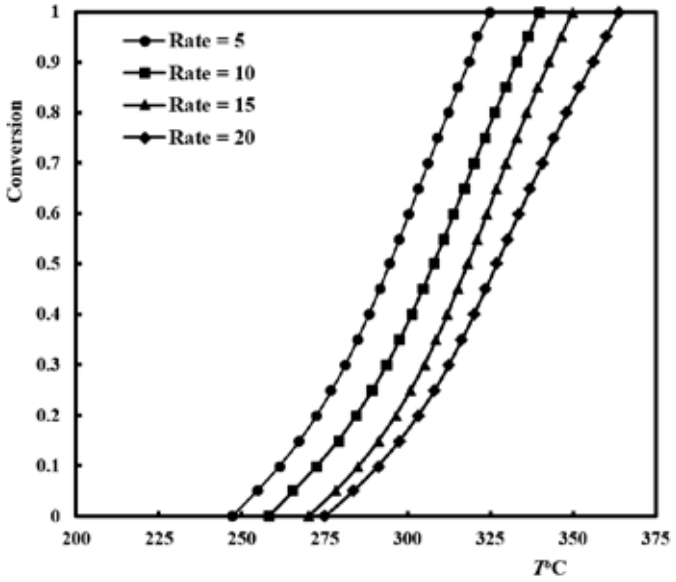

Fig. 3. Conversion – temperature curves for ground date seeds (Step 1)

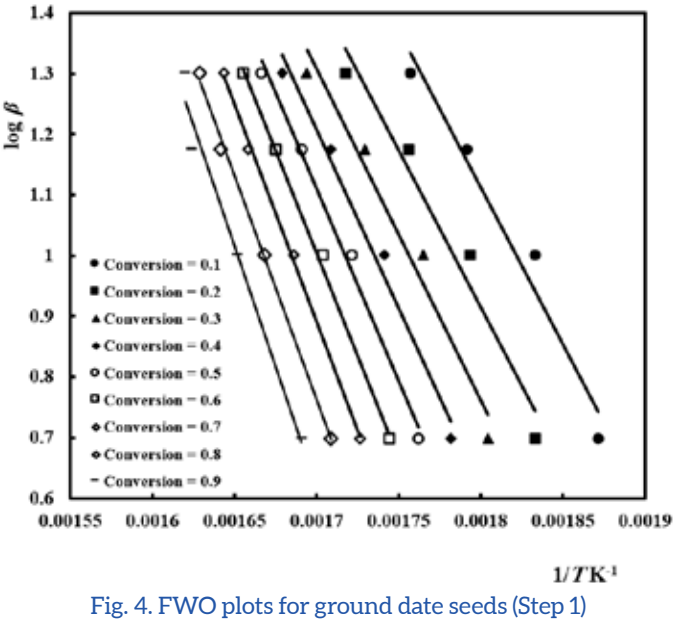

Fig. 4. FWO plots for ground date seeds (Step 1)

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2. Application of the KAS method

In this method, values of $\ln \frac{\beta}{T_\alpha^2}$ were plotted against $1/T$ to obtain the series of straight lines appearing in Figure 5. The average activation energy = 117.80 kJ.mol^{-1}, a value almost identical to that obtained by the previous technique.

3. Application of the Friedman method

As previously explained, plots of $\ln \beta \frac{\Delta\alpha}{\Delta T}$ against $1/T$ were carried out for different conversion levels, with an increment $\Delta\alpha = 0.05$ to obtain the set of straight lines in Figure 6. Once again, it was possible to determine the value of activation energy at each conversion. The average value of E = 113.76 kJ.mol^{-1}, a value slightly lower than those obtained previously.

Next, the intercepts of the lines in Figure 6 were determined and the values of $\ln A f(\alpha)$ calculated at each value of conversion. Following most previous findings, a first order reaction was assumed, having the kinetic function:

$$f(\alpha) = -\alpha \qquad (9)$$

This allowed plotting the values of $\ln A$ against E. A straight line was obtained (Figure 7) with R^2 = 0.980, assessing the validity of the proposed kinetic mechanism.

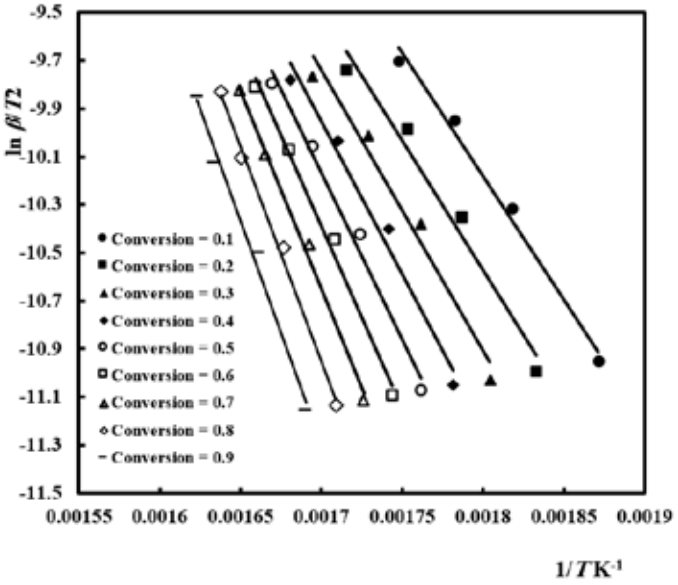

Fig. 5. KAS plots for ground date seeds (Step 1)

The discrepancies in the average values of activation energy obtained by different methods are a common occurrence, caused by the various assumptions made along the establishment of the kinetic model [49, 50]. A comparison of the values of activation energy obtained at different conversion levels by the three methods is given in Table II.

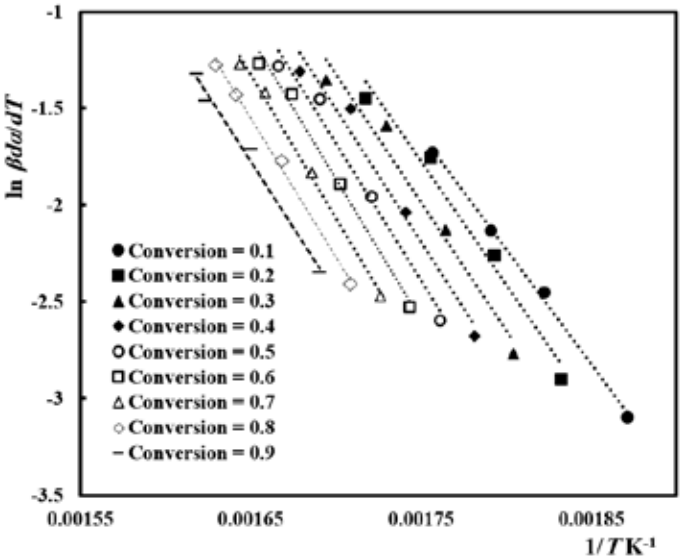

Fig. 6. Friedman plots for ground date seeds (Step 1)

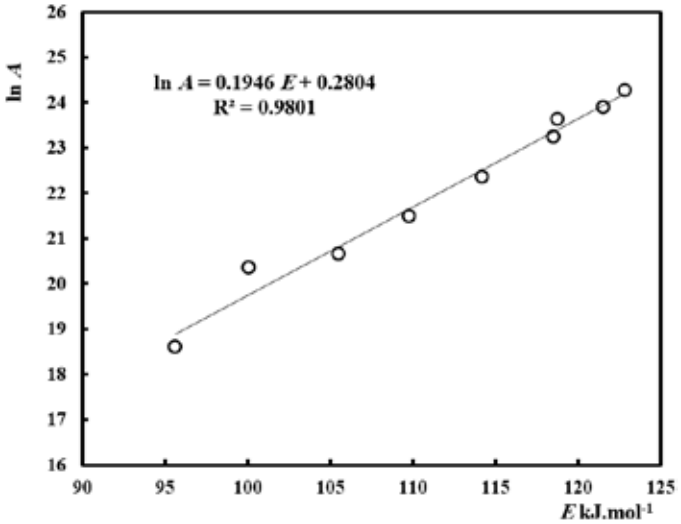

Fig. 7. Application of kinetic compensation (Step 1)

TABLE II
ACTIVATION ENERGIES OBTAINED BY DIFFERENT METHODS FOR DATE SEEDS (kJ.mol-1)

α	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Mean
FWO	94.16	94.37	99.47	106.95	115.35	123.38	130.91	134.93	144.98	**116.06**
KAS	85.58	89.93	96.47	105.56	115.40	126.12	137.20	148.73	155.22	**117.80**
Friedman	98.73	105.49	109.78	114.19	118.50	121.53	122.85	118.77	114.03	**113.76**

The values obtained for the activation energy using different non-model techniques are close to those obtained by Aly et al. [40], on studying the kinetics of pyrolysis of date kernels, varying from 126.5 to 145 kJ.mol^{-1}, depending on the heating rate and method of calculation, although they did not specify the particle size used in their work. The results obtained by Rasa et al. [41] (170 – 190 kJ.mol^{-1}) are less reliable, being obtained by the Coats – Redfern technique, which is unsuitable for use for complex reactions [23].

E. Conversion – Temperature Curves for the Second Degradation Step

In Figure 8, the conversion – temperature curves for the second step of the degradation of the lignocellulosic components ending by the formation of biochar are illustrated.

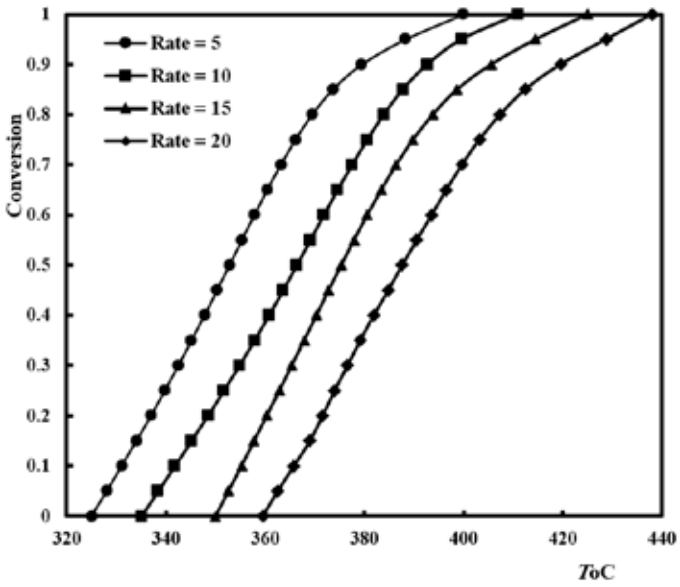

Fig. 8. Conversion – temperature curves for ground date seeds (Step 2)

F. Determination of Kinetic Parameters for the Second Degradation Step

To avoid any redundancy, only the results obtained for average activation energy, as obtained by the three techniques (FWO, KAS and Friedman), are summarized in Table III.

TABLE III
AVERAGE ACTIVATION ENERGIES FOR THE SECOND DEGRADATION STEP

Method	FWO	KAS	Friedman
***E* kJ.mol^{-1}**	130.99	123.07	127.52

IV. RESULTS OF ARTIFICIAL NEURAL NETWORK MODELLING

A. Modelling of Conversion Curves

Conversion curves for the first degradation step were modelled using Artificial Neural Networks (ANN) and compared to experimental points. Figure 9 illustrates one instance, namely, the case of particles heated at 5°C.min^{-1}. The figure reveals an excellent match of conversion data. The Root Mean Squared Error (RMSE) between experimental and calculated conversions possessed a very low value (0.0500).

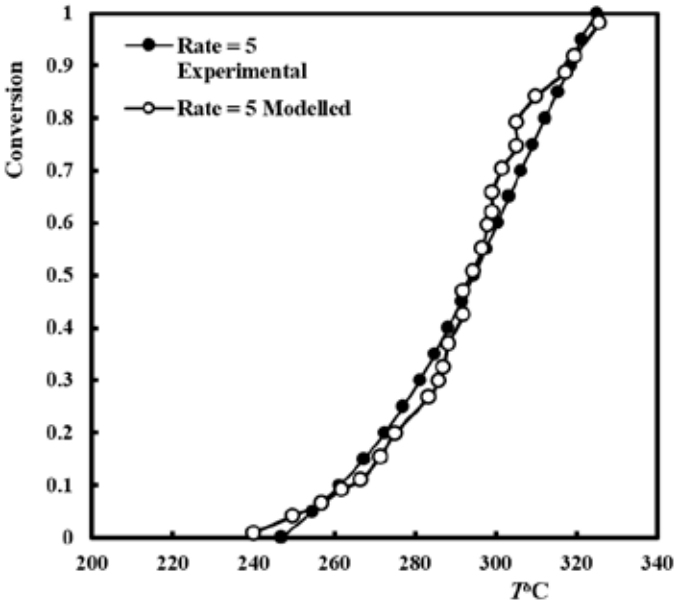

Fig. 9. Experimental and modelled data for pyrolysis at 5oC. min-1

B. Biochar Yield

According to the findings of most authors [51 – 53], biochar is produced from the pyrolysis of vegetable

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waste at temperatures ranging from 300 to 500°C. Its use as adsorbing material necessitates, however, increasing the temperature to more than 600°C to ensure the formation of enough porosity to allow for its use to that aim [54]. The percentage biochar formed in the present work was assessed from TG data at the temperature at which the second DTG peak ends (Figure 1). As can be seen from that figure, corresponding to pyrolysis at 10°C.min^{-1}, the second peak ends at 420°C, followed by a constant rate weight loss up to 455°C, after which the rate of weight loss slightly decreased up to 600°C. At 420°C, the total weight loss was about 62.8%, corresponding to the remaining char percentage of 36.6% (Excluding about 0.62% ash content). At 600°C, this value drops to about 22.9%. These ratios were determined at all heating rates. A comparison between the observed values and calculated values from the neural networks model at 400°C and 600°C at 10°C.min^{-1} are shown in Table IV. The average error in the evaluation of the biochar yield, using neural network simulation is 4.76%, with a maximum of 11.65%, proving that the simulated values fairly coincide with the values determined experimentally. The root mean squared error (RMSE) was calculated and found to be 1.61 and 1.84, on comparing experimental to simulated values at 400°C and 600°C, respectively.

TABLE IV
COMPARISON BETWEEN OBSERVED AND CALCULATED VALUES OF BIOCHAR YIELD

Heating rate °C.mi^{n-1}	Biochar yield %			
	420°C		600°C	
	Observed	Simulated	Observed	Simulated
5	34.3	33.17	26.6	23.5
10	36.6	36.12	27.0	26.42
15	37.5	35.43	27.3	26.78
20	38.4	40.54	27.5	25.67
RMSE	1.61		1.84	

C. *Activation Energy*

The calculated values of activation energy of the first degradation step, at different levels of conversion, by the three iso-conversional models, were different but yielded very close average values. Also, it can be noticed that the first two methods resulted in an increase in activation energy while in the Friedman method, it reached a local maximum at a conversion ≈ 0.7.

As for the values obtained from ANN simulation, they were higher than those obtained by the three models by an average of 11.6% besides reaching a maximum value at a conversion ≈ 0.6, as is the case with the Friedman method (Figure 10). The values of RMSE for the comparison between the results of the three methods and the simulated values were found to be 21.42 kJ.mol^{-1}, 15.29 kJ.mol^{-1} and 7.96 kJ.mol^{-1} for the KAS, FWO and Friedman methods respectively, proving that the results of this last method were the closest to those obtained by ANN simulation.

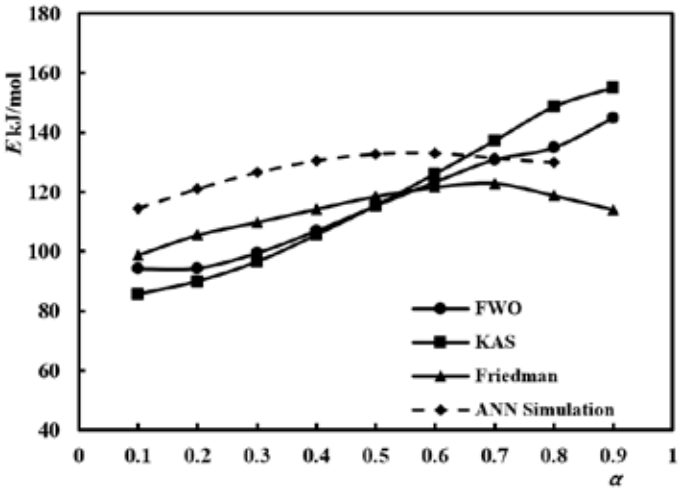

Fig. 10. Experimental and ANN simulated values of activation energy

It seems therefore, that ANN simulation could produce very close values to those determined experimentally for conversion – temperature points and biochar yield. The prediction of activation energy, however, resulted in higher results.

V. CONCLUSIONS

Date seeds were ground to an average particle size of 0.714 mm and subjected to pyrolysis in a thermal analyzer with flowing Nitrogen at four different heating rates: 5, 10, 15 and 20°C.min^{-1}. In all cases, two DTG peaks showed up associated with the devolatilization of lignocellulosic components.

Activation energies were calculated for the two degradation steps by three different iso-conversional methods, namely the Flynn – Wall – Ozawa, the Kissinger – Asahira – Sunoze and the Friedman methods. The calculated values showed slight variations between the three methods. For the first degradation step, these values were respectively 116.06, 117.80 and 113.76 kJ.mol^{-1}, while for the second step, the obtained values were: 130.99, 123.07 and 127.52 kJ.mol^{-1}.

ANN simulation was carried out for the first degradation step and the simulated values for conversion – temperature curves and biochar yield

at 420°C and 600°C were in excellent agreement with experimentally obtained values, resulting in low values of RMSE between experimental and simulated data. On the other hand, simulated values for activation energies showed moderate deviation from those calculated by the three iso-conversional methods. In particular, the Friedman method gave the minimum RMSE between experimental and simulated data among the three methods.

It is recommended to extend ANN simulation to predict the proportion of the lignocellulosic components of various agricultural waste as well as the effect of particle size on the different pyrolysis parameters.

References

[1] M. V. L. Chhandama, A. C. Chetia, K. B. Satyan, Supongsenla Ao, J. V. Ruatpuia, and S. L. Rokhum, "Valorisation of food waste to sustainable energy and other value-added products: A review," *Bioresour Technol Rep*, vol. 17, p. 100945, Feb. 2022, doi: 10.1016/j.biteb.2022.100945.

[2] A. Sridhar, A. Kapoor, P. Senthil Kumar, M. Ponnuchamy, S. Balasubramanian, and S. Prabhakar, "Conversion of food waste to energy: A focus on sustainability and life cycle assessment," *Fuel*, vol. 302, p. 121069, Oct. 2021, doi: 10.1016/j.fuel.2021.121069.

[3] W. Zieri and I. Ismail, "Alternative Fuels from Waste Products in Cement Industry," in *Handbook of Ecomaterials*, Cham: Springer International Publishing, 2019, pp. 1183–1206. doi: 10.1007/978-3-319-68255-6_142.

[4] N. Chatziaras, C. S. Psomopoulos, and N. J. Themelis, "Use of waste derived fuels in cement industry: a review," *Management of Environmental Quality: An International Journal*, vol. 27, no. 2, pp. 178–193, Mar. 2016, doi: 10.1108/MEQ-01-2015-0012.

[5] A. Sarker, R. Ahmmed, S. M. Ahsan, J. Rana, M. K. Ghosh, and R. Nandi, "A comprehensive review of food waste valorization for the sustainable management of global food waste," *Sustainable Food Technology*, vol. 2, no. 1, pp. 48–69, 2024, doi: 10.1039/D3FB00156C.

[6] F. Ronsse, S. van Hecke, D. Dickinson, and W. Prins, "Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions," *GCB Bioenergy*, vol. 5, no. 2, pp. 104–115, Mar. 2013, doi: 10.1111/gcbb.12018.

[7] N. Cai, H. Zhang, J. Nie, Y. Deng, and J. Baeyens, "Biochar from Biomass Slow Pyrolysis," *IOP Conf Ser Earth Environ Sci*, vol. 586, no. 1, p. 012001, Oct. 2020, doi: 10.1088/1755-1315/586/1/012001.

[8] M. Maniscalco, G. Infurna, G. Caputo, L. Botta, and N. Tz. Dintcheva, "Slow Pyrolysis as a Method for Biochar Production from Carob Waste: Process Investigation and Products' Characterization," *Energies (Basel)*, vol. 14, no. 24, p. 8457, Dec. 2021, doi: 10.3390/en14248457.

[9] P. Srivatsav, B. S. Bhargav, V. Shanmugasundaram, J. Arun, K. P. Gopinath, and A. Bhatnagar, "Biochar as an Eco-Friendly and Economical Adsorbent for the Removal of Colorants (Dyes) from Aqueous Environment: A Review," *Water (Basel)*, vol. 12, no. 12, p. 3561, Dec. 2020, doi: 10.3390/w12123561.

[10] B. Qiu, X. Tao, H. Wang, W. Li, X. Ding, and H. Chu, "Biochar as a low-cost adsorbent for aqueous heavy metal removal: A review," *J Anal Appl Pyrolysis*, vol. 155, p. 105081, May 2021, doi: 10.1016/j.jaap.2021.105081.

[11] N. Jagadeesh and B. Sundaram, "Adsorption of Pollutants from Wastewater by Biochar: A Review," *Journal of Hazardous Materials Advances*, vol. 9, 2023, doi: 10.1016/j.hazadv.2022.100226.

[12] C. L. Yiin, S. Yusup, P. Udomsap, B. Yoosuk, and S. Sukkasi, "Stabilization of Empty Fruit Bunch (EFB) derived Bio-oil using Antioxidants," 2014, pp. 223–228. doi: 10.1016/B978-0-444-63456-6.50038-7.

[13] Y. Y. Chong, S. Gan, L. Y. Lee, H. K. Ng, and S. Thangalazhy-Gopakumar, "Role of catalysts in biofuel production through fast pyrolysis," in *Bioenergy Engineering*, Elsevier, 2023, pp. 115–132. doi: 10.1016/B978-0-323-98363-1.00023-5.

[14] S. Bielfeldt *et al.*, "Observer-blind randomized controlled study of a cosmetic blend of safflower, olive and other plant oils in the improvement of scar and striae appearance," *Int J Cosmet Sci*, vol. 40, no. 1, pp. 81–86, Feb. 2018, doi: 10.1111/ics.12438.

[15] O. Onay and O. M. Kockar, "Slow, fast and flash

pyrolysis of rapeseed," *Renew Energy*, vol. 28, no. 15, pp. 2417–2433, Dec. 2003, doi: 10.1016/S0960-1481(03)00137-X.

[16] J. O. Ighalo *et al.*, "Flash pyrolysis of biomass: a review of recent advances," *Clean Technol Environ Policy*, vol. 24, no. 8, pp. 2349–2363, Oct. 2022, doi: 10.1007/s10098-022-02339-5.

[17] C. Gai, Y. Dong, and T. Zhang, "The kinetic analysis of the pyrolysis of agricultural residue under non-isothermal conditions," *Bioresour Technol*, vol. 127, pp. 298–305, Jan. 2013, doi: 10.1016/j.biortech.2012.09.089.

[18] A. Saffe, A. Fernandez, M. Echegaray, G. Mazza, and R. Rodriguez, "Pyrolysis kinetics of regional agro-industrial wastes using isoconversional methods," *Biofuels*, vol. 10, no. 2, pp. 245–257, Mar. 2019, doi: 10.1080/17597269.2017.1316144.

[19] M. Nour, M. Amer, A. Elwardany, A. Attia, X. Li, and S. Nada, "Pyrolysis, kinetics, and structural analyses of agricultural residues in Egypt: For future assessment of their energy potential," *Clean Eng Technol*, vol. 2, p. 100080, Jun. 2021, doi: 10.1016/j.clet.2021.100080.

[20] R. K. Mishra, S. U. Naik, S. M. Chistie, V. Kumar, and A. Narula, "Pyrolysis of agricultural waste in a thermogravimetric analyzer: Studies of physicochemical properties, kinetics behaviour, and gas compositions," *Mater Sci Energy Technol*, vol. 5, pp. 399–410, 2022, doi: 10.1016/j.mset.2022.09.001.

[21] N. Madany, M. Gadalla, F. Ashour, and M. Abadir, "Investigating the kinetic parameters in the thermal analysis of jojoba cake," *Egypt J Chem*, vol. 0, no. 0, pp. 0–0, Oct. 2022, doi: 10.21608/ejchem.2022.160576.6924.

[22] S. T. Aly, Sh. K. Amin, S. A. El Sherbiny, and M. F. Abadir, "Kinetics of isothermal oxidation of WC–20Co hot-pressed compacts in air," *J Therm Anal Calorim*, vol. 118, no. 3, pp. 1543–1549, Dec. 2014, doi: 10.1007/s10973-014-4044-4.

[23] R. Ebrahimi-Kahrizsangi and M. H. Abbasi, "Evaluation of reliability of Coats-Redfern method for kinetic analysis of non-isothermal TGA," *Transactions of Nonferrous Metals Society of China*, vol. 18, no. 1, pp. 217–221, Feb. 2008, doi: 10.1016/S1003-6326(08)60039-4.

[24] A. C. R. Lim, B. L. F. Chin, Z. A. Jawad, and K. L. Hii, "Kinetic Analysis of Rice Husk Pyrolysis Using Kissinger-Akahira-Sunose (KAS) Method," *Procedia Eng*, vol. 148, pp. 1247–1251, 2016, doi: 10.1016/j.proeng.2016.06.486.

[25] B. Khiari, M. Massoudi, and M. Jeguirim, "Tunisian tomato waste pyrolysis: thermogravimetry analysis and kinetic study," *Environmental Science and Pollution Research*, vol. 26, no. 35, pp. 35435–35444, Dec. 2019, doi: 10.1007/s11356-019-04675-4.

[26] F. Zaman, Z. Du, A. Munawar, M. W. Ishaq, and Y. Guan, "Pyrolysis kinetics and conversion of pomegranate peels into porous carbon," *Environ Prog Sustain Energy*, vol. 42, no. 5, Sep. 2023, doi: 10.1002/ep.14153.

[27] M. M. Alashmawy, H. S. Hassan, S. A. Ookawara, and A. E. Elwardany, "Thermal decomposition characteristics and study of the reaction kinetics of tea-waste," *Biomass Convers Biorefin*, vol. 13, no. 11, 2023, doi: 10.1007/s13399-023-04017-y.

[28] F. Demir, B. Dönmez, H. Okur, and F. Sevim, "Calcination Kinetic of Magnesite from ThermogravimetricData,"*ChemicalEngineering Research and Design*, vol. 81, no. 6, pp. 618–622, Jul. 2003, doi: 10.1205/026387603322150462.

[29] Fedunik-Hofman, Bayon, and Donne, "Comparative Kinetic Analysis of CaCO3/CaO Reaction System for Energy Storage and Carbon Capture," *Applied Sciences*, vol. 9, no. 21, p. 4601, Oct. 2019, doi: 10.3390/app9214601.

[30] P. E. Sánchez-Jiménez, L. A. Pérez-Maqueda, A. Perejón, and J. M. Criado, "Limitations of model-fitting methods for kinetic analysis: Polystyrene thermal degradation," *Resour Conserv Recycl*, vol. 74, pp. 75–81, May 2013, doi: 10.1016/j.resconrec.2013.02.014.

[31] H. Mahmood, A. Shakeel, A. Abdullah, M. Khan, and M. Moniruzzaman, "A Comparative Study on Suitability of Model-Free and Model-Fitting Kinetic Methods to Non-Isothermal Degradation of Lignocellulosic Materials," *Polymers (Basel)*, vol. 13, no. 15, p. 2504, Jul. 2021, doi: 10.3390/polym13152504.

[32] A. Dhaundiyal, S. B. Singh, M. M. Hanon, and R. Rawat, "Determination of Kinetic Parameters for the Thermal Decomposition of Parthenium hysterophorus," *Environmental and Climate Technologies*, vol. 22, no. 1, pp. 5–21, Feb. 2018, doi: 10.1515/rtuect-2018-0001.

[33] hanaa abdelhady, magdi Abadir, H. Sibak, and jasmine abdelraouf, "Kinetics of pyrolysis of water hyacinth: A novel empirical approach," *Egypt J Chem*, vol. 0, no. 0, pp. 0–0, Mar. 2022,

doi: 10.21608/ejchem.2022.125143.5565.

[34] P.N. Sheth and B.V. Babu, "Kinetic modeling of the pyrolysis of biomass" National Conference on Environmental Conservation (NCEC-2006), BITS-Pilani," https://www.researchgate.net/publication/265379709_Kinetic_Modeling_of_the_Pyrolysis_of_Biomass.

[35] A. Bieniek, M. Reinmöller, F. Küster, M. Gräbner, W. Jerzak, and A. Magdziarz, "Investigation and modelling of the pyrolysis kinetics of industrial biomass wastes," *J Environ Manage*, vol. 319, p. 115707, Oct. 2022, doi: 10.1016/j.jenvman.2022.115707.

[36] S. Sunphorka, B. Chalermsinsuwan, and P. Piumsomboon, "Artificial neural network model for the prediction of kinetic parameters of biomass pyrolysis from its constituents," *Fuel*, vol. 193, pp. 142–158, Apr. 2017, doi: 10.1016/j.fuel.2016.12.046.

[37] T. Xie, R. C. Wei, C. Z. Gong, and J. Wang, "Thermal Oxidative Decomposition of Soybean Straw: Thermo-Kinetic Analysis via Thermogravimetric Analysis and Artificial Neural Networks," *IOP Conf Ser Earth Environ Sci*, vol. 581, no. 1, p. 012019, Nov. 2020, doi: 10.1088/1755-1315/581/1/012019.

[38] A. Hai *et al.*, "Valorization of groundnut shell via pyrolysis: Product distribution, thermodynamic analysis, kinetic estimation, and artificial neural network modeling," *Chemosphere*, vol. 283, p. 131162, Nov. 2021, doi: 10.1016/j.chemosphere.2021.131162.

[39] L. Dong, R. Wang, P. Liu, and S. Sarvazizi, "Prediction of Pyrolysis Kinetics of Biomass: New Insights from Artificial Intelligence-Based Modeling," *International Journal of Chemical Engineering*, vol. 2022, pp. 1–8, Mar. 2022, doi: 10.1155/2022/6491745.

[40] S. T. Aly, I. A. Ibrahim, and M. F. Abadir, "Kinetics of Pyrolysis of Date Kernels," *Int J Eng Adv Technol*, vol. 9, no. 3, pp. 930–935, Feb. 2020, doi: 10.35940/ijeat.C5419.029320.

[41] M. Raza and B. Abu-Jdayil, "Synergic interactions, kinetic and thermodynamic analyses of date palm seeds and cashew shell waste co-pyrolysis using Coats–Redfern method," *Case Studies in Thermal Engineering*, vol. 47, p. 103118, Jul. 2023, doi: 10.1016/j.csite.2023.103118.

[42] ASTM International, "ASTM C136/C136M Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates," *ASTM Standard Book*, 2019.

[43] S. Vyazovkin, "Kissinger Method in Kinetics of Materials: Things to Beware and Be Aware of," *Molecules*, vol. 25, no. 12, p. 2813, Jun. 2020, doi: 10.3390/molecules25122813.

[44] N. Koga and J. šesták, "Further aspects of the kinetic compensation effect," *Journal of Thermal Analysis*, vol. 37, no. 5, 1991, doi: 10.1007/BF01932804.

[45] D. Rammohan, N. Kishore, and R. V. S. Uppaluri, "Reaction Kinetics of Non-isothermal Pyrolysis of Tube Waste in Thermogravimetric Analyzer," in *Sustainable Energy Generation and Storage*, Singapore: Springer Nature Singapore, 2023, pp. 185–193. doi: 10.1007/978-981-99-2088-4_15.

[46] J. Li *et al.*, "Comparative Study on Pyrolysis Kinetics Behavior and High-Temperature Fast Pyrolysis Product Analysis of Coastal Zone and Land Biomasses," *ACS Omega*, vol. 7, no. 12, pp. 10144–10155, Mar. 2022, doi: 10.1021/acsomega.1c06363.

[47] O. A. Montesinos López, A. Montesinos López, and J. Crossa, "Fundamentals of Artificial Neural Networks and Deep Learning," in *Multivariate Statistical Machine Learning Methods for Genomic Prediction*, Cham: Springer International Publishing, 2022, pp. 379–425. doi: 10.1007/978-3-030-89010-0_10.

[48] I. M. S. Anekwe, "Artificial Intelligence Applications in Solar Photovoltaic Renewable Energy Systems," 2023, pp. 47–86. doi: 10.21741/9781644902530-3.

[49] J. Arcenegui-Troya, P. E. Sánchez-Jiménez, A. Perejón, and L. A. Pérez-Maqueda, "Determination of the activation energy under isothermal conditions: revisited," *J Therm Anal Calorim*, vol. 148, no. 4, pp. 1679–1686, Feb. 2023, doi: 10.1007/s10973-022-11728-3.

[50] I. Bakhattar *et al.*, "Physicochemical characterization, thermal analysis and pyrolysis kinetics of lignocellulosic biomasses," *Biofuels*, vol. 14, no. 10, pp. 1015–1026, Nov. 2023, doi: 10.1080/17597269.2023.2201732.

[51] Y. Li *et al.*, "Pyrolysis kinetics and thermodynamic parameters of bamboo residues and its three main components using thermogravimetric analysis," *Biomass Bioenergy*, vol. 170, p. 106705, Mar. 2023, doi: 10.1016/j.biombioe.2023.106705.

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http://dx.doi.org/10.21622/RESD.2024.10.1.811

[52] J. Cheng, S. C. Hu, G. T. Sun, Z. C. Geng, and M. Q. Zhu, "The effect of pyrolysis temperature on the characteristics of biochar, pyroligneous acids, and gas prepared from cotton stalk through a polygeneration process," *Ind Crops Prod*, vol. 170, 2021, doi: 10.1016/j.indcrop.2021.113690.

[53] N. M. Noor, A. Shariff, N. Abdullah, and N. S. M. Aziz, "Temperature effect on biochar properties from slow pyrolysis of coconut flesh waste," *Malaysian Journal of Fundamental and Applied Sciences*, vol. 15, no. 2, 2019, doi: 10.11113/mjfas.v15n2.1015.

[54] K. Wystalska and A. Kwarciak-Kozłowska, "The Effect of Biodegradable Waste Pyrolysis Temperatures on Selected Biochar Properties," *Materials*, vol. 14, no. 7, p. 1644, Mar. 2021, doi: 10.3390/ma14071644.

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Promoting User Well-being in Central Business District: The Role of Sustainable Open Spaces

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ABSTRACT

Sustainable Open spaces are the heart of every community. They play a great role in connecting people with places. This connection should be considered by every urban designer and architect, especially in the Central Business District (CBD), which is the core of this study. CBDs often face several challenges such as high-density usage and limited open spaces that can serve people. This research aims to define how the design of sustainable open spaces can contribute to the physical, social, and environmental well-being of users and achieve Sustainable Development Goals (SDGs): 3 – "Good Health and Well-being" and 11 – "Sustainable Cities and Communities". In addition to highlighting the main aspects of sustainable urban design elements and user needs for enhancing well-being. Exploring the relation between these two domains as well as identifying their elements and indicators to define the most suitable sustainable design considerations exclusively for open spaces in CBD. The research's methodology adopts a detailed analysis of both international and national case studies, which offers a comparative and contextual understanding of open spaces in different urban settings. In addition to validating the effectiveness of this strategy through urban analysis and questionnaire for users of CBD. Together, they are all used to develop an evaluation matrix to identify the relationship between design elements and their role in transforming open spaces in CBDs to places that can enhance users' well-being and achieve sustainability goals. The research proves that well-designed sustainable open spaces can serve as vital components in healthy urban environments, significantly contributing to the overall quality of life and satisfaction of individuals in CBDs.

Index-words: *User Well-being, Sustainable Open Spaces, SGDs, Urban Design, Central Business Districts.*

I. INTRODUCTION

The Central Business District (CBD) is the vital core of any urban context, which operates as a dynamic hub where business, urban life, and the decision-making process intersect. Cities are rapidly changing, and CBDs continue to evolve into more complex and vibrant spaces. Yet as retail, office, and commercial land uses generate high land values and activity density, the design of sustainable open spaces is often given minimal attention although they form a high percentage of every land which sometimes exceeds the percentage of buildings' footprint. These sustainable open spaces within the CBD have the potential to contribute to the overall well-being of individuals by providing opportunities for physical activity, relaxation, social interaction, and connection with the urban context [1].

The insightful quote from Gehl (2013), "First we shape the cities – then they shape us," highlights the profound impact urban environments can have on its users, which urges the crucial need for thoughtfully designed open spaces. The implications of the oversight of these open spaces are extensive for the overall social, physical, and environmental health of urban citizens.

According to Sustainable Development Goal no. 3 (SDG 3), "Good Health and Well-being" and no. 11, "Sustainable Cities and Communities" together they emphasize the need for creating urban areas that are inclusive, safe, resilient, and sustainable. In these new urban precincts, open spaces have a lead role that supports user well-being, serves a diversity of users, and enhances community interaction, physical health and environmental sustainability which are deemed pivotal. The importance of open spaces in urban areas has been recognized in various studies, highlighting their role in promoting physical activity, reducing stress, fostering social interactions, and enhancing well-being [2]. As urban

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cores continue to grow and evolve, prioritizing the well-being of individuals within these areas becomes increasingly paramount, making this an important area of study.

This research investigates the urban design aspects of these sustainable open spaces that are vital in fulfilling users' well-being needs and seeks to address a significant void in urban design literature. The study aims to articulate the sustainable design of open spaces within the CBD in Egypt which will fulfill the users' well-being needs and constitute its urban form and function. In addition, the significance of this study lies in establishing for the first time the direct links of the relationship between users' well-being and the design of sustainable open spaces within CBDs. It therefore broadens the urban design literature by describing the users' well-being and their spatial and functional needs for sustainable open spaces in CBDs.

Following this manner, analysis for international and national case studies was proposed to develop an evaluation matrix consisting of the two main domains: the urban design aspects of sustainable open spaces and the users' well-being needs. This matrix will not only enhance one's understanding of the critical role of sustainable open spaces in CBDs but also guide future urban design efforts to create healthier, more vibrant, and more sustainable urban environments.

II. CENTRALBUSINESS DISTRICT 'CBD'

CBD, short for Central Business District, serves as the core of a city and is commonly known as downtown or the city center. Originally proposed by E. W. Burgess, an American urban geographer, in 1923, the concept was introduced within his well-known model featuring concentric circles outlining the regional structure of a city [3]. The CBD represents the core of the city, providing optimal accessibility, extensive commercial and banking sectors, as well as governmental establishments. Positioned at the central hub of the city, the CBD is strategically situated for easy access via major rail and road routes, making it the primary focal point for both pedestrian and vehicular traffic. CBD is the hub for offices, banks, shops, and culture and entertainment activities [3].

Characteristics of the city center or CBD make it the most important zone of the city influencing and controlling the morphological form of the city and its expansion [4]. CBD is typically located in the heart of the city' near its oldest part and at the convergence of major road and railway networks, epitomizes urban accessibility and prime location. Its strategic position ensures easy reach from all city areas, making it a magnet for retail outlets and a focal point of the public transport system. This prime location fosters intense competition for space, resulting in exceptionally high land and rent values. Consequently, the CBD is marked by its high-rise architecture, with the tallest buildings often found here due to the premium on land use. However, the CBD is not a monolithic urban space; it boasts a diversity of activities and recreational areas. This internal specialization means that different functions, such as shopping districts, theaters, cinema halls, and entertainment venues, develop their concentrated areas, benefiting from proximity to similar establishments and the ability to attract a large customer base [5] [4].

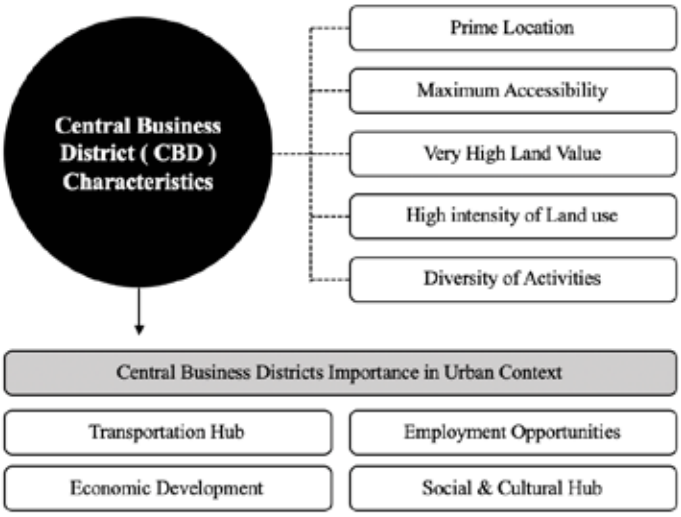

Fig. 1: CBD characteristics and importance
Source: Author

A. Evolution of CBD in Egypt

The evolution of Egypt's CBD reflects the dynamic growth and the changing urban design of the country. Historically centered around downtown Cairo, characterized by its bustling streets and iconic landmarks, the CBD has undergone a transformative shift towards a multi-core model shown in Figure 3. The emergence of west and east Cairo as prominent business hubs signifies a departure from the traditional single-city in Figure 2. This new prototype of the CBD admits the need for decentralization and accommodates the expanding business activities in different regions of the capital. The decentralization trend aims to alleviate congestion, enhance accessibility, and foster economic development across diverse areas, contributing to a more balanced and resilient urban environment. As multiple cores continue to develop, Egypt's CBD is evolving into a networked system that strategically distributes economic activities, thereby shaping a more sustainable and inclusive urban design.

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Fig. 2. Egypt Layout

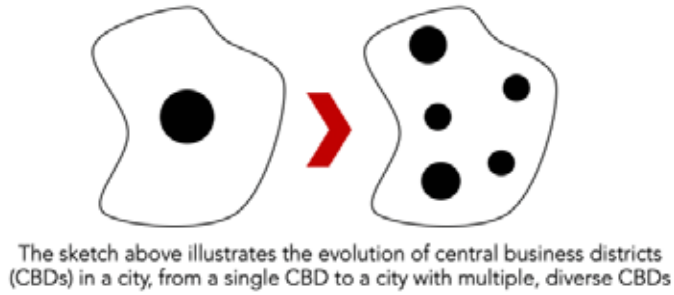

Fig. 3. New Pattern Of CBDs

2.2 Challenges Facing CBDs

The challenges facing the CBD urban design include:

- Traffic Congestion: CBDs often tackle high levels of traffic congestion due to a concentrated number of users, leading to inefficiencies and lost economic productivity [6].
- Air Quality: The high density of vehicles and urban activities in CBDs can lead to poor air quality, posing health risks and reducing the quality of life [7].
- Crime and Security: Perception of crime and actual safety concerns can deter people from visiting or working in CBDs, impacting businesses and property values [8].
- Parking Availability: Limited parking due to high land use can result in a scarcity of convenient parking, further exacerbating traffic congestion [9].
- High Land Values Elevated land prices in CBDs can limit the development of open spaces, contributing to social inequality [10].
- Noise Pollution: The concentration of commercial activity and traffic in CBDs leads to high levels of noise, impacting the well-being of residents and workers [11].
- Social Inequality: The focus on commercial development in CBDs can overshadow the needs of users, leading to improvement and displacement [12].
- Lack of Open Spaces: In many CBDs, the emphasis on building development has come at the cost of open spaces, which are crucial for social interaction and recreation [13].

III. SUSTAINABLE OPEN SPACES 'MORE THAN JUST A SPACE'

Urban sustainable open spaces are vital components of the urban environment, providing areas for social interaction, recreation, and ecological functions within cities. These spaces include a variety of public areas such as parks, gardens, plazas, green belts, and natural landscapes integrated within urban settings. The definition of urban open spaces is multifaceted, reflecting their diverse functions and forms. They are often characterized by their accessibility to the public, their contribution to the aesthetic and cultural aspects of urban life, and their role in improving environmental quality. Urban sustainable open spaces serve as crucial elements for urban planning and development, offering benefits such as enhancing the quality of life and contributing to the well-being of urban users [14]. Considered the living room of any city, these spaces serve as places where people gather to enrich their social lives, contributing to a higher quality of life in the city.

A. Open Spaces within CBDs

In the context of CBDs, urban open spaces such as parks, plazas, squares, and pedestrian walkways are essential for creating a balance between the built environment and natural elements. These spaces in CBDs serve as crucial green lungs, providing residents, workers, and visitors with areas for relaxation, socialization, and engagement with nature within the urban hustle [15]. The integration of such open spaces is vital for enhancing the livability and sustainability of CBDs, offering benefits like improved air quality, reduced urban heat island effect, and increased biodiversity [16]. Furthermore, these areas have been recognized for their role in improving well-being and fostering community interaction in urban settings [17].

B. Urban Design Elements of Sustainable Open Spaces

This section explores urban design elements of sustainable open spaces supported by many experts, it outlines key design elements such as accessibility, safety, comfort, and engagement with nature, which are essential in cultivating open spaces that serve as catalysts for healthy urban living. The characteristics identified in this section are not merely theoretical ideals but are grounded in a growing body of research that underscores the tangible benefits of well-conceived open spaces.

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Table I
Open Space Characteristics. (Source: Author)

Characteristics	Reference 01: Smith 2020	Reference 02: Johnson 2019	Reference 03: Lee 2021	Reference 04: Davis 2018	Reference 05: Patel 2022
Accessibility	Easy access for all	Wheelchair accessibility	Proximity to public transit	Well-defined entry points	Safe pedestrian pathways
Connectivity	Network with other public spaces	Links to urban amenities	Bicycle friendly paths	Access to public transportation	Integration with the neighborhood
Usability	Flexible space for events	Suitable for all age groups	Areas for both active & passive use	Durable materials for high-use	Technology integration for convenience
Safety	Good lighting	Emergency services access	Visible security presence	Low crime rate areas	Well-maintained facilities
Comfort	Adequate & art	Shade & shelter	Clean restrooms	Quiet zones for relaxation	Temperature control features
Aesthetic	Landscaping & art	Natural elements integration	Harmonious design with surroundings	Seasonal decorations	Unique architectural features
Amenities	Water fountains	Food & beverage options	Restrooms and first aid stations	Children's play area	Fitness equipment
Green spaces	Native plant species	Eco-friendly maintenance	Community garden areas	Biodiversity support	Sustainable water features
Sustainability	Renewable energy sources	Waste recycling facilities	Eco-friendly materials	Water conservation practices	Energy-efficient lighting
Sociability	Spaces for social gatherings	Community event hosting	Areas for group activities	Welcoming layout for meeting friends	Family-friendly environment

The unique methodology of Jan Gehl Architects is based on the principle that people are the most important priority of public space in the process of planning cities. Public space should be a place for everyone that includes unique qualities and benefits of a particular urban environment, open to a variety of activities and opportunities [13].In his books, such as "Life Between Buildings" and "Cities for People," Gehl emphasizes the following characteristics as essential for good open spaces:

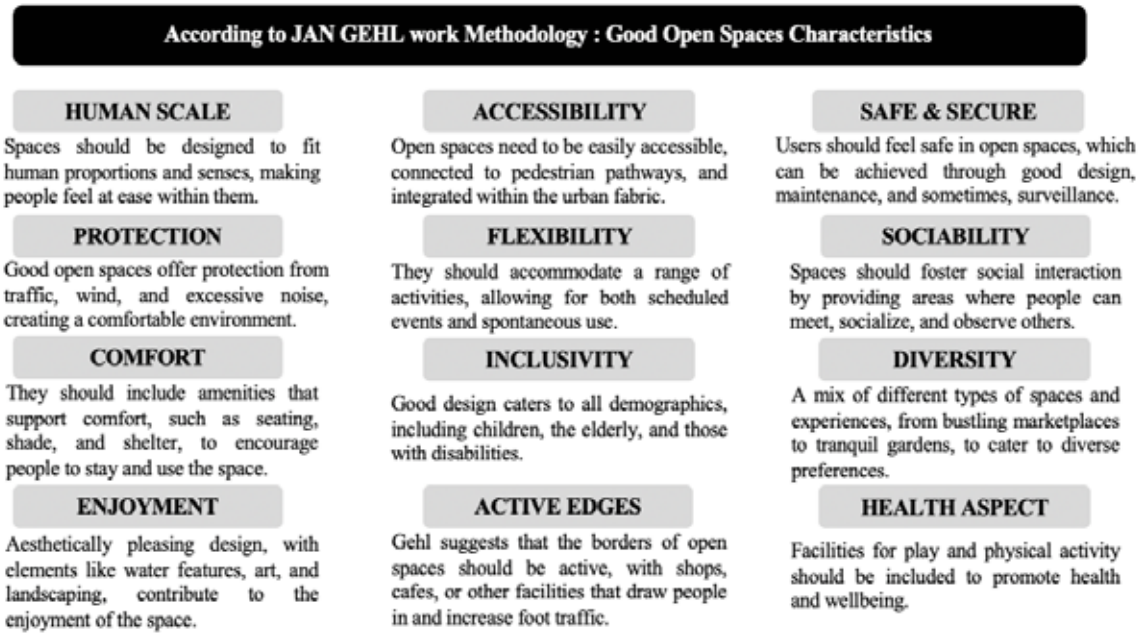

Fig. 4. Open spaces design elements according to Jan Gehl

Gehl's approach to urban design is user-centric, focusing on enhancing the quality of life by making cities more livable, sustainable, and healthy through well-designed open spaces.

IV. WELL-BEING

Well-being, a multifaceted concept allowing for diverse interpretive approaches, is generally defined as a state of happiness, health, or prosperity [18]. It is a valuable aspect of life, often influenced by living conditions and circumstances. Various fields of study, including philosophy [19], social sciences [20] and psychology, have explored the concept of well-being. In psychology, a notable framework is Maslow's Hierarchy of Needs (1981) which suggests that people satisfy a series of needs in a specific order, from basic survival needs at the bottom of the hierarchy to self-actualization needs at the top. Maslow theorized that a person cannot pursue a higher need until the current one is met. In the context of urban design, Mehan and Soflaei equate human needs with those in Maslow's hierarchy, translating these needs into spatial qualities projected into space design.

A. User's Well-being Needs

The wellness wheel illustrates a wellness model with eight dimensions: social, physical, emotional, occupational, spiritual, intellectual, environmental, and financial. All of the dimensions are interconnected and important to a well-rounded and balanced lifestyle [21]. This research focuses on three dimensions of the Well-being Wheel Physical, Social, and Environmental Well-being that can be achieved through the good design of open spaces within CBD.

- ***Social Well-being Needs***

The social dimension encourages connecting with others and contributing to one's community, with the understanding that satisfying relationships are basic to physical and emotional health [22]. Enhancing social well-being in open spaces involves creating environments that facilitate positive social interactions, community engagement, and a sense of belonging. Here are key considerations to meet user needs and promote social well-being in open spaces: seating arrangements, gathering spaces, plazas and community squares, cultural & art installations, outdoor cafes, and event spaces.

- ***Physical Well-being Needs***

Physical well-being is the ability to maintain a healthy and balanced life without physical limitations, physical stress, and excessive fatigue [22]. The World Health Organization [7] defines physical well-being as being a key factor when it comes to one's overall health. Meeting user needs in open spaces to enhance physical well-being involves thoughtful planning, design, and maintenance of these spaces. Here are key considerations to ensure open spaces effectively contribute to the physical well-being of users: Accessibility, safety and security, diversity of activities, greenery and natural elements, seating areas, landscape, and fitness facilities.

- ***Environmental Well-being Needs***

The environmental dimension encompasses a healthy relationship with the earth and its resources, as well as fostering a positive connection with one's immediate surroundings. It entails grasping the interactive link between the environment and individuals and acknowledging one's accountability for the quality of the air, water, and land that envelops man. Simultaneously, it recognizes the impact of social, natural, and constructed environments on one's health and overall well-being. One's environment and one's sentiments towards it significantly influence one's lifestyle and engaging with natural settings can contribute to enhancing one's overall well-being [22].

A. Importance of Well-being & Sustainable Development

The nexus of well-being, urban design, and sustainable development in open spaces within CBD is increasingly recognized as vital for the holistic health of individuals and communities. Sustainable urban design is pivotal in crafting spaces that support physical, social, and environmental needs for enhancing well-being, aligning with the broader goals of sustainable development to foster resilient, inclusive, and environmentally responsible urban environments [23]. Well-designed open spaces encourage physical activity, provide opportunities for social interaction, and facilitate a connection with nature, all of which are crucial components of well-being [24]. Furthermore, these sustainable open spaces offer ecosystem services such as improved air quality and natural cooling, contributing to the environmental dimension of sustainability. By integrating sustainability principles, urban design can address the needs of present and future generations, promoting well-being through the creation of livable cities that balance ecological integrity with human health and happiness [25].

V. RESEARCH METHODOLOGY

This study consists of a two-part methodology to explore the impact of open spaces on user well-being in CBDs.

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A. Theoretical Framework

- **Literature Review**

CBDs: Research the characteristics, challenges, and dynamics of CBDs. Focus on aspects of economic activities and urban design. Sustainable Open Spaces: Define open spaces in the context of urban environments, especially in CBDs. Explore characteristics and their roles in urban ecology and social interactions. User Well-Being: Investigate how well-being is defined and should have more attention in urban studies. Include physical, social, and environmental needs. Impact of Sustainable Open Spaces on Well-Being: Synthesize existing research on how open spaces influence well-being in urban settings, focusing on CBDs.

- **Evaluation Matrix**

Matrix Creation: Develop an evaluation matrix from the literature review and analysis of international cases. This matrix should outline key design elements of sustainable open spaces and their potential impacts on user well-being.

B. Empirical Research

- **Analysis of International Case Study**

International Case Study: Select exemplary CBDs where open spaces have been integrated effectively. Analyze the design, usage, and impact on physical, social and environmental well-being.

- **Analysis of National Case Study**

Selection of a National Case Study: Choose one of the new prototypes of CBD with notable open spaces for an in-depth case study. This should ideally be a location where substantial changes in open space design have been implemented.

Data collection tools used employed both primary and secondary tools. The primary tools included: On-site observations through twenty field trips to selected CBDs to indicate the design of open spaces using the well-being indicators deduced from stage one. Eight trips were made on weekends (Four trips in the day and four trips at night). The other twelve trips were done on the weekdays (six trips a day and six trips at night).

The secondary tools included a questionnaire distributed for the National Case Study Arkan Plaza.

- **Filling the Matrix**

Application of Findings: Use the literature review data, the empirical data from the case study, Observation, and results of the questionnaire to fill the evaluation matrix. This should help in identifying which design elements are most effective in enhancing well-being.

Comparative Analysis: Compare these findings with the initial literature review to validate or challenge existing theories to set the most important design elements for sustainable open spaces based on user well-being.

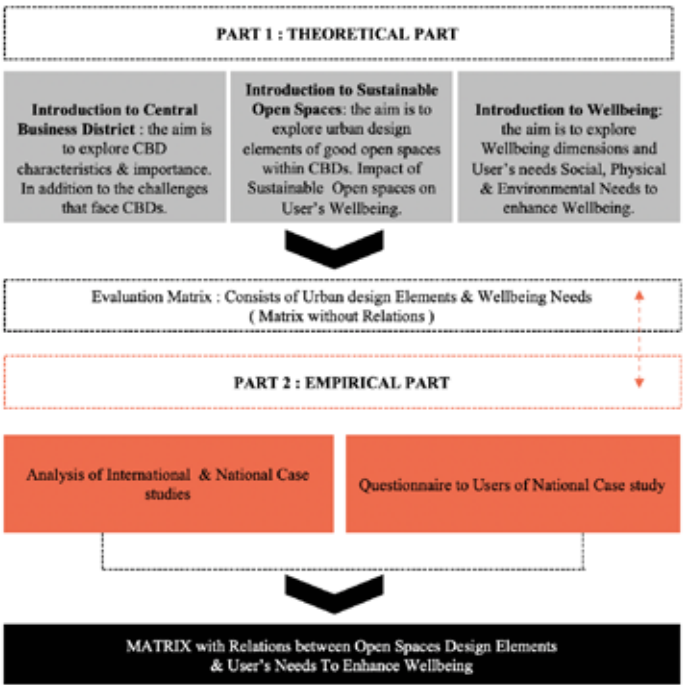

Fig. 5. Research methodology
Source: Author

VI. EVALUATION MATRIX AS A TOOL: RELATIONSHIPS BETWEEN OPEN SPACES AND USER'S WELL_BEING

As mentioned before, stage one of this study is concerned with identifying indicators for measuring the impact of open space design and user well-being especially in CBD, According to the literature review, open space can be classified in terms of space characteristics as compatibility to surroundings, location, comfort, legibility, flexibility, continuity and enclosure, active façade, diversity of activities, landscape elements, accessibility, circulation, services, safety and security and sociability, while the well-being indicators and user needs within the open spaces of the following categories: Physical Well-being, Social Well-being, and Environmental well-being are shown in table II.

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TABLE II
MATRIX (Source: Author)

URBAN DESIGN ELEMENTS			WELLBEING INDECATORS																		
			Evaluation Matrix ; Relationships between CBD Design and the User Needs & Wellbeing				Physical Needs						Social Needs				Environmental Needs				
				Strong Relation	Moderate Relation	Weak Relation	Promote safe Walking	Promote Sport Activity	Promote Cyclying	Access to green spaces	Access to recreational facilities	Access to Eat & Drink	promote Safety & security	Access to Gathering Events	Promote Social interaction	promote a sense of attachment to place	Easy access to resources	Protect biodiversity	promote shading areas	Keep space clean	Reduce Noise pollution	Availability of green spaces
				●	◒	○															
			Compatibility to Surroundings																		
			location																		
			Comfort																		
			Flexibility																		
			Continuity & Enclosure																		
			Inclusivity																		
			Human Scale																		
			Active Edges																		
			Active Building facades																		
			Diversity of Activities																		
	Landscape Elements		Green Spaces																		
			Outdoor Furniture																		
			Shaded Areas																		
			Lighting Arrangement																		
			Landmarks																		
			Water Features																		
	Space Accessibility		Vehicles																		
			Public Transportation																		
			Pedestrian																		
			Cycling																		
	Circulation & Legibility		Connected Pedestrian Paths																		
			Cycling Lanes																		
			Entry & Exist Nodes																		
	Amenities		Public Toilets																		
			Parking																		
			Cafes & Restaurants																		
			Management & Maintenace																		
	Safety & Security		Signs for ease movement																		
			Suitable Lighting																		
			surveillance																		

VII. CASE STUDIES

Two case studies were selected: An international case study and a national case study provided that each case study meets the criteria for designing open spaces within CBD. Certainly, the requirements and needs of the user within the open space are carefully considered in general and indicators for better well-being. The study is analyzed through the observation and documentation of the open spaces within CBD using the concluded criteria of analysis from the matrix review in terms of the open spaces' design elements. Besides, the study analysis of the user needs to enhance physical, social, and environmental well-being. Later, this helps identify the nature and components of the open spaces and the requirements to be considered when dealing with or designing an open space with the help of urban design elements.

The selection criteria for urban open spaces in CBDs, aimed at enhancing user well-being, prioritize spaces that are integral to the health, happiness, and vitality of the urban spaces. These criteria include:

1. Accessibility: Open spaces must be easily reachable by pedestrian, cycle, and public transportation, ensuring that all user types can access these spaces.
2. Diversity of Use: They should offer a variety of functions and facilities to cater for different activities, such as leisure, exercise, social gatherings, and cultural events, encouraging varied and regular use.
3. Safety and Security: The area should be designed to feel safe at all hours, with adequate lighting, visibility, and potentially, surveillance measures.
4. Environmental Quality: The space should contribute to environmental health, incorporating greenery to mitigate air pollution and urban heat island effects, and providing the feeling of comfort.
5. Social Interaction: Design elements should facilitate social behavior, with seating arrangements and open areas that encourage gatherings and community-building activities.
6. Aesthetic Appeal: The design should include elements that enhance the beauty and character of the CBD, making the space inviting and uplifting for users.

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A. International Case Study: Exchange Square, Broadgate CBD in London

CATEGORIES: **URBAN & LANDSCAPE**
DESIGNER: **DSDHA**
CLIENTS: **British Land**
SIZE: **6,000 sqm**

Introduction for Broadgate CBD
Broadgate is a 32-acre pedestrianized estate, formerly the site of Broad Street Railway Station, featuring office buildings, shops, and facilities. Conveniently located next to Liverpool Street station and within walking distance to Shoreditch, Old Street, and Spitalfields, it is a preferred location for many businesses. The estate is planning a 6,000-square-meter park that will feature a water element, a new restaurant, and an event space.

Broadgate is a 32-acre pedestrianized estate, formerly the site of Broad Street Railway Station, featuring office buildings, shops, and facilities. Conveniently located next to Liverpool Street station and within walking distance to Shoreditch, Old Street, and Spitalfields, it is a preferred location for many businesses. The estate is planning a 6,000-square-meter park that will feature a water element, a new restaurant, and an event space.

Fig. 6. Master plan
Source: DSDHA

Fig. 7. Exchange Square
Source: DSDHA

Project Aim:

HEALTH AND WELL-BEING form a vital part of the investment in Broadgate to create an environment that brings people together to work, shop, drink, and dine.

The Broadgate development serves as a compelling case study in the successful application of urban design principles to enhance user well-being. The project's success can be attributed to its emphasis on key open space indicators such as accessibility, character, diversity, legibility, safety, and comfort. Broadgate's strategic location adjacent to Liverpool Street station and within walking distance to Shoreditch, Old Street, and Spitalfields, ensures high accessibility as shown in Figure 8, making it a preferred choice for many businesses. The character of the space is defined by its unique blend of office buildings, shops, and facilities within a pedestrianized estate as shown in Figure 9 that was once the site of the Broad Street Railway Station.

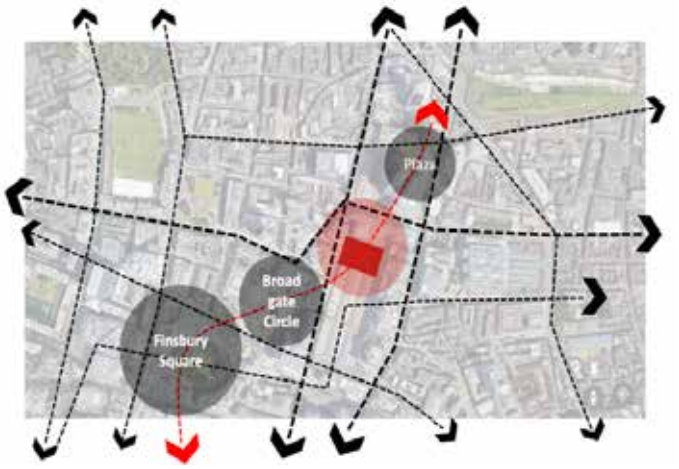

Fig. 8. Accessibility layout
Source: Author

Fig. 9. Main Plaza in Exchange Square
Source: DSDHA

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Physical Needs: The square provides pedestrian-friendly pathways, promoting safe walking and potentially dedicated lanes that encourage cycling, contributing to active transportation. It may feature open areas or equipment for physical activities, fostering sport and exercise in an urban setting. Providing a diversity of amenities such as cafes, restaurants, and restrooms within the space, as well, the square is near Broadgate Circle as shown in Figure 8 which has commercial and retail activities around the square that can offer convenient access to food and drink, serving user needs.

Fig. 10. Main Plaza at night
Source: DSDHA

Fig. 11. Liverpool station
Source: DSDHA

Social Needs: The design of Exchange Square probably includes seating arrangements and gathering spaces that promote social interaction and facilitate community events, which are crucial for social well-being as shown in Figure 10. The square includes features like public art, water features, and performance spaces, which can enhance the social environment, fostering engagement and a sense of attachment to the place. The layout design provides easy accessibility, legibility, and safety feelings for users as shown in Figure 11.

Environmental Needs: The inclusion of greenery through landscaping or the presence of trees can help protect biodiversity and offer shading areas as shown in Figure 12, enhancing environmental quality and user comfort. Maintenance protocols aim to keep the space clean, contributing to both environmental stewardship and the users' sense of well-being. Measures to reduce noise pollution, such as the strategic placement of vegetation and water features as illustrated in Figures 13 and 12, create a more tranquil urban atmosphere. The availability of green spaces within Exchange Square can offer users a connection to nature, which is known to have several benefits for mental health and overall well-being.

Fig. 12. Main Plaza at night
Source: DSDHA

Fig. 13. Liverpool station
Source: DSDHA

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Exchange Square stands as a good model of how urban open spaces within CBDs can significantly contribute to enhancing user well-being. Its strategic design links accessibility, safety, and a connection to nature, addressing the physical, social, and environmental needs of its users. Through its commitment to inclusivity and quality of space, Exchange Square does not only support the vitality of the CBD, but also elevates the urban experience, affirming the essential role of well-designed open spaces in the health and happiness of city residents.

B. National Case Study: Arkan Plaza in Cairo

LOCATION: AL SHEIKH ZAYED, GIZA, EGYPT.
SCOPE: URBAN & LANDSCAPE
SCALE: 260,000 m2.
OWNER: BADER ELDEIN DEVELOPMENT

INTRODUCTION FOR ARKAN CBD

Arkan was Established by El Badr Commercial Development in 2012. Arkan Plaza is a prominent mixed-use commercial project encompassing offices, clinics, retail establishments, and restaurants. Over time, Arkan has transformed into the principal commercial and social hub in West Cairo, centrally located in the heart of Sheikh Zayed.

Fig. 14. Arkan Plaza
Source: Author

Fig. 15. Arkan Main Plaza
Source: Savills

Arkan Plaza, located in the heart of Sheikh Zayed, Egypt, serves as a model of a CBD that prioritizes user well-being through thoughtful design of open spaces. Arkan Plaza has quickly become a significant commercial and social destination in the city. Arkan Plaza is a highly accessible location, it is surrounded by Main Streets from all three sides, and one side is attached to another project. The Main Highway (26th of July Corridor), El Bostan Road & El Zouhor Road as shown in Figure 16.

Fig. 16. Arkan location
Source: Author

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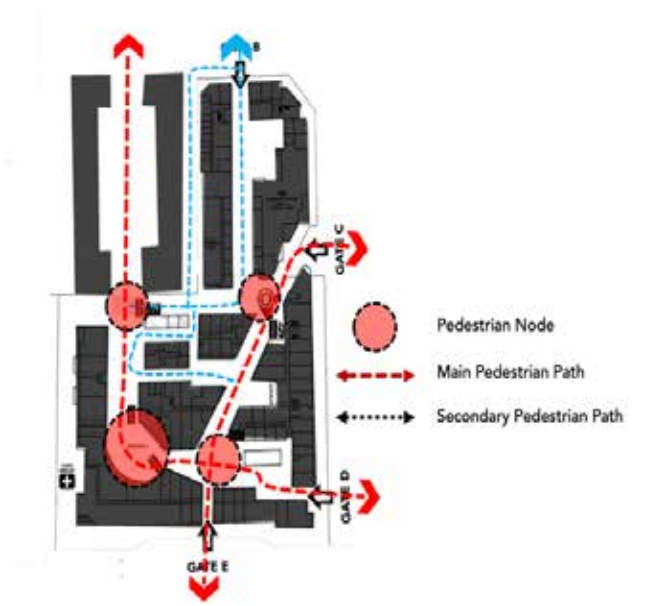

Fig. 17. Circulation at Arkan
Source: Author

Physical Needs: The design of the Plaza emphasizes accessibility by continuity of pedestrian paths and nodes as shown in Figure 17, with a variety of shops, kiosks, and restaurants catering to diverse needs of users from food, beverage, clothing, and fashion to gifts, and antiques, making it a convenient one-stop destination for visitors. The character of Arkan Plaza is defined by its architectural design, which strikes a balance between modernity and timeless elegance. Lighting arrangement in open spaces and high-quality materials creates a visually stunning environment that enhances the overall user experience and promotes safe walking at night as shown in Figures 18 and 19.

Fig. 18. Main plaza at night
Source: Author

Fig. 19. Lighting at night
Source: Author

Social Needs: The Plaza provides diversity. It houses a mix of commercial and office spaces, and its culinary offerings range from high-end restaurants to coffee shops as shown in Figure 18. This diversity does not only cater for a broad variety of tastes but also contributes to the vibrant and dynamic atmosphere of the Plaza. Providing gathering spaces, common areas, and seating encourages socialization, allowing for meetings and community bonding as manifested in Figure 20. As for the event venues, the Plaza may host event spaces for cultural, entertainment, leisure, or market activities that bring people together as shown in Figure 21.

Fig. 20. Main Plaza at night
Source: Author

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Fig. 21. Night events at Arkan
Source: Author

Environmental Needs: Arkan Plaza prioritizes safety and comfort. The Plaza is designed to be a welcoming and secure environment where visitors can relax and enjoy their time. As for the sustainable practices, the Plaza incorporates sustainable design elements such as energy-efficient lighting and design features likely to address the hot Egyptian climate with shading devices, water features, and environment-friendly material to cool the environment as shown in Figures 21 and 23.

Fig. 22. Shading device for main pathway
Source: Author

Fig. 23. Comfort shaded pathways
Source: Author

VIII. QUESTIONNAIRE RESULTS

A comprehensive questionnaire was distributed to users of Arkan Plaza in Egypt, to evaluate their well-being in the open spaces within the mixed-use complex. The survey, which was conducted over five months from October 2023 to February 2024, garnered a total of 100 responses. The distribution of the questionnaire at different times ensured a diverse range of insights reflective of various user experiences. Before the full-scale survey, a pilot study was executed to refine the questionnaire, ensuring that the questions effectively seized the relevant aspects of well-being as experienced by the users of Arkan Plaza. The primary objective of this questionnaire was to assess how these open spaces contribute to the physical, social, and environmental well-being of the individuals who frequent them, thus providing a data-driven foundation for further enhancements to the urban design of Arkan Plaza.

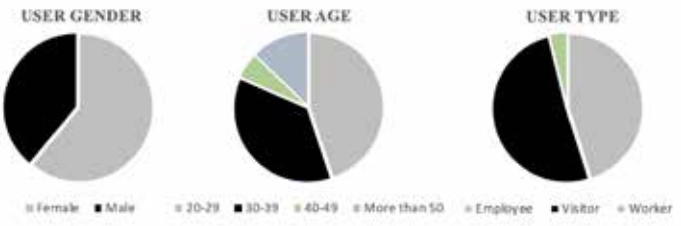

Fig. 24. User Gender, User Age & User Type
Source: Author

User Gender: This chart is split into two categories, showing the distribution between Female and Male users. The chart indicates a larger segment for females 61% of users compared to Male users.

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User Age: The largest portion of users falls within the 30-39 age group, followed by the 20-29 age group. The 40-49 and more than 50 age groups make up a smaller portion of the users.

User Type: The final chart categorizes users into three types: Employee, Visitor, and Worker. The Visitor segment appears to be the most significant 52%, followed by Employees 46%, with Workers being the smallest group.

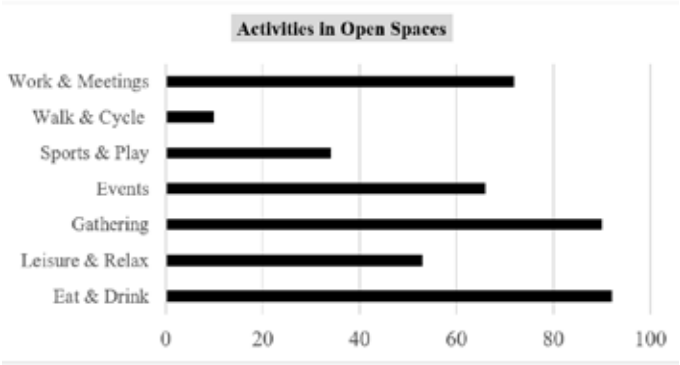

Fig. 25. User Gender, User Age & User Type.
Source: Author

'Eat & Drink' activities emerge as the most popular, suggesting that open spaces serve not only as places of leisure but also as social hubs where food and beverages play a significant role in the user experience. Following closely is 'Gathering', which indicates these areas are vital for community engagement and social events. 'Work & Meetings' also scored notably, revealing that open spaces are increasingly to have formal interactions and professional exchanges. 'Leisure & Relax' activities are surprisingly less common than one might expect, possibly due to the multi-use nature of these spaces that prioritize more active and social uses. Meanwhile, 'Walk & Cycle' activities are the least engaged in, perhaps reflecting a need for better infrastructure to support these modes of movement or a user preference for more stationary activities in such environments as shown in Figure 23.

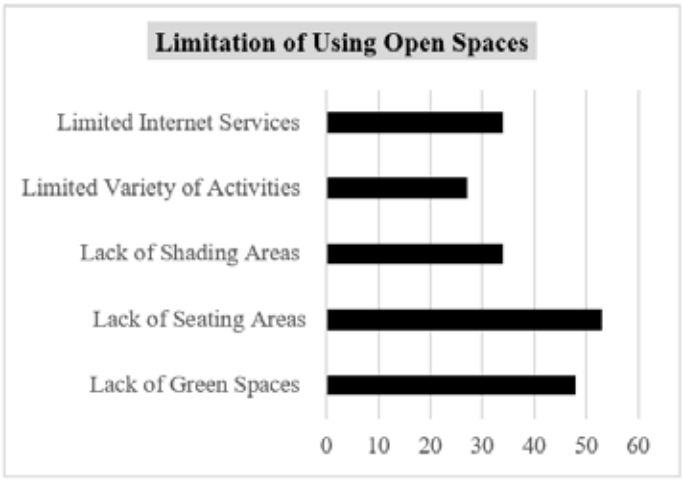

Fig. 26. Limitations of open spaces
Source: Author

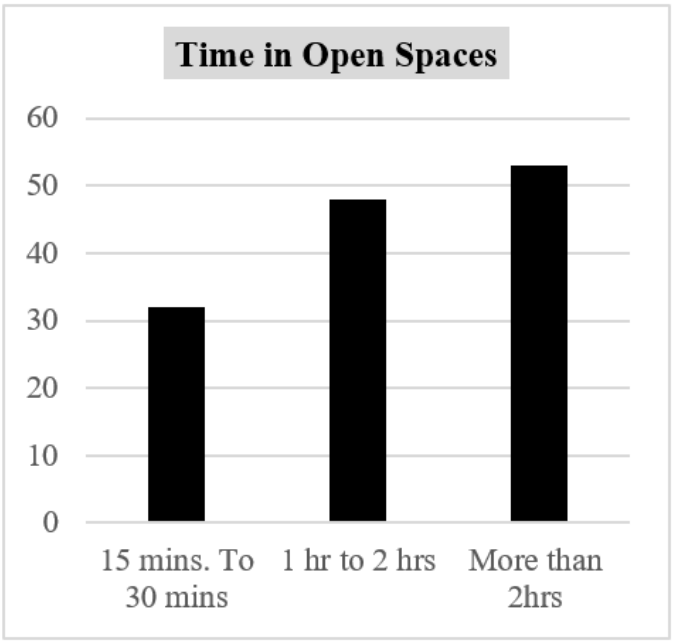

Fig. 27. Time in open spaces
Source: Author

The first graph, "Limitations of Open Spaces," Figure 24, lists factors that limit the duration of stay in these areas. Each factor has a bar associated with it, indicating the relative impact it has on limiting user stay. It appears that the lack of seating areas is the most significant limitation, followed by the lack of shading areas, and a limited variety of activities. The second graph, "Time in Open Spaces," Figure 25, illustrates the duration that users typically spend in these open spaces, the longest duration of more than two hours has the highest bar, suggesting that a significant number of users tend to spend extended periods in these spaces, provided the conditions are right.

Together, these graphs suggest that while users are inclined to spend substantial time in open spaces,

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certain limitations, particularly related to comfort and amenities, can significantly shorten their visits. Enhancements in seating, shading, and a variety of activities could potentially increase the time users spend in open spaces, maximizing their benefits for user well-being.

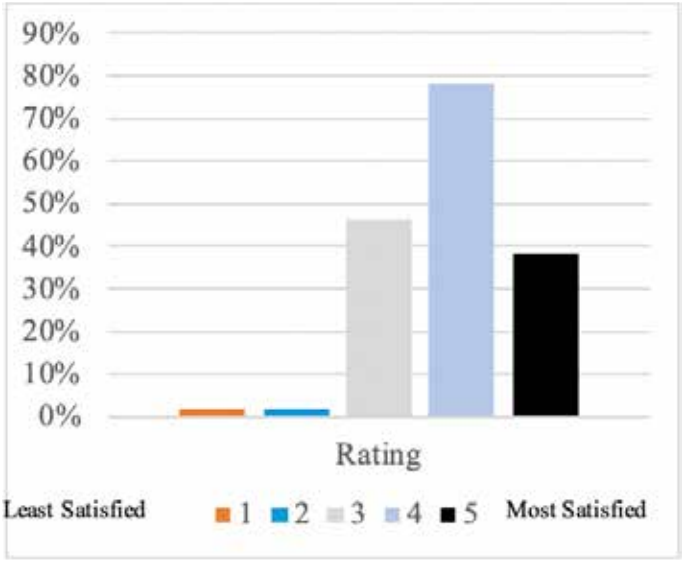

Fig. 28. Limitations of open spaces
Source: Author

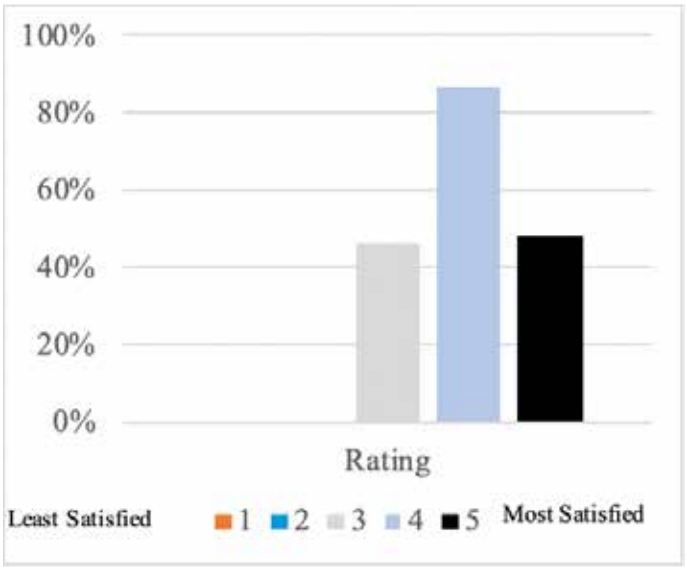

Fig. 29. Time in open spaces
Source: Author

In Figure 26, which represents user comfort, respondents rated their satisfaction on a scale from 1 (least satisfied) to 5 (most satisfied). The majority of users appear to report high levels of comfort, with the highest percentage of responses in category 4, followed closely by ratings of 5, indicating that most users find open spaces quite comfortable. The second chart, Figure 27, evaluates how effectively these open spaces help users reduce stress, using the same satisfaction scale. Here, users mainly rate the quality of open spaces with a 4, suggesting a strong positive impact on stress reduction, while the second-highest group of responses falls in the category 5. This demonstrates that the majority of users consider open spaces beneficial for their mental well-being. Both charts together reveal that users generally find open spaces to be comfortable and beneficial to their stress levels, which is indicative of the success of these spaces in fulfilling some of their core objectives in urban design.

IX. EVALUATION MATRIX AS A TOOL: RELATIONSHIPS BETWEEN OPEN SPACES AND USER'S WELL-BEING

The matrix serves as an analytical tool for assessing the impact of various characteristics of open spaces within a CBD on well-being indicators, which are categorized under Physical, Social, and Environmental dimensions. Each row represents a well-being indicator, such as "Promote safe walking" or "Protect biodiversity". Each column represents a characteristic of open spaces, grouped into broader categories like Landscape, Accessibility, Circulation, Services, Safety and Security, and Sociability. Each characteristic is detailed with specific attributes like "Lighting Arrangement", "Public Transportation", "Connected Paths", "Public Toilets", and "Events". The cells of the matrix are filled with symbols indicating the strength of the relationship between each characteristic and the well-being indicator:

- solid circle (●) indicates a "Strong Relation" suggesting that the characteristic significantly impacts the well-being indicator.
- A half-filled circle (◑) signifies a "Moderate Relation" implying a noticeable but less significant impact on the well-being indicator.
- An empty circle (○) denotes "No Relation", indicating no substantial impact on the well-being indicator from the characteristic.

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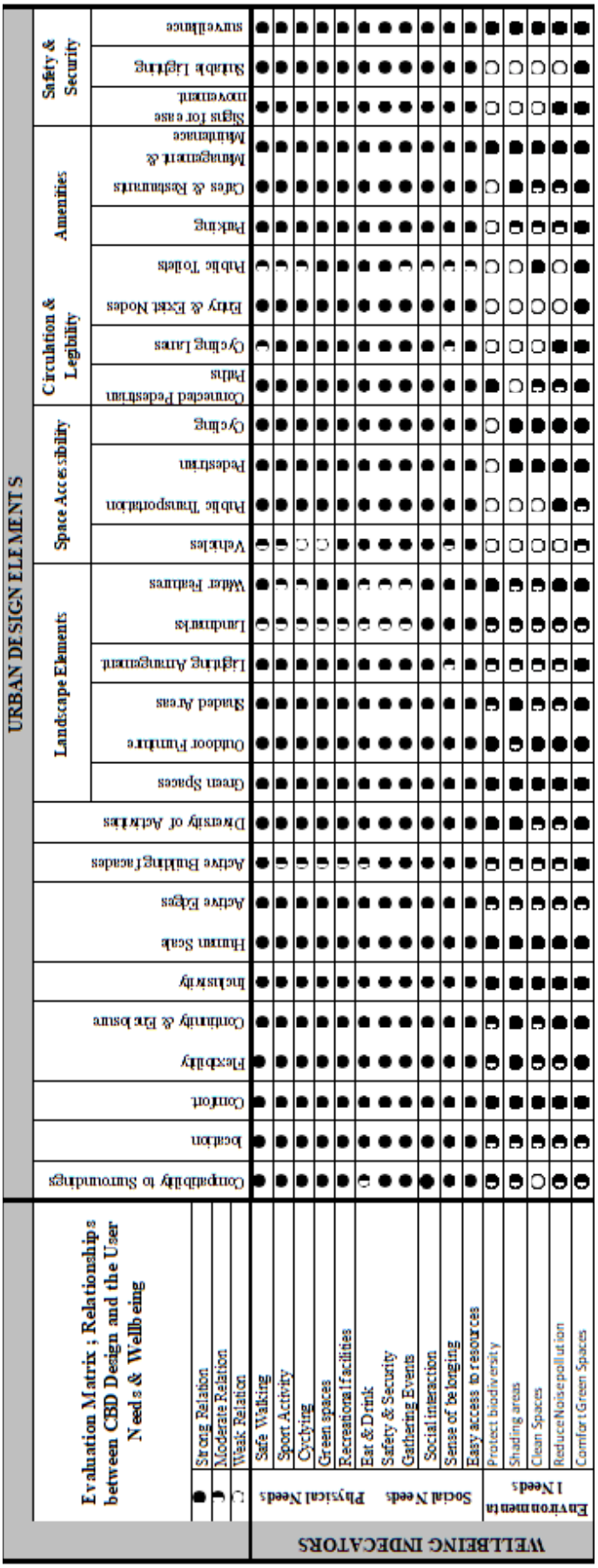
Table (03): MATRIX wit Relations Between Urban Design Elements & Well-being
Source: Author



X. CONCLUSION

The critical exploration of literature on the CBD and the design of sustainable open spaces demonstrates a significant link to user's well-being. The research indicates a clear and important relationship between the urban design of sustainable open spaces and the enhancement of social, physical, and environmental aspects of well-being. This connection is essential and must be a central consideration for urban designers, experts, and academics who are key in shaping the sustainable communities and urban spaces of the future.

The research contributes an evaluation matrix that serves as a tool to define the relationships between the urban design elements of sustainable open spaces within CBDs in Egypt and user needs to enhance well-being. By identifying the impact of each design element on specific user needs, this matrix provides a structured approach to assess and guide the development of open spaces.

A. Findings

1. Well-designed sustainable open spaces have a strong impact on enhancing the user's well-being.
2. Elements of successful sustainable open spaces can be concluded in comfort, accessibility, diversity of activities, flexibility and safety.
3. Design of sustainable open spaces within CBDs in Egypt can be neglected due to the need of developers to build more to maximize the profit.
4. Environmental aspect should be highly considered when designing sustainable open spaces within CBDs in Egypt to achieve user's comfort.
5. User's well-being should be a primary design aspect not a secondary one.

XI. FUTURE STUDIES

Future studies may look to expand beyond quantitative methods, incorporating qualitative approaches to capture the nuanced human experiences and perceptions of open spaces. Additionally, the impact of policy changes, economic fluctuations, and technological advancements on the use and design of these spaces permits ongoing investigation. Recognizing the diversity within urban populations, subsequent research should also

examine the differential impacts of open spaces across various socio-economic groups, aiming to ensure equitable access and benefits. Given the complexity of urban ecosystems, interdisciplinary research drawing from environmental science, urban sociology, and public health is recommended to construct a more holistic understanding of how sustainable open spaces contribute to well-being in CBDs. This comprehensive approach can help to refine urban design practices, creating more inclusive, resilient, and healthy urban spaces for all community members.

References

[1] V. JELOVAC, "HUMAN CITIES," *Human Cities*, 2018.

[2] C. J. Fausold and R. J. Lilieholm, "The economic value of open space: A review and synthesis," *Environmental Management*, vol. 23, no. 3. 1999. doi: 10.1007/s002679900188.

[3] R. Murphy, "THE CENTRAL BUSINESS DISTRICT," https://itunes.apple.com/WebObjects/MZStore.woa/wa/viewBook?id=0 This material may be protected by copyright. NY,USA: Routledge.

[4] WCED, "Report of the World Commission on Environment and Development: Our Common Future: Report of the World Commission on Environment and Development," *World Commission on Environment and Development*, 2018.

[5] S. S. , & A. S. S. AlShahed, "DESIGNING PUBLIC OPEN SPACES AFTER THE PANDEMIC TOWARDS A HEALTHY AND SAFE ENVIRONMENT," *Contingency Planning of Adaptive Urbanism*, 2022.

[6] S. America, "The Importance of Green Spaces," *Scenic America*, 2022.

[7] T. Arnold and J. Hickson, "'LEVELLING UP' POST-INDUSTRIAL CITY-REGIONS IN ENGLAND," *Transactions of the Association of European Schools of Planning*, vol. 6, no. 1, 2022, doi: 10.24306/TrAESOP.2022.01.001.

[8] A. Krefis, M. Augustin, K. Schlünzen, J. Oßenbrügge, and J. Augustin, "How Does the Urban Environment Affect Health and Well-Being? A Systematic Review," *Urban Science*, vol. 2, no. 1, 2018, doi: 10.3390/urbansci2010021.

[9] T. Beatley, "Integrating nature into urban design and planning," *Biophilic Cities* , 2010.

[10] T. Blackburn, " Shifting Urban Gravity, from 'Central' To 'Core' Business Districts," *CTBUH Journal*, 2016.

[11] A. e Brown, "Urban Regeneration and Social Sustainability: Best Practice from European Cities," *Routledge*, 2020.

[12] K. Colley, C. Brown, and A. Montarzino, "Understanding Knowledge Workers' Interactions With Workplace Greenspace," *Environ Behav*, vol. 49, no. 3, 2017, doi: 10.1177/0013916516629194.

[13] P. M. Cozens, "Sustainable urban development and crime prevention through environmental design for the British City. Towards an effective urban environmentalism for the 21st century," *Cities*, vol. 19, no. 2. 2002. doi: 10.1016/S0264-2751(02)00008-2.

[14] A. Deaton, "Income, health, and well-being around the world: Evidence from the Gallup World Poll," in *Journal of Economic Perspectives*, 2008. doi: 10.1257/jep.22.2.53.

[15] E. Diener, S. D. Pressman, J. Hunter, and D. Delgadillo-Chase, "If, Why, and When Subjective Well-Being Influences Health, and Future Needed Research," *Appl Psychol Health Well Being*, vol. 9, no. 2, 2017, doi: 10.1111/aphw.12090.

[16] A. Downs, *Still stuck in traffic: Coping with peak-hour traffic congestion*. 2005.

[17] S. El Khateeb and I. M. Shawket, "A new perception; generating well-being urban public spaces after the era of pandemics," *Developments in the Built Environment*, vol. 9, 2022, doi: 10.1016/j.dibe.2021.100065.

[18] EPOA, "The Essex Design Guide. Essex Planning Officers ," *European Environment Agency. Environmental noise in Europe.*, 2023.

[19] EEA, "Environmental noise in Europe — 2020. European Environment Agency (EEA). Copenhagen, Denmark," 2020.

[20] J. Gehl, "Cities for people," *Island Press*. 2013.

[21] E. Glaeser, "Triumph of the City: how our greatest invention makes us richer, smarter, greener, healthier, and happier", Penguin Random House, 2010.

[22] C. Grodach, "Urban cultural policy and creative city making," Edward Elgar Publishing, 2017.

[23] J. Honey-Rosés *et al.*, "The impact of COVID-19 on public space: an early review of the emerging questions–design, perceptions and inequities," *Cities Health*, vol. 5, no. sup1, 2021, doi: 10.1080/23748834.2020.1780074.

[24] Indiana University Bloomington, "Wellness Whell (Psychological Health & Stress Reduction)," *Indiana University Bloomington*, 2022.

[25] T. Jagannath, "Central Business District Characteristics, Examples," *Pros and Cons. Planning Tank* . 2020.

[26] T. Jagannath, "Central Business District Characteristics, Examples," *Pros and Cons. Planning Tank* . 2020.

[27] T. Jagannath, "Central Business District Characteristics, Examples," *Pros and Cons. Planning Tank* . 2020.

[28] P. James *et al.*, "Towards an integrated understanding of green space in the European built environment," *Urban For Urban Green*, vol. 8, no. 2, 2009, doi: 10.1016/j.ufug.2009.02.001.

[29] V. Jennings, C. Johnson Gaither, and R. S. Gragg, "Promoting environmental justice through urban green space access: A synopsis," *Environmental Justice*, vol. 5, no. 1. 2012. doi: 10.1089/env.2011.0007.

[30] S. Kahlmeier *et al.*, "The Health Economic Assessment Tool (HEAT) for walking and for cycling: methodology and user guide: economic assessment of transport infrastructure and policies, World Health Organization, 2014.

[31] A. Kakkar and M. Supriya, "Socio-economic Benefits of Open Spaces: Towards Sustainable Housing," *International Journal of Environmental Research and Development*, 2014.

[32] Krefis, A.C.; Augustin, M.; Schlünzen, K.H.; Oßenb. How does the urban environment affect health and well-being? A systematic review. *Urban Sci.*, 2,12, 2018.

[33] P. Marcuse, "Globalizing Cities: A New Spatial Order?," *Blackwell Publishers*. 2000.

[34] A. Maslow, "Motivation and Personality. Prabhat Prakashan," *Prabhat Prakashan*. 1981.

[35] C. Mathew, "Public Places-Urban spaces," *Routledge*. 2010.

[36] Miller, J. The role of green infrastructure in mitigating urban heat in the central business district. *Environmental Management*, 2017.

[37] Z. Myers, "Green for well-being – science tells us how to design urban spaces that heal us," *The Conversation*. 2017.

[38] S. Oishi, E. Diener, and R. E. Lucas, "The Optimum Level of Well-Being: Can People Be Too Happy?," *Perspectives on Psychological Science*, vol. 2, no. 4, 2007, doi: 10.1111/j.1745-6916.2007.00048.x.

[39] L. Orii, L. Alonso, and K. Larson, "Methodology for establishing well-being urban indicators at the district level to be used on the cityscope platform," *Sustainability (Switzerland)*, vol. 12, no. 22, 2020, doi: 10.3390/su12229458.

[40] M. Pacione, "Urban environmental quality and human well-being—A social geographical perspective," *Landsc. Urban Plan.* 2003.

[41] PPS, "What Makes a Successful Place ?," PPS Project for Public Spaces.

[42] Shoup, D. Cruising for parking. *Transport Policy*, 2006.

[43] Smith, N. The New Urban Frontier: Gentrification and the Revanchist City. *Routledge*, 2018.

[44] D. Stoewen, "The 8 Dimensions of Well-being," *PubMed Central*. 2017.

[45] M. Suárez, D. N. Barton, Z. Cimburova, G. M. Rusch, E. Gómez-Baggethun, and M. Onaindia, "Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway," *Environ Sci Policy*, vol. 108, 2020, doi: 10.1016/j.envsci.2020.03.014.

[46] O. Tandogan and B. S. Ilhan, "Fear of Crime in Public Spaces: From the View of Women Living in Cities," in *Procedia Engineering*, 2016. doi: 10.1016/j.proeng.2016.08.795.

[47] The Western Sydney Health Alliance, "Integrating health and well-being indicators into built environment practice within the Western Parkland City," *Western Sydney Health Alliance*. 2023.

[48] Thompson, J., & Sorvig, K. Sustainable Landscape Construction: A Guide to Green Building Outdoors. *Island Press, 2000*.

[49] K. , B. H. , M. S. , & D. M. Villanueva, "Developing indicators of public open space to promote health and well-being in communities," ELSEVIER.

[50] G. Wellington, "Open Spaces Working Group," *Greater Wellington*, 2009.

Volume 10, Issue 1, June 2024 - ISSN 2356-8569
http://dx.doi.org/10.21622/RESD.2024.10.1.827

[51] Wellness Corporate, " The Healing Power of Nature: How Outdoor Spaces Can Improve Employee Well-Being," *Corporate Wellness Magazine*. 2023.

[52] Western, M., & Tomaszewski, W. Subjective well-being, objective well-being and inequality in Austrlia. *PLoS ONE*, 2016.

[53] WHO, "Physical Activity," 2022.

[54] WHO, "How can we assess the benefits of urban nature?," 2023.

[55] Y. Sun, "Development and characteristics of central business district under the philosophy of health," in *Procedia Engineering*, 2011. doi: 10.1016/j.proeng.2011.11.2013.

[56] J. Zhang, Z. Yang, Z. Chen, M. Guo, and P. Guo, "Optimizing urban forest landscape for better perceptions of positive emotions," *Forests*, vol. 12, no. 12, 2021, doi: 10.3390/f12121691.

[57] J. Zinsstag, E. Schelling, D. Waltner-Toews, and M. Tanner, "From 'one medicine' to 'one health' and systemic approaches to health and well-being," *Prev Vet Med*, vol. 101, no. 3–4, 2011, doi: 10.1016/j.prevetmed.2010.07.003.

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Applying Citizen Science Method for Odor Measurement in Urban Areas

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ABSTRACT

Urban site analysis includes tangible factors such as the physical site features and intangible factors as the sensory site features like odors affect the inhabited area in the site. Environmental and chemical studies have much greater attention and studies to the odor effects in urban areas than urban designers. This paper aims to provide a validated and applicable method for urban designers in odor measurement. The objective of this research is to present the various methods of measuring odors adopted in chemical and environmental studies to achieve an applicable odor measurement method in the urban design field. The odor measurement tools are usually dedicated to measuring odor concentration at the odor source or at the receptor location that are used in chemical and environmental studies. However, in urban design studies the odor measurement could be performed using a method called citizen science considering the FIDOL factor to evaluate the odor nuisance including odor frequency, intensity, duration, offensiveness, location, and hedonic tone. This research conducts a case study in Tripoli city and determines Tripoli landfill as a significant odor source that affects people in their inhabited areas. A questionnaire was distributed in the affected area by the odor source, and the respondents of the inhabitants ensured that the summer season is the most season that they can feel the odor in their places associated with the wind direction. The results ensure that the citizen science method in measuring odors is validated, applicable, and available for urban designers to detect and estimate the affected area by odor source.

Index-words: *Citizen Science, Odor measurement, Weather factors, FIDOL Factors.*

I. INTRODUCTION

One of the urban site analysis factors is the sensory assessment of the location, this includes the noise and odor that negatively affect the site. Although urban designers pay significant attention to noise studies, the consideration of the odor nuisance at the site is at a lower level of urban designers' interest.

The lack of interest of the urban designers concerning the sensory factor of odor assessment in the urban site analysis is the main problem of this research. The odor assessment tools are mainly used by specialists in the chemical and environmental fields, and these tools are dedicated to measuring odor concentration. In contrast, in the urban design field, odor measurement could be done in another method called the Citizen Science method which depends on measuring people's perception according to FIDOL factors which is one of the odor assessment tools.

This paper aims to provide a validated and applicable method for urban designers for odor measurement. The objective of this research is to present the various methods of measuring odors adopted in chemical and environmental studies to achieve an applicable odor measurement method in the urban design field.

The methodology of this research includes the following steps; as first defining the odor and odor categories, second presenting the most significant factor in controlling the odor dispersion which is the weather factor, third providing the odor impact evaluation methods to select an applicable method in this research, and fourth conducting a case study in Tripoli city.

As this method is not widely applicable in urban design studies to evaluate people's annoyance from an odor source, this research conducts a case study in Tripoli city to find out the corresponding results

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between determining the area of odor dispersion by wind direction and the odor perception by people.

II. LITERATURE REVIEW

The word "odor" refers to a smell, frequently an unpleasant one (Cambridge, 2023) (Oxford, 2023). However, several researchers such as (Li & Wang, 2021) (Jo et al., 2020) (Rho et al., 2021) (Poncet et al., 2021) (Hou & Meng, 2021) consider that odor can be characterized as pleasant, unpleasant, or neutral. Odor is a property of a group of compounds that can sufficiently activate the olfactory sense to cause an odor perception. Sensory input is often transferred from the nose cavity to the brain, where it may have either pleasant or unpleasant effects. Odor perception starts in the nasal cavity. Sniffing causes molecules of the odorant present in the air to travel past the turbinate, which are curved bones. In the top nasal tube, where the nerve cells that detect odors are located, the turbinate creates turbulent airflow patterns that deliver the volatile compound mixture there (Capelli et al., 2019).

The odor was categorized in the thesis of (Jingyan, 2021) as follows:
psychological reactions: Scent and odor are the two broad categories into which odor perception can be divided. Even though this method is inaccurate, it is suitable for a wide sample of scents.
Chemical characteristics: Volatile aromatic molecules with a range of molecular weights give off odors. Some of these molecules are inorganic, but the majority are organic.
Odor class: Fruity, aromatic, minty, lemony, chemical flavor, woody, sweet, popcorn, sour, and putrid are the ten main sorts of odors.
Source of odor: This approach is particularly pertinent to the study of odor cities since there are many major categories from which odor sources may be classified, and doing so reveals both formal and spatial distributions.

St. Croix Sensory, a market-leading sensory evaluation laboratory, has begun to offer analytical testing of chemical odorants and built an odor wheel to include a wide range of naturally occurring and artificially produced aromas. Natural Offensive, Marine, Animal, Chemical, Earth, Vegetable, Naturally Pleasant, and Culinary are the eight major odor classifications. The wheel contains trigeminal sensations as the basic tastes occasionally recognized in the mouth because fundamental tastes might occasionally be observed in the mouth while smelling smells. (Sensory, 2020).

The several predicted scents in the urban area are provided by the odor wheel shown in Fig.1

Fig. 1. Odor Wheel (Sensory, 2020)

These eight odor groups further break down into 22 additional layer odor categories, such as the naturally disagreeable category which is further divided into two subgroups (sulfur and decay), and the chemical category which is further divided into four subgroups (petroleum, chemical, plastics, and medical). Vinyl, rubber, and Styrofoam are listed as the types of each specific category in the outer ring for the plastics category (Sensory, 2020).

A. Weather Factor

Weather conditions that have a significant impact on odor occurrence, such as temperature, wind speed, and precipitation, are related to the likelihood of odor (Jia et al., 2021). The main results of (Piringer & Knauder, Odour Impact Assessment in a Changing Climate, 2021) research presented that the developed odor impact might change as a result of climate changes between the present and the future. The geographical qualities and atmospheric conditions will determine how the odorous composites diffuse and change over time and space (Bruce & Antileo, Assessment of odour emissions by the use of a dispersion model in the context of the proposed new law in Chile, 2021).

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The analysis of the study discussed the rural smells and their effects on odor dispersion considering the weather conditions (Caffyn, 2021). Weather conditions including rain and humidity, as well as wind speed and direction, have an impact on how odors are interpreted and identified (Allen, 2021). The variations in climatic circumstances could not support the air dispersion (Hoang et al., 2022). The weather factor affects the smell produced in rainy weather as this smell will be more intense (Febrian, 2021).

To determine the damaging impact distance of odor irritation, (Fang et al., 2022) regarded the climatic data to be a crucial aspect in modeling the dispersion of odorous substances. Calculating odor exposure using air dispersion (Zhang et al., 2021).

Weather conditions, concentration, time, turbulence, and volume, along with wind velocity, temperature changes, relative humidity, and air pressure, have a significant impact on the smell identity and impression (Badach et al., 2018). Nearly 60 percent of the fluctuation in daily odor report totals is accounted for by meteorological conditions and air pollutants (Bhandari et al., 2022).

The focus on the elements of wind and temperature will be provided as follows, by earlier research that demonstrates the critical importance of weather conditions in odor diffusion:

III. Wind Factor Study

Earlier research has noted the significance of the wind element in smelling diverse odors as in (Brancher et al., 2019) study which shows why it is important to consider wind direction when determining how far a given spot is from the source of an odor.-To help prevent odor disruption at two distinct places, (Piringer et al., 2016) offer models of separation distances that are estimated based on wind speed and direction. As well (Eltarkawe & Miller, 2019) provide a research on odor problems in various areas while taking wind studies into account. In the case study of (Allen, 2021), the weather conditions varied significantly during one very windy day, making it difficult to smell anything. The vast amount of water in the chosen area such as the bay, sea, and lake, along with the humid climate, suggested that on calm days, fragrance intensity was strong. For each smell walk, (Allen, 2021) noted the time, day, and weather conditions, taking wind strength and direction into account. (Caffyn, 2021) addressed the weather, focusing on the wind effect and noting that stronger breezes are likely to cause odors to be dissipated in areas on higher ground.

The meteorological information of the research area, such as wind speed and direction, air pressure, temperature, and relative humidity, was used to evaluate the influence of odors from wastewater treatment plants (Zhang et al., 2021). Wind and the Pasquill stability class climate dataset were used in the study of (Kiefer et al., 2022) to evaluate the geographical and temporal variability of cattle odor dispersion potential in Michigan.

Wind speed and direction significantly influence the value of the odor concentration (Bruce & Antileo, Assessment of odour emissions by the use of a dispersion model in the context of the proposed new law in Chile, 2021).

The smell is moved by the wind and dispersed by the wind direction (Conchou et al., 2019). High wind speeds reduce the strength of the smell while dispersing it across a wider region (Song & Wu, 2022). Wind measurements in the context of the wind direction frequency dispersion are the necessary atmospheric data for the application of the Austrian and German experimental calculations (Schauberger et al., 2020). According to a study by (Çeven et al., 2022) based on smell preferences and the dispersion of smells according to climatic and spatial properties, the recommendation to control urban smell makes it clear that smell is possibly directed with the wind direction and impacted by geographical closeness, as locations with high closeness enable higher smell perception and locations with high openness enable low smell perception. (Ma et al., 2022) offer a numerical simulation based on research of wind velocity to investigate the impact of the spread of olfactory pollution. The 'volatiles' of odors disperse from their source due to ambient motion and molecular dispersion. In natural environments, wind is the most potent and unstable agent for odor dispersion. With larger volatile contents and a faster wind speed, the odor plume became a sharper cone and diminished as it got farther away from the source of the odor (Cai et al., 2022) as shown in Fig.2

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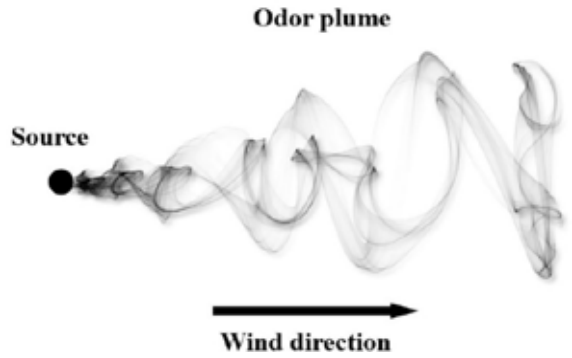

Fig. 2. The odor plume from the source moves downwind (Cai et al., 2022)

IV. Temperature and Humidity Factors Study

Heat-related smells especially, make waste smell unpleasant and breed bacteria and flies (Huang et al., 2021). The main complaints of the nearest residents are unpleasant smells and noise, especially in hot weather (Hoang et al., 2022). The research of (Devonald et al., 2022) stated that the unpleasant smell is made worse by rising temperatures and severe weather. The relationship between odor concentrations and temperature, as well as daytime weightings, was primarily deemed to be upsetting (Zhang et al., 2021). As temperatures increase, vapor pressure rises, raising the amount of odor that is present (DeGreef & Maughan, 2022). Unpleasant odors and noise annoyance are among the major issues, especially in hot weather (Tran, 2020) (Pham et al., 2022). (Jo et al., 2020) demonstrated that stimuli become stronger and more unpleasant at high temperatures, especially when an unpleasant odor is present. Humidity in the air traps odor-causing molecules, allowing them to travel further and linger longer, increasing the smell intensity by 1.29 on average (Billottet, 2020). The study of (Jia et al., 2021) highlighted that odor pollution worsens in hot climates. (Çeven et al., 2022) confirmed that at 27 °C and higher temperatures and 55% humidity, smell intensity rose. Particularly, the intensity was not particularly notable during the cold months of November to May, but it did grow between May and September. Although it was lower in places with short buildings, the perception of scent intensity was higher in regions with narrow streets, tall buildings surrounding them, and high walls. Additionally, smell diffusion increased as the distance between smell sources grew. Depending on the distance, smell strength had an impact on smell dispersal as well. Under the same temperatures, the stench got stronger as the humidity rose. It turns out that the smell strength dropped as wind speed increased, despite the humidity rising as a result. According to the thesis of (ÇEVEN, 2021), the smell intensity varies according to the openness and closedness of the space and changes as a function of temperature and humidity. Wind speed, temperature, humidity, and the study site are the factors that have an impact on the amount of CO in the surrounding air. Because the wind speed in an open, flat lowland is high enough, the atmosphere can diffuse and minimize the pollutants (Brontowiyono et al., 2022).

V. Methodology

A. Odor Impact Evaluation Methods

The research of (Zarra et al., 2021) offered several approaches to assess the effects of odors brought on by an industrial plant situated in a sensitive area:

First Method: The grid method, which involves dividing the study area into cells and assigning teams of trained assessors to each cell to conduct a field assessment. This approach is based on the FIDOL variables, which stand for frequency (F), intensity (I), duration (D), offensiveness (O), and location (L) in the definition of odor nuisance. This method adheres to the regulations for odor nuisance assessment, which vary depending on the country. It also considers the weather conditions, particularly the wind and temperature that change depending on the research. This strategy is thought to be the most practical one for assessing odor nuisance. This method is expensive and time-consuming.

Second Method: This method for describing odor nuisance takes the prevailing wind in the area into account as well as the FIDOL components. The interviewees' emotional investment in the issue can have an impact on this methodology. To produce accurate evaluations, a broad social involvement and significant community participation are afterward formed. The Citizen Science approach is used in this method. Additionally, this method is used in the research of (Lotesoriere et al., 2021) (Eykelbosh et al., 2021) (Cangialosi et al., 2021) (Bokowa et al., 2021) and numerous further researches.

Third Method: In modeling atmospheric dispersion, meteorological elements including wind speed, wind direction, climatic stability, precipitation, temperature, and more are considered. This method

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aids in identifying the minimum separation distances from the odor source and the nearest receptors as well as the necessary protection level. This method of getting the results is claimed to conserve time. The research of (Bruce & Antileo, Assessment of odour emissions by the use of a dispersion model in the context of the proposed new law in Chile, 2021) (Schauberger et al., 2021) (Oettl et al., 2022) and several others applied this method in determining the odor dispersion.

The study of (Jonca et al., 2022) supports the use of earlier methods for odor nuisance evaluation.

The bigger categories of odor effect assessment methodologies, which may include mathematical methods like dispersion models, determine how odors are measured. Four categories can be used to group these techniques:
First: sensorial as using the human nose as the receptor, second: instrumental, third: odor measurements at a specific emission level such as at the odor source might be measured, and fourth: odor measurements at the receptor level, in the neighborhood where the complainants live (Capelli et al., 2019) as shown as Fig. 3.

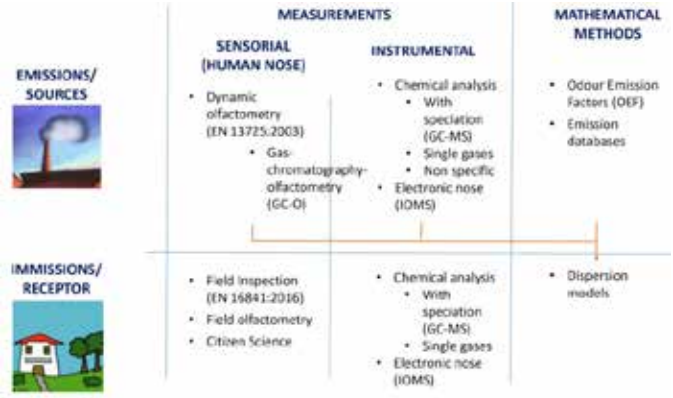

Fig. 3. Overview of odor impact assessment methods (Capelli et al., 2019)

Chemical analysis, Gas Chromatography-Olfactometry (GC-O), Tracer analysis, Instrumental odor monitoring like e-noses, Field inspection, Field olfactometry, and Citizen science are among the important methods for measuring odors (Bax et al., How Can Odors Be Measured? An Overview of Methods and Their Applications, 2020) as shown as Fig. 4.

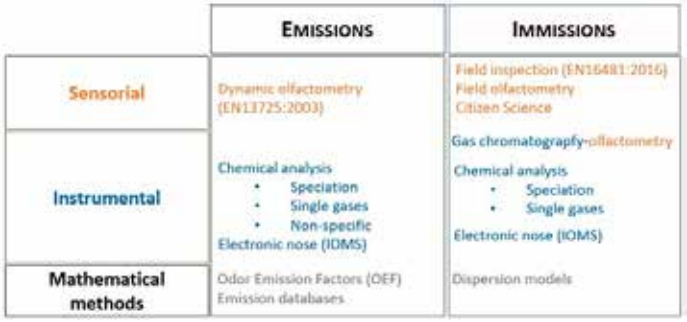

Fig. 4. Schematization of odor impact assessment methods (Bax, Sironi, & Capelli, 2020)

The following part is a summary of the odor effect evaluation techniques:

1. The European Standard EN 13725:2003 regulates the sensory dynamic olfactometry approach. This technique determines the concentration of odors released at the source, confirms compliance with regulatory requirements, and provides information used as input data for dispersion modeling to determine the exposure of residents to scents. However, this approach is regarded as discontinuous; it offers no details regarding the scents distinctive qualities or hedonistic tones, nor does it reveal whether they are present in the surrounding air as shown in Fig. 5.

2. Chemical analysis with speciation method GC-MS is a practical technique that may be used to analyze emissions at the source or ambient air at the receiver. This method provides details on the chemical makeup of the scents and categorizes the chemical compounds that are discovered to aid in determining how they might affect the environment and human health. Due to masking effects between odorants, this method is not always effective, particularly when it comes to classifying compound odors. It also only approximates the relationship between the chemical arrangement and the mixture odor concentration, and it is less sensitive to malodorous compounds with low odor thresholds than the human nose. As shown as Fig. 5.

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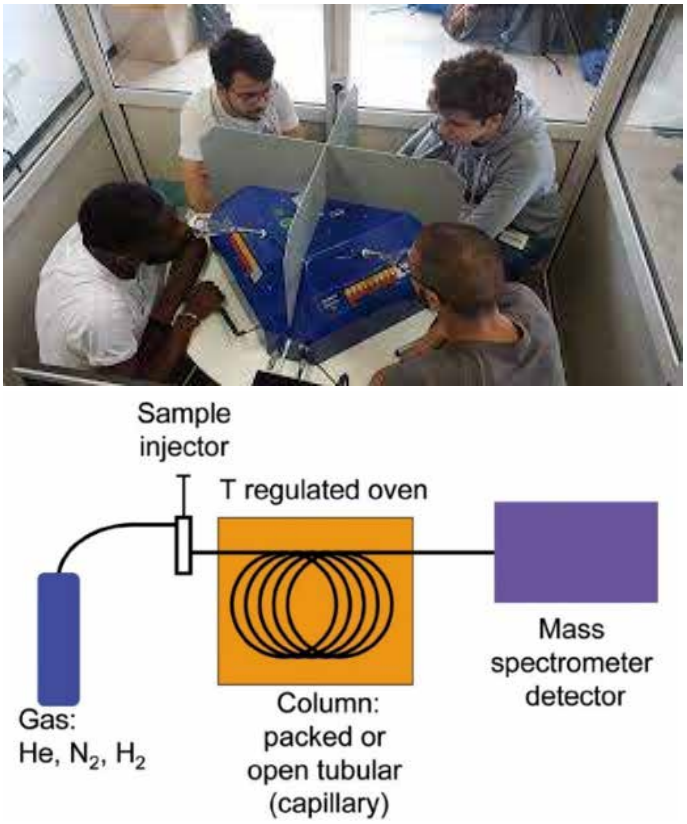

Fig. 5. Dynamic olfactometry session (left). Schematization of a GC-MS (gas chromatography coupled with mass spectrometry) analysis system (right) (Bax, Odor Measurement Methods, 2022)

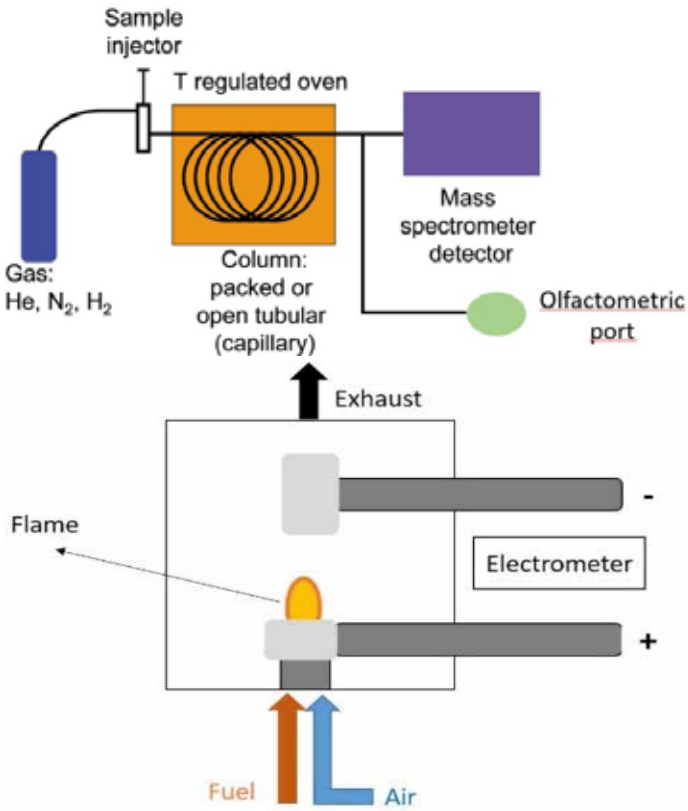

Fig. 6. Gas chromatography analysis with olfactometric detection (GC-O) (left). Flame ionization detector (FID)(right) (Bax, Odor Measurement Methods, 2022)

3. As it combines traditional gas chromatography analysis with human olfaction to distinguish volatile organic molecules eluting from GC separation, gas-chromatography olfactometry GC-O is a mixed method instrumental and sensory. It is applied at the emission level. This technique, which has a high sensitivity since the human nose is more sensitive than an instrument sensor, gathers information on the olfactory character associated with the different particles present in an odor sample. However, because the sample is broken down into its individual components, this method cannot provide information about the odor concentration of the sample, so the olfactory properties of the sample as a whole are not considered. Additionally, because this method is unable to offer information for the odor impact, it is not used as an input for dispersion modeling. As shown in Fig. 6.

4. Chemical analysis—non-specific is a useful technique that might be used at the emission level. This technique enables the detection of gas leaks, which may be associated with diffusing odor emissions. However, this approach provides no information regarding the odor characteristics of the tested gas. As shown in Fig. 6.

5. Chemical analysis—single gases is an instrument method that could be used for ambient air or emissions which is a chemical analysis of single gases. In the rare instances where the odor is directly correlated to tracers and the source can be uniquely identified, this method offers an assessment of the impact of the odor in surrounding air, a calculation of the odor concentration in emissions, and a quantification of the concentration of single gases in emissions or ambient air. It could be supplemented with other ways for a more thorough olfactory description; however, this method is ineffective for complicated odorous combinations because it does not reveal their composition.

6. Instrumental odor monitoring E-noses is an instrumental technique that may be used for ambient air or emissions. With a constrained budget, this method offers continuous and quick results, continuous monitoring of the odor concentration at emissions, a direct assessment of the odor effect at receptors, and identification of the odor source. However, this technique cannot replace dynamic olfactometry because it cannot provide information on odor intensity and hedonic tone. As shown as Fig.7

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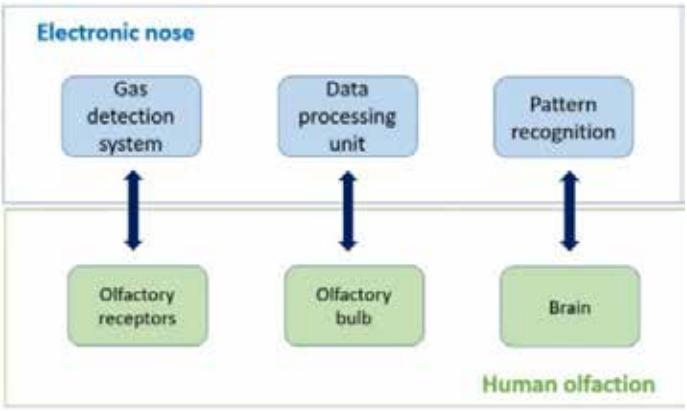

Fig. 7. Electronic nose structure. (Bax, Odor Measurement Methods, 2022)

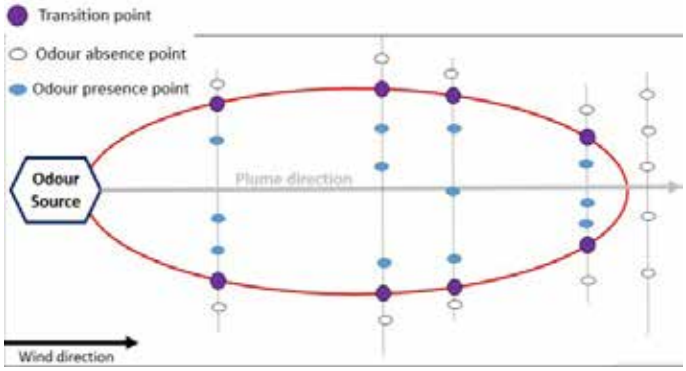

Fig. 8. Example of an assessment area in the surroundings of an odor emission source with assessment squares and measurement points(left). Stationary plume method—field inspection(right). (Bax, Odor Measurement Methods, 2022)

7. A sensory technique that may be used at the immissions receptor level of ambient air is field inspections. This method specifies the extent of the odor plume from a facility under specific climatic circumstances plume method; experienced assessors can provide information about the odor quality; it assesses the degree of irritation concerning odor hours in a designated negatively affected area. However, this procedure is time-consuming and expensive, and it gives no information regarding the odor concentration grid method as shown in Fig. 6.

The grid method is a statistical study technique that can offer a symbolic map of odor detection while also being descriptive of the local meteorological circumstances.

The plume method is used to determine the region that, under specific weather and operational conditions, may be used to identify and detect an odor plume emanating from a specific odor source as shown in Fig. 8.

8. Field olfactometers, which are portable odor detection and measurement instruments, are used in field olfactometry, a sensory technique, to quantify scents in ambient air. This technique shows how many times ambient air must be compressed to become odorless close to an odor source. On the other hand, the dynamic olfactometry method following EN 13725:2003 at the emissions level is the sole way to determine the odor concentration in ouE/m3, which is not provided by this method. Another drawback is the results great unpredictability when considering numerous uncontrollable elements like wind speed and direction, etc. Field olfactometry provides data that can practically never be compared to any other odor characterization techniques. Therefore, for various sensorial approaches, the assessors' measurement is an important aspect of the reproducibility of results.

9. A sensory technique called citizen science may be used at the emissions receptor level of ambient air. This approach involves involving the public in the mapping and management of odor problems and estimates the level of irritability by discussing the impact on the public. However, this method has a significant degree of result unpredictability, and the potential for biased information, and is rarely suitable in contentious circumstances such as legal proceedings.

After presenting the numerous odor evaluation techniques, it is revealed that not all of them could be applicable in this study as the main emphasis is at the receptor level and the measurement techniques that rely on chemical measuring tools will not be used in this research. The first technique, Dynamic Olfactometry, is only effective at the emissions source level and is unable to detect scents in the

surrounding air. Even though the second approach, Chemical Analysis with Speciation approach GC-MS, is valid at the emissions source or/and ambient air receptor, it is less sensitive than the human nose because, in the situation of mixed scents, this method is regarded as ineffective. The third technique, gas chromatography olfactometry GC-O, is applicable at the emission level and is also regarded as a study of chemical analysis. The fourth technique, non-specific chemical analysis, is valid at the emission level and relies solely on gas measurement, giving no details about the odor qualities. The fifth technique, Chemical analysis of single gases, can be used to analyze emissions or ambient air, but it must be paired with other techniques to provide a more thorough description of the odor. The sixth technique, E-noses, is valid for emissions and/or ambient air, but it is unable to provide data on the study important measurement variables, odor strength, and hedonic tone. The seventh method, although it identifies the many environmental factors that influence odor dispersion, field inspections are only valid at the receptor level ambient air because they need the presence of qualified assessors who are not present in the study region. The measurements of the assessors are a major factor for the repeatability of results in the eighth method, field olfactometry, which is usable in ambient air. The ninth technique, citizen science, is valid at the receptor level of ambient air. Despite the significant variability of outcomes and the possibility of biased information, this method is best for measuring odor annoyance and mapping results based on citizen participation. Additionally, this approach has no need to perform chemical investigations that rely on the molecular characteristics of odors.

B. The Citizen Science Method

The goal of citizen science CS is to increase public participation and collaboration in scientific research (Heigl et al., 2019). The citizen science method is an essential part of place-making, research investigates the way citizen science may promote a closer relationship between individuals and their surroundings, lead to fresh perspectives on those locations, and inspire people to take an active role in protecting those environments. In order to gain a deeper understanding of the connections between citizen science and sense of place in relation to urban waterfronts, researchers assessed the goals and experiences of citizen scientists (Toomey et al., 2020). Place-making can be challenging in cities; it can be experienced by taste, smell, sound, and skin sensation. Many Taipei residents believe that their city lacks a distinct international identity (Freeman et al., 2019). Another researcher has also embedded the collaborative sensory act of place-making as some residents declined the smells (Perkins, 2023). Researchers studying smells say that distinct cities may be distinguished by their smell, as demonstrated by the way one's nose distinguishes between urban and rural areas, according to Porteous (1985) and Henshaw (2014), communities used to be recognizable as pulp mill, colliery, leatherworking, chemical, or smelting towns because they each had a unique scent associated with their respective industries. Early 20th-century rural areas, on the other hand, were distinguished by the natural scents of hay, plants, horses, and cows. Though city design and urban management strategies have diminished the perceived role of odor to one that is limited and viewed as having a typically negative influence on the urban environment, modern urban smellscapes are less odorous (Allen, 2021).

The human nose, one of the most effective odor sensors, is used in the CS method to detect and analyze scents. Populations are actively involved in mapping and managing odor concerns. Citizens are specifically asked to create surveys based on questions on the frequency, severity, length, source of the odor, and type of odors they encounter. A clear description of the odor matter can be built using several personal observations, but because this methodology is relatively new, it is also important to examine prospective solutions. The method drawbacks include the potential for biased data, the difficulty of implementation in contentious contexts like court cases, and the high degree of outcome variability (Bax et al., How Can Odors Be Measured? An Overview of Methods and Their Applications, 2020).

(Seltenrich, 2022) applied a smartphone application to pinpoint the location of the odor on a map, he has used the citizen science technique to characterize different odor sources and create a comprehensive picture of how environmental aromas and air pollution are perceived. The research of (Chen et al., 2022) conducted a poll to determine the preferences of 103 German participants and 96 Chinese participants for 40 different odors. The goal of (Lotesoriere et al., 2021) project is to verify a novel approach to managing odor pollution developed using citizen scientists. Despite

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traditional methods for measuring and analyzing odor intensity, olfactory impact, and hedonic tone, the analysis typically ignores the knowledge of the general public. Additionally, real-time citizen odor observations are employed to evaluate the impact of odor on a community (Schleenstein et al., Advanced psichometrics based on citizen science. A history, a new standard, a European project and a case study in Chile., 2021).

Numerous elements that this method depends on can be listed as follows:
The four main determinants of sensitivity are generally agreed to be experience, expectations, motivation, and the receiver's level of attentiveness. These four criteria also have an impact on the sensitivity of groups, the number of affected people city, town, scattered houses, etc. The land use where the receptors are located is industrial, rural, hospital, school, etc. The housing uses continuous, occasional, fortuitous, etc. Even the type of environmental protection that the impacted area may have affects group sensitivity in the case of people exposed to odor impact (Schleenstein et al., Advanced psichometrics based on citizen science. A history, a new standard, a European project and a case study in Chile., 2021).

In order to quantify and calculate odor emission rates OERs and utilize them as an input for air dispersion models, the odor concentration is the factor that is most frequently used. Human perception or social interaction are crucial tools for odor assessment (Capelli et al., 2013). The analysis regional and temporal scope, the region difficulties, the availability and predictability of weather and emission data, as well as the needed time solution for effect assessment, are the main influences on the odor dispersion method (Onofrio et al., 2020).

Odor concentration fluctuations vary depending on a number of parameters, including the unpredictable nature of emissions, the type of source, the steady air state, and the distance between the source and the receiver (Zanetti et al., 2020).

When compared to a dispersion model, the study of (Schauberger et al., 2020) simplifies the process of confirming the direction-dependent influence of air data on calculated separation distances.

As shown as Figures 9 and 10 in this study, participants were given the opportunity to translate their thoughts through the use of numerical indicators that represent odor intensity as well as hedonic tone. Due to the lack of chemical characteristics of the odors in this study and the lack of odor meters often used in this field, it will not be possible to determine the concentration of odors.

Fig. 9. Odor concentration definition, odor intensity scale and hedonic tone scale (Dynamic Olfactometry- Odour Observatory, 2018)

Hedonic Tone	Verbal Description
−4	extremely unpleasant
−3	moderate unpleasant
−2	unpleasant
−1	slightly unpleasant
0	neutral
1	slightly pleasant
2	pleasant
3	moderate pleasant
4	extremely pleasant

Degrees	Intensity	Properties
0	None	People cannot feel an odorous smell with a normal sense of smell
1	Threshold	People smell something but cannot recognize the type of smell
2	Moderate	People smell something and can recognize the type of smell
3	Strong	People easily smell something strongly like a cresol smell in hospitals
4	Very Strong	People strongly smell something like a conventional rest room
5	Over Strong	People strongly smell something and gag or hold their breath

Fig. 10. The 9-point hedonic scale for odors (left) (Li, Zou, Li, & Yang, 2019), Classification of odor intensity by the human nose (right) (Park, 2020)

Human assessors breathe air to test and record how they perceive odors. Hedonic impression, perception frequency, and odor concentration are the established standard criteria for odor measurement. In order to eventually determine typical measurement values, numerical procedures play a crucial role in the assessment of the unprocessed data gathered from the assessors (Petrich & Delan, 2021). In the study by (Çeven et al., 2022), the human

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assessors identified the types of smells. (Bax, Odor Measurement Methods, 2022), (Bax et al., How Can Odors Be Measured? An Overview of Methods and Their Applications, 2020).

A study team created a particular application (APP) to gather citizen reports. The purpose of the APP is to request that users identify an odorous event and its primary features. Citizens are requested to complete a questionnaire with their observations regarding the odor incident intensity (weak, distinguishable, strong); duration (instant odour, more than 1 hour; and more than 6 hours), offensiveness ("unpleasant" or " unpleasant"), type of odour perceived (listed in wheel precisely designed to analyze all the probable odour sources in the studied area) (Oliva et al., 2024).

An engagement strategy that includes the phases of pilot design and data collecting has been established by a pilot study conducted in Chile. The participants were instructed to record odor episodes as they happened using a pen and paper odour diary or OdourCollect, a smartphone app that enables the collection of real-time odor observations. The software allows users to report odors by asking "what does it smell like?" and to provide details about the intensity, hedonic tone, subtypes of odors, duration of the odor episode, and possible source. The location, time, and date of the odor observations are automatically noted (Schleenstein et al., 2021).

C. Case Study

In the process of planning and designing, site study is a crucial phase. A site geographic, climatic, legal, historical, and infrastructural surroundings are examined as part of site analysis, a pre-design phase in architectural and urban design. The site evaluation contains the following:
Site Location: This comprises the site specifics, such as its roads and landmarks, context, such as nearby buildings, and vehicular and pedestrian access.

Neighborhood context: this category covers both proposed and existing structures, as well as outdoor areas, activities, vernacular settings, architectural elements, and landscaping.
Site-Specific Information: This section covers the site boundaries and measurements, buildable area, building height limitations, access to the site, and safety on the site and in the immediate vicinity.
Natural Features: these include the site geography, vegetation, and elevations. In addition to accessibility and circulation for both automobiles and people.
Utilities: this category comprises the location of all services, including water, power, gas, and sewer.
Sensory: This category covers views of the location from various angles as well as noise, odor, and pollution.

Human and Cultural: This category consists of local cultural, psychological, behavioral, and sociological elements. Along with the population, it considers the density, family size, ethnic tendencies, occupation, and leisure pursuits.
Climate: comprises site orientation, weather parameters such as temperature, rainfall, predominant wind directions, and the movement of the sun during the day and distinct seasons. (Urban Design Site Analysis, 2022)

Fig. 11. Tripoli City map with odor source location (Google Map, 2023)

To examine the efficiency of the citizen science method in measuring odor perception, the measurement of odor intensity and hedonic tone is applied in this part of the study. The selected case study is located in Tripoli city in Lebanon, and as the focus of this study is on the unpleasant odor, the measurement will focus on the unpleasant part of the hedonic tone, in addition to the measurement of the odor frequency, and intensity. As the main focus is on the unpleasant odor, the landfill of Tripoli city is selected as a significant source of unpleasant odor that affects people in their inhabited areas.

It was mentioned previously that the odor dispersion is affected by wind direction, and it is increased in hot and humid weather. For these reasons, the criteria of the selected impacted inhabited area by Tripoli landfill odors depend on:

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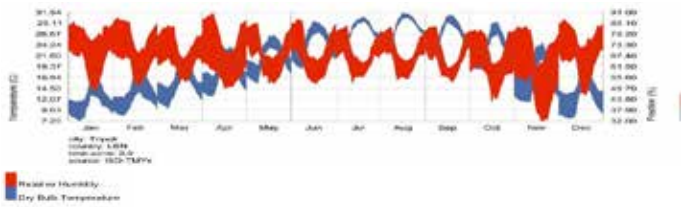


Fig. 12. The relative temperature and humidity in Tripoli city (EPW Map, 2023)

First: the selected season to apply for this study is the summer as this season has the most months of humid and hot days as shown in Fig.12.

Second: the location of the impacted area is selected according to Tripoli city wind rose in the selected season; the summer season. The wind rise of this season shows that the dominant wind direction is from the northwest, so the expected affected inhabited area by odor is located in the southeast of the odor source as shown in Fig.13.

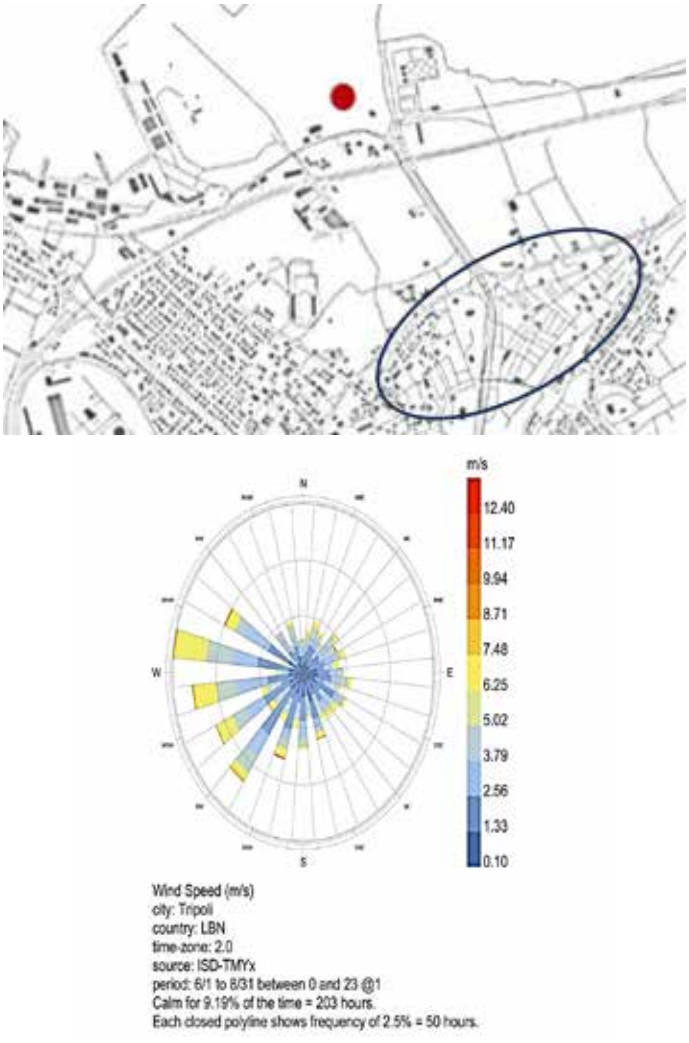
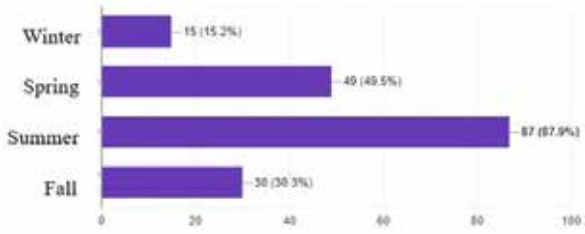


Fig. 13. The selected inhabited area with the odor source location (left), the wind rose of Tripoli city in the summer (right) (EPW Map, 2023)

As this research aims to apply the citizen science method for odor measurement, the questionnaires were distributed to the people in the selected area using Google Forms, and the questions include:
Section One: Socio-Demographic data: Gender, Age group, Employment status, Place of residence, and Duration of residency.

Section Two: includes the odor perceptions of the people living near the landfill site: The landfill odor perception on a scale of -4 extremely unpleasant -3 Moderate unpleasant -2 Unpleasant -1 slightly unpleasant 0 Neutral. The seasons in which people feel the smell or odor become stronger: Winter, spring, summer, and autumn. Time of the day people receive the odor: morning, noon, afternoon, evening, night. Duration of odor: a few hours, a day, more than a day. The odor intensity on a scale of 0 Not perceptible 1 very weak 2 weak 3 distinct 4 strong 5 very strong 6 extremely strong. The odor frequency on a scale of 1 seldom 2 sometimes 3 often 4 very often 5 always. The hedonic tone scale was limited to the nature of the landfill odor as an unpleasant smell, so the scale of this question is from 0 neutral -1 slightly unpleasant -2 unpleasant -3 moderate unpleasant to -4 extremely unpleasant.

The collected answers show that 93 percent of people living in this area are affected negatively by odor sources, and 88 percent of the answers indicate that the summer season is the season that enables people to receive the odors. For the time of the day that people can receive the strongest odors, 57 percent of the answers indicate that noon time is the significant time to receive the odors. The duration of odors according to the answers could last for more than a day according to 44 percent of the answers. For the odor intensity, the answers were equal between Distinct the scale of 3, and Strong the scale of 4 with 30 percent answers for each of these two scales. The odor frequency answers show that 37 percent of people Often receive the odor; on a scale of 3. The hedonic tone question shows that 63 percent of people consider the odor extremely unpleasant; on a scale of -4 as shown as Fig.14.



a. The season.

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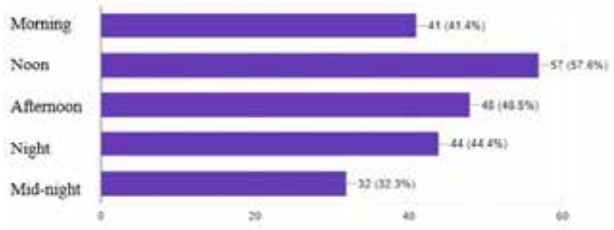
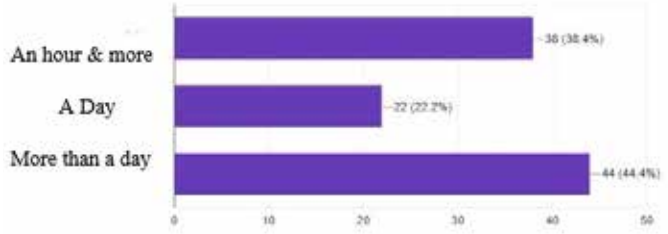
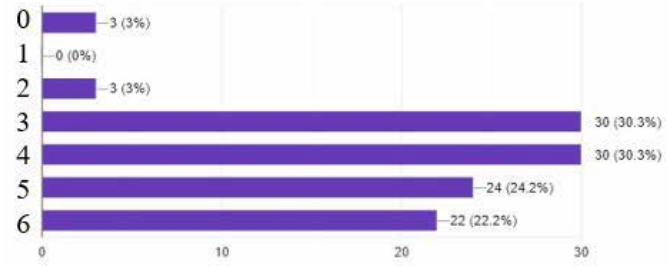


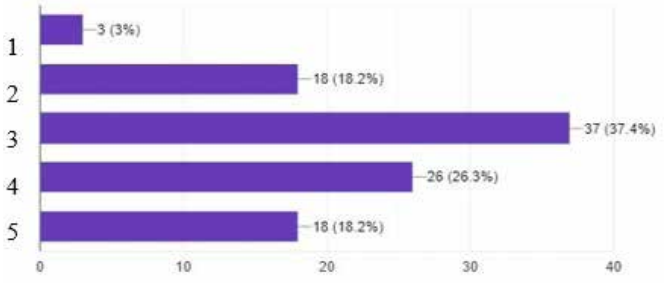
b. Time of the day.



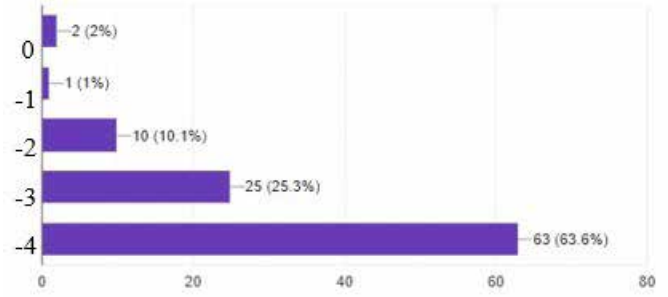
c. Duration of odors.



d. Intensity of odor.



e. Odor frequency.



F. Hedonic tone.

Fig. 14. People's responses to the questionnaire (Author)

The people's answers ensure the expected outcomes as the theoretical part presents the role of wind in carrying odors and the wind direction controls the odor dispersion side. In addition, the high temperature following the high humidity level plays a significant role in increasing odor intensity which causes people to receive a high level of odors.

Citizen science is an applicable measurement tool that could be adopted to measure and estimate the odor intensity and frequency with less requirement to odor measurement tools that might be not available for the urban designers while studying the sensory part of the urban site analysis.

FIDOL factors are significant analyzing factors that help the urban designers to assess the people perception and determine the scale of odor nuisance in the investigated area. Therefore, applying the citizen science method for odor measurement is an effective method to evaluate the odors that affect people.

VI. CONCLUSION

The smell concept has received more attention recently, especially in architectural and urban studies. The consequences of odors in metropolitan settings, however, are a topic that receives much more attention from chemical and environmental studies. This paper aims to provide a validated and applicable method for urban designers in odor measurement. The objective of this research is to present the various methods of measuring odors adopted in chemical and environmental studies to achieve an applicable odor measurement method in the architectural urban field. Chemical and environmental investigations use odor measurement equipment that is typically specialized in measuring odor concentration at the odor source or at the receptor location. However, in urban design studies, a separate technique known as the citizen science approach could be used to assess the odor if the urban designer intended to estimate the odor effects in the examined region. The measurement in this case considers the FIDOL factor to evaluate the odor including odor frequency, intensity, duration, offensiveness, and location, in addition to hedonic tone to estimate the degree of odor nuisance that people can feel. This method aids the urban designer in estimating the odor nuisance that adversely affects the people in their inhabited areas. This study was applied in Tripoli, Lebanon, as a case study to identify Tripoli landfill as a significant source of odor that affects residents there. An odor source circulated a questionnaire to the affected region, and the residents who responded confirmed that summer is the most common time of year for them to notice the odor in their locations to be related to the wind direction. The findings confirm

the validity, applicability, and accessibility of the citizen science approach for assessing odors for urban designers.

References

[1] L. Allen, "The smell of lockdown: Smellwalks as sensuous methodology," *Qualitative Research*, vol. 23, no. 1, 2023, doi: 10.1177/14687941211007663.

[2] C. Bax, S. Sironi, and L. Capelli, "How can odors be measured? An overview of methods and their applications," *Atmosphere*, vol. 11, no. 1. 2020. doi: 10.3390/atmos11010092.

[3] L. Capelli, R. Arias, J. Uribe-Echevarria, and S. Sironi, "Overview of odour measurement methods: The odour observatory as an informative tool for citizen science based approaches to odour management," *Detritus*, vol. 12, 2020, doi: 10.31025/2611-4135/2020.14003.

[4] D. Dobrzyniewski, B. Szulczyński, and J. Gębicki, "Determination of Odor Air Quality Index (OAQII) Using Gas Sensor Matrix," *Molecules*, vol. 27, no. 13, 2022, doi: 10.3390/molecules27134180.

[5] K. A. L. H. Sari, A. Hayati, and F. T. B. Samodra, "Perception of Visual Impairment Towards the Aesthetic of Architectural Elements," *IPTEK Journal of Proceedings Series*, vol. 0, no. 6, 2021, doi: 10.12962/j23546026.y2020i6.11102.

[6] A. Bokowa *et al.*, "Short introduction to the summary and evaluation of the odour regulations worldwide," *Chemical Engineering Transactions*, vol. 85. 2021. doi: 10.3303/CET2185021.

[7] M. Brancher, M. Piringer, A. F. Grauer, and G. Schauberger, "Do odour impact criteria of different jurisdictions ensure analogous separation distances for an equivalent level of protection?," *J Environ Manage*, vol. 240, 2019, doi: 10.1016/j.jenvman.2019.03.102.

[8] W. Brontowiyono, E. R. Sihayuardhi, F. B. Maziya, and L. Hakim, "Distribution Patterns of Ambient Air Quality Pre and During Pandemic in the Urban Area of Yogyakarta, Indonesia," *Journal of Ecological Engineering*, vol. 23, no. 10, 2022, doi: 10.12911/22998993/152362.

[9] C. Varela-Bruce and C. Antileo, "Assessment of odour emissions by the use of a dispersion model in the context of the proposed new law in Chile," *J Environ Manage*, vol. 295, 2021, doi: 10.1016/j.jenvman.2021.113208.

[10] F. Cangialosi, E. Bruno, and G. De Santis, "Application of machine learning for fenceline monitoring of odor classes and concentrations at a wastewater treatment plant," *Sensors*, vol. 21, no. 14, 2021, doi: 10.3390/s21144716.

[11] V. Guadalupe-Fernandez *et al.*, "Industrial odour pollution and human health: a systematic review and meta-analysis," *Environmental Health: A Global Access Science Source*, vol. 20, no. 1. 2021. doi: 10.1186/s12940-021-00774-3.

[12] X. Cai *et al.*, "Variation in the ratio of compounds in a plant volatile blend during transmission by wind," *Sci Rep*, vol. 12, no. 1, 2022, doi: 10.1038/s41598-022-09450-z.

[13] A. Caffyn, "Contesting countryside smells: The power of intensive livestock odours," *J Rural Stud*, vol. 86, 2021, doi: 10.1016/j.jrurstud.2021.07.021.

[14] E. A. ÇEVEN, "URBAN SMELLSCAPES: KASTAMONU URBAN PROTECTED AREA." Kastamonu Üniversitesi, 2021.

[15] E. A. , B. N. , & A. M. Çeven, "Analysis of Odor Distribution in Urban Landscape With GIS," *Res Sq*, 2022.

[16] Z. Chen, P. L. P. Rau, J. Kamenezkaja, N. Qie, and R. Zhong, "How Does It Feel? Odor-Evoked Emotion Among Chinese People," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2022. doi: 10.1007/978-3-031-06038-0_1.

[17] L. Conchou, P. Lucas, C. Meslin, M. Proffit, M. Staudt, and M. Renou, "Insect odorscapes: From plant volatiles to natural olfactory scenes," *Frontiers in Physiology*, vol. 10, no. JUL. 2019. doi: 10.3389/fphys.2019.00972.

[18] L. E. DeGreeff and M. Maughan, "Understanding the Dynamics of Odor to Aid in Odor Detection," in *Canines*, 2021. doi: 10.1201/9781003261131-9.

[19] M. Devonald, N. Jones, and S. Youssef, "'We Have No Hope for Anything': Exploring Interconnected Economic, Social and Environmental Risks to Adolescents in Lebanon," *Sustainability (Switzerland)*, vol. 14, no. 4, 2022, doi: 10.3390/su14042001.

[20] M. Diaconu, "Being and Making the Olfactoru Self. Lessons from Contemporary Artistic Practices," Springer Link.

[21] M. Eltarkawe and S. Miller, "Industrial odor source identification based on wind direction and social participation," *Int J Environ Res Public Health*, vol. 16, no. 7, 2019, doi: 10.3390/ijerph16071242.

[22] Retrieved https://www.ladybug.tools/epwmap/, "EPW Map."

[23] A. Eykelbosh *et al.*, "Elucidating the community health impacts of odours using citizen science and mobile monitoring," *Environmental Health Review*, vol. 64, no. 2, 2021, doi: 10.5864/d2021-010.

[24] W. Fang, Y. Huang, Y. Ding, G. Qi, Y. Liu, and J. Bi, "Health risks of odorous compounds during the whole process of municipal solid waste collection and treatment in China," *Environ Int*, vol. 158, 2022, doi: 10.1016/j.envint.2021.106951.

[25] I. Febrian, "Rider's Response To The Existence Of A Chicken Cutting On The Road Of Korong Gadang Kecamatan Kuranji Kota Padang," *Jurnal Buana*, 2021.

[26] G. Freeman, S. Y. Liu, J. Bardzell, X. Lu, S. Bardzell, and D. Cao, "Smart and fermented cities: An approach to placemaking in urban informatics," in *Conference on Human Factors in Computing Systems - Proceedings*, 2019. doi: 10.1145/3290605.3300274.

[27] F. Heigl, B. Kieslinger, K. T. Paul, J. Uhlik, and D. Dörler, "Toward an international definition of citizen science," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 116, no. 17. 2019. doi: 10.1073/pnas.1903393116.

[28] A. N. Hoang, T. T. K. Pham, D. T. T. Mai, T. Nguyen, and P. T. M. Tran, "Health risks and perceptions of residents exposed to multiple sources of air pollutions: A cross-sectional study on landfill and stone mining in Danang city, Vietnam," *Environ Res*, vol. 212, 2022, doi: 10.1016/j.envres.2022.113244.

[29] H. R. Hou and Q. H. Meng, "A Double-Square-Based Electrode Sequence Learning Method for Odor Concentration Identification Using EEG Signals," *IEEE Trans Instrum Meas*, vol. 70, 2021, doi: 10.1109/TIM.2021.3090177.

[30] X. R. Huang, S. S. Yang, W. S. Chen, Y. Q. Zhang, C. Te Lee, and L. B. Chen, "An IoT-Based Smart Trash Cans Monitoring System," in *2021 IEEE 10th Global Conference on Consumer Electronics, GCCE 2021*, 2021. doi: 10.1109/GCCE53005.2021.9621358.

[31] I. Imamović, B. Sousa, and A. Azevedo, "Urban Sensescapes," in *Encyclopedia of Tourism Management and Marketing*, 2022. doi: 10.4337/9781800377486.urban.sensescapes.

[32] C. Jia *et al.*, "Identification of origins and influencing factors of environmental odor episodes using trajectory and proximity analyses," *J Environ Manage*, vol. 295, 2021, doi: 10.1016/j.jenvman.2021.113084.

[33] Z. Jingyan, "The Preliminary Study on Smellscape Theory," webthesis.biblio.polito.it.

[34] H. G. Jo *et al.*, "Effect of odor pleasantness on heat-induced pain: An fMRI study," *Brain Imaging Behav*, vol. 15, no. 3, 2021, doi: 10.1007/s11682-020-00328-0.

[35] J. Jońca, M. Pawnuk, A. Arsen, and I. Sówka, "Electronic Noses and Their Applications for Sensory and Analytical Measurements in the Waste Management Plants—A Review," *Sensors*, vol. 22, no. 4, 2022, doi: 10.3390/s22041510.

[36] M. T. Kiefer, J. A. Andresen, D. W. Rozeboom, and X. Bian, "Development of a wind and Pasquill stability class climate dataset for the North American Great Lakes region," *International Journal of Climatology*, vol. 42, no. 10, 2022, doi: 10.1002/joc.7534.

[37] D. Li and X. Wang, "The processing characteristics of bodily expressions under the odor context: An ERP study," *Behavioural Brain Research*, vol. 414, 2021, doi: 10.1016/j.bbr.2021.113494.

[38] B. J. Lotesoriere, A. D. Giacomello, C. Bax, and L. Capelli, "The italian pilot study of the D-noses project: An integrated approach involving citizen science and olfactometry to identify odour sources in the area of castellanza (VA)," *Chem Eng Trans*, vol. 85, 2021, doi: 10.3303/CET2185025.

[39] C. Ma, J. Liu, H. Li, and J. Zhong, "Impact Assessment of Waste Odor Source Locations on Pedestrian-Level Exposure Risk," *Buildings*, vol. 12, no. 5, 2022, doi: 10.3390/buildings12050528.

[40] L. Nissin, "Smellscape of a Pompeian neighborhood," *Journal of Roman Archaeology*, vol. 35, no. 2, 2022, doi: 10.1017/S1047759421000830.

[41] D. Oettl, E. Ferrero, H. Moshammer, L. Weitensfelder, M. Kropsch, and M. Mandl, "Recent developments in odour modelling

and assessment in five provinces in Austria," *Air Qual Atmos Health*, vol. 15, no. 9, 2022, doi: 10.1007/s11869-022-01207-x.

[42] G. , C. F. , G. M. , F. I. , B. V. , N. V. , & Z. T. Oliva, *Urban odour annoyance management: An advanced embedded system for real-time monitoring enhanced by citizen science*. 2024.

[43] M. Onofrio, R. Spataro, and S. Botta, "A review on the use of air dispersion models for odour assessment," *International Journal of Environment and Pollution*, vol. 67, no. 1. 2020. doi: 10.1504/IJEP.2020.108358.

[44] D. Oxford, "Retrieved from https://www.oxfordlearnersdictionaries.com/definition/american_english/smell_2," Oxford University Press.

[45] S. Park, "Odor characteristics and concentration of malodorous chemical compounds emitted from a combined sewer system in Korea," *Atmosphere (Basel)*, vol. 11, no. 6, 2020, doi: 10.3390/atmos11060667.

[46] L. Perkins, "Making Sense of Place: An Ethnography of Toxicant Encounters in South Portland, Maine," *Tufts University ProQuest Dissertations & Theses*. 2023.

[47] R. , & D. A. Petrich, "Odor Measurements," *Springer Handbook of Atmospheric Measurements*. 2021.

[48] T. T. , T. P. T. , & N. T. Pham, "Factors Influencing Residents' Satisfaction Under Multiple Sources of Environmental Pollution," *A Structural Equation Modelling Approach. Research Square*. 2022.

[49] M. Piringer, W. Knauder, K. Baumann-Stanzer, I. Anders, K. Andre, and G. Schauberger, "Odour impact assessment in a changing climate," *Atmosphere (Basel)*, vol. 12, no. 9, 2021, doi: 10.3390/atmos12091149.

[50] M. , K. W. , P. E. , & S. G. Piringer, "Factors influencing separation distances against odour annoyance calculated by Gaussian and Larangian dispersion models," *Atmospheric Environment*. 2016.

[51] F. Poncet *et al.*, "Odor-evoked hedonic contexts influence the discrimination of facial expressions in the human brain," *Biol Psychol*, vol. 158, 2021, doi: 10.1016/j.biopsycho.2020.108005.

[52] G. , J. C. D. , & I. C. Schleenstein, "Advanced psichometrics based on citizen science. A history, a new standard, a European project and a case study in Chile," *Odors and Air Pollutants. Water Environment Federation*. 2021.

[53] G. Schleenstein, N. Muñoz, M. Balestrini, V. Righi, and L. Errandonea, "Outcomes of a Citizen Science Methodology and Traditional Odour Impact Evaluation Techniques Applied in a Chilean Pilot Study," *Chem Eng Trans*, vol. 85, 2021, doi: 10.3303/CET2185024.

[54] A. L. Schwabe, S. K. Naibauer, M. E. McGlaughlin, and A. N. Gilbert, "Human olfactory discrimination of genetic variation within Cannabis strains," *Front Psychol*, vol. 13, 2022, doi: 10.3389/fpsyg.2022.942694.

[55] S. Sensory, "Exploring Characters of Odors." 2020.

[56] X. Song and Q. Wu, "Study on smellscape perception and landscape application of fragrant plants," *Urban For Urban Green*, vol. 67, 2022, doi: 10.1016/j.ufug.2021.127429.

[57] A. H. Toomey, L. Strehlau-Howay, B. Manzolillo, and C. Thomas, "The place-making potential of citizen science: Creating social-ecological connections in an urbanized world," *Landsc Urban Plan*, vol. 200, 2020, doi: 10.1016/j.landurbplan.2020.103824.

[58] N. Tran, "Efforts to remove bad smells from Khanh Son Landfill." 2020.

[59] W. Tullett *et al.*, "Smell, History, and Heritage," *American Historical Review*, vol. 127, no. 1, 2022, doi: 10.1093/ahr/rhac147.

[60] Urban Design Lab, "Urban Design Site Analysis." 2022.

[61] J. W. Wägele *et al.*, "Towards a multisensor station for automated biodiversity monitoring," *Basic Appl Ecol*, vol. 59, 2022, doi: 10.1016/j.baae.2022.01.003.

[62] J. Xiao, "Smell, smellscape, and place-making: A review of approaches to study smellscape," in *Handbook of Research on Perception-Driven Approaches to Urban Assessment and Design*, 2018. doi: 10.4018/978-1-5225-3637-6.ch010.

[63] M. Ravina, S. Bruzzese, D. Panepinto, and M. Zanetti, "Analysis of separation distances under varying odour emission rates and meteorology: A WWTP case study," *Atmosphere (Basel)*, vol. 11, no. 9, 2020, doi: 10.3390/ATMOS11090962.

[64] T. Zarra, V. Belgiorno, and V. Naddeo, "Environmental odour nuisance assessment in urbanized area: Analysis and comparison of different and integrated approaches," *Atmosphere (Basel)*, vol. 12, no. 6, 2021, doi:

10.3390/atmos12060690.

[65] Y. Zhang *et al.*, "Determination of dose-response relationship to derive odor impact criteria for a wastewater treatment plant," *Atmosphere (Basel)*, vol. 12, no. 3, 2021, doi: 10.3390/atmos12030371.

[66] M. Brancher, M. Piringer, W. Knauder, C. Wu, K. D. Griffiths, and G. Schauberger, "Are empirical equations an appropriate tool to assess separation distances to avoid odour annoyance?," *Atmosphere (Basel)*, vol. 11, no. 7, 2020, doi: 10.3390/atmos11070678.

[67] G. , P. M. , W. C. , & K. J. A. Schauberger, "Environmental Odour," *atmosphere MDPI*, 2021.

[68] G. Rho, A. L. Callara, N. Vanello, C. Gentili, A. Greco, and E. P. Scilingo, "Odor valence modulates cortico-cortical interactions: A preliminary study using DCM for EEG," in *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS*, 2021. doi: 10.1109/EMBC46164.2021.9629910.

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Understanding Walkability Criteria in High-density Communities: A Case Study in Alexandria, Egypt

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ABSTRACT

Walkability has recently been a major topic and an essential attribute in the sustainability approach to urban design and planning. Studying urban dimensions and qualities in a specific context is essential to developing walkability criteria, as each environment has its conditions and spatial scale that affects walkability scenarios differently. This paper studies the main criteria contributing to successful walkable environments in high-density communities. The methodology consists of developing detailed walkability criteria by studying urban qualities related to three dimensions: morphological/visual, functional, and social. Each urban quality is analyzed by stating its definition, assessment method and studying its condition in high-density communities. The assessment methods are based on quantitative and qualitative indicators depending on the nature of the criteria, which include imageability, transparency, scale of enclosure, complexity, connectivity, land use mix, legibility, as well as pedestrian comfort and safety. Providing tools to upgrade walkability in a city like Alexandria in Egypt is another objective of this study. Walkability criteria are tested on a typical city center street where buildings of every age and condition are mingled, and which is similar to many other Alexandria streets, thus, the results and recommendations can contribute to enhancing the walkability of everyday streets in the city.

Index-words: *Walkability, High-density, Urban dimensions, Urban qualities, Alexandria.*

I. INTRODUCTION

The concept of walkability was proposed by researchers at the beginning of the twenty-first century and received substantial attention, especially in the fields of health and transportation. Walkability is a term used to describe built and social environment aspects that have impacts on health, energy balance, and physical activity (Tobin *et al.*, 2022). The topic was then soon integrated into interdisciplinary studies and urban design. Residential density is a generally accepted factor that encourages people to choose walking as their means of mobility (Wang *et al.*, 2022). Thus, planners and designers should integrate walking into people's daily lives through the design of a pedestrian-friendly environment, as providing walkability in high-density contexts helps achieve a healthier, safer, and more sustainable environment (Li, 2015). Population density can be defined as the number of people per land area where the land area is measured in square miles or square kilometers (Rosenberg, 2019). According to Socio Economic Data and Applications Center (SEDAC), the world population density is categorized into six categories, the highest category is above 1000 persons/ km^2 (SEDAC, 2020). Therefore, in this research, high-density means population density above 1000 persons/km^2. High-density communities have several benefits and problems. This environment increases opportunities for walking due to the presence of near destinations. On the other hand, it causes the quick spread of diseases and air pollution due to traffic congestion, negative impact on mental health, and urban temperature rise (Udell *et al.*, 2014), (Kent, 2015), (Dawodieh, 2017).

To get people out of their cars and walk, inclusive walkable urban spaces that suit most types of users need to be designed because each type of users has its specific needs and priorities to walk (Udell *et al.*, 2014). Moreover, time is an essential dimension in walkability criteria because urban aspects are related to temporalities and the environment is perceived and used differently at different times of day, night, and seasons (Carmona *et al.*, 2003). Besides, walking appears negligible if it is assessed in terms of travel distance. However, it should be measured

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in terms of travel time, trips, or even outdoor exposure to public spaces and social infrastructure because the pedestrian experience is affected by public exposure as walking has slower speeds than motorized transport due to spending time waiting at bus stations, loading bays or standing in front of stores windows (Ang, Taclendo *et al.*, 2023). This confirms the need for new approaches and new criteria to tackle the most urgent environmental and urban design challenges. The main aim of the study is to contribute to creating a successful vital walkable environment in high-density urban areas. The main research questions are what the urban dimensions and qualities that affect walkability criteria are, how to evaluate walkable urban qualities and dimensions of walkability criteria, and how to reach a better walkable environment in high-density communities. The methodology in this paper consists of detailed walkability criteria derived from a literature review based on several references such as Carmona *et al.*, 2003; Ewing & Handy, 2009; Clos, 2013; Tibbalds, 2000; Lynch, 1960 and others through studying urban qualities that are provided from three dimensions: morphological/ visual, functional and social. Each urban quality is studied through illustrating its definition, assessment method and studying its conditions in high-density communities. Then applying the criteria on Syria Street in Alexandria City as a case study to study factors that help in improving walkability in the city.

A. Walkability Criteria in High-density Communities

Ewing and Cervero proposed the five D to measure walkability: Density, Diversity, Design, Destination accessibility and Distance to transit (Ewing & Cervero, 2010). In line with this approach, a large body of research focused on evaluating the degree of walkability according to the following criteria: characteristics of the near environment including accessibility, security, and the quality of the environment, the urban network including density and diversity of land use, destinations, and activities, the willingness of people to walk including comfort, legibility, safety and efficient modal interchanges (Cerema, 2021). Hence, it is important to create localized walkability criteria that respond to local contexts instead of adapting international codes to respect the sense of place and the specific requirements that need to be understood and analyzed (Sulaiman, 2020). The proposed criteria in this research include all the physical and psychological attributes that were revealed in the recent literature to increase people's willingness to walk. The criteria are classified into three main dimensions, including morphological and visual, functional and social dimensions (Fig. 1) based on Carmona *et al.*, 2003; Ewing & Handy, 2009; Clos, 2013 and others.

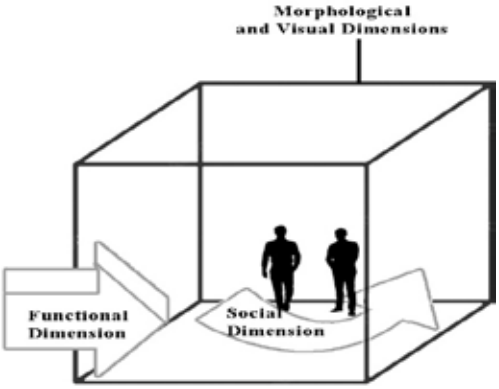
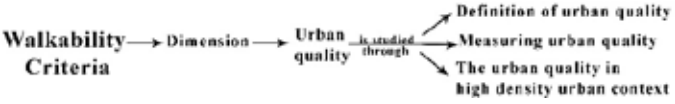


Fig. 1. Walkability criteria in high-density communities (Source: The researchers based on Carmona et al., 2003, Ewing & Handy, 2009; Clos, 2013 and others).



Each dimension is investigated through specific urban qualities and each urban quality is studied by stating its definition, methods of assessment and showing the urban quality condition in high-density urban communities (Fig. 2).

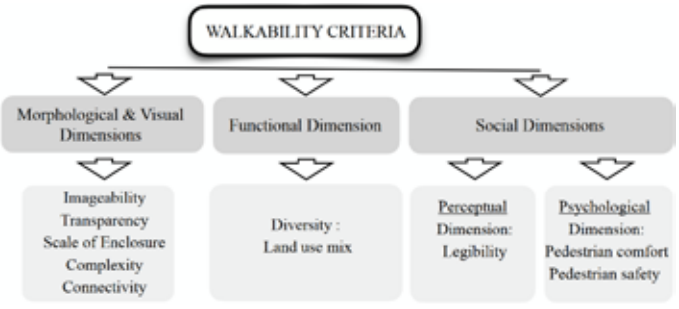


Fig. 2. Methodology of studying each dimension in the mentioned criteria of the research (Source: The researchers).

1. Morphological and Visual Dimensions

Morphological and visual dimensions are the first section in the research criteria, and they are investigated by studying five urban qualities as illustrated in (Fig. 1), which are imageability, transparency, scale of enclosure, complexity, and connectivity. These qualities are classified into

three categories, which are urban qualities that are related to the user, surrounding buildings, and the street network. Imageability, transparency, and complexity are related to the scale of buildings while scale of enclosure quality is related to both the scale of buildings and users, and connectivity is an urban quality that is related to the street network.

a. Imageability

Imageability is an urban quality that makes the elements of the physical environment easily recognizable to people through shape, color, and arrangement (Lynch, 1960). Some indicators help in the evaluation of imageability, such as counting special recognizable features like the number of courtyards, and major landscape features, calculation of the proportion of historic building frontage, number of buildings with identifiers and buildings with non-rectangular shapes, and observing the presence of outdoor dining areas (Clemente *et al.*, 2005), (Ewing *et al.*, 2013). Imageability in high-density can be enhanced through creating open green spaces (Udell *et al.*, 2014). Moreover, in denser cities, there are flexible methods to create a recognizable landmark, which enhances imageability by benefiting from existing buildings of exceptional design qualities and elements of the cityscape (Hong Kong 2030+ Planning Department, 2016).

b. Transparency

Transparency can be defined as an urban quality that allows visual connection and public engagement beyond the façade through glass windows, which provides interest and activity for pedestrians along sidewalks (The San José City Council, 2004). The evaluation of transparency in urban spaces can be derived from indicators such as the proportion of windows at street level, which allow visual connection between users of public space and what is beyond the buildings' facades, proportion of street wall, and active uses in public space (Clemente *et al.*, 2005). In crowded spaces, blurring borders in urban spaces and creating clear visual connections, which provide a sense of openness are priorities (Shi *et al.*, 2014).

c. Scale of enclosure

Scale of enclosure can be defined as a physical urban quality that refers to the ratio between the width of a particular space to the height of its walls and it considers that the urban environment should be designed for people and not just for vehicles (Tibbalds, 2001). Scale of enclosure can be assessed using several methods. In this research, two evaluation methods are mentioned. The first method is the ratio between the height and width of the street. The ideal recommended height-to-width street ratio is 1:1 and the minimum ratio is 1:2 according to Jacobs (1996) as cited in Ewing (1999). The ratio of 1.5:1 between the height and width of the street creates claustrophobic space based on Hedman and Jaszewski's (1984) (Kahraman & Cubukcu, 2017). The second method is assessed through indicators such as recording the number of long sight lines, proportion of windows at street level, average of building heights, and number of small planters, and pieces of furniture in the street (Clemente *et al.*, 2005). In compact urban contexts, openness and less enclosed open spaces are priorities. Each outdoor activity has its requirement of enclosure of space so the functionality of open space should be studied to determine enclosure of space and its design (Shi *et al.*, 2014). To achieve a more human-scaled city in high-density communities, cities should be attractive at eye level (Harrouk, 2020). A plinth is the ground floor of a building, which is the most effective part at eye level. Plinths set 90% of the building's contribution to the experience of the environment (Karssenberg *et al.*, 2016).

d. Complexity

Complexity is the urban quality that describes the extent of visual elements and information in the surrounding environment, which describes the richness of a particular scene (Kaplan & Kaplan, 1989). High complexity is achieved when the urban design elements are not too similar, ordered, and predictable but when the pedestrians are provided with interesting things to see. Complexity is evaluated through some indicators such as the number of buildings, basic and accent colors of buildings, public art (murals, sculptures, and landscape works), and the presence of outdoor dining. These factors indicate the degree of visual information received by the user in urban space (Clemente *et al.*, 2005).

e. Connectivity

Connectivity is the quality that refers to the density of street connections and the directness of street links (Victoria Transport Policy Institute, 2017). Connectivity can be measured in several methods. The first method is by measuring the directness of available routes from numerous origins to particular destinations (Clos 2013 cited in Elfouly, 2017). An index of 1.0 is the best possible rating while an

average value of 1.5 is considered acceptable (Clos, 2013).

Pedestrian Route Directness Index= Actual Walking Distance / Direct Distance. The second method is a Composite Street Connectivity Index (CSCI) that compiles quantitative measures including land allocated to streets (LAS); street density (SD); intersection density (ID) and it is calculated using this formula based on Clos (2013) as cited in Elfouly (2017). The closer the CSCI to 0, the less connected is the street network of a city, while the closer the CSCI to 1, the more connected is the street network of a city. The CSCI method is used to compute connectivity for cities (Clos, 2013).

UN-CSCI = 1/3 [LAS + SD + ID]

The third method is a simple most commonly used quantitative method. This method is the one used in measuring connectivity in the case study because the other two methods are used on a larger scale and for comparing cases with numerous origins to particular destinations. The larger the number produced by the index indicates the greater the street connectivity (ONESTL, 2021). Link is defined to be the pathway segment between two nodes. 1.4 is the minimum required ratio of a walkable community (Clos, 2013).

Link-Node Ratio=Links/Nodes

High densities provide comfortable walkable distances to destinations. It is observed that new settlements have lower urban density than in the city core. Thus, one of the approaches to improve this is by providing better sustainable urban development in new communities that are closer to cities through providing mixed land uses and transport options rather than the car. In addition, one of the upgrade approaches is providing service lanes, more spaces for walking, and cycling, well-maintained pavements, pedestrian crosswalks, and bridges (Clos, 2013).

2. The Functional Dimension

It is the second dimension of the walkability criteria. It is understood through studying diversity, which is achieved by land use mix in urban space.

Diversity (Land use mix): Mixed land use is the presence of a variety of uses close to each other, which enhances walking (Transportation Efficient Communities, 2022). Diversity of land uses and pedestrian populations provides vitality in urban space (Garau & Annunziata, 2022). The formula below is used to help in measuring land use mix, but it has some limitations because it cannot indicate the types and distribution of land uses (Mavoa *et al.*, 2018). In this formula, H = land use mix score, pi = the proportion of the area covered by land use i against the summed area for land use classes of interest (including i), and n is the number of land use classes of interest (Frank *et al.*, 2005 cited in Christian *et al.*, 2011).

$$H = -1(\sum_{i=1}^{n} pi * ln(pi))/ln(n)$$

Increasing density in compact contexts provides access to a variety of needs with shorter travel distances, which enhances walkability (Udell *et al.*, 2014). However, density brings land uses together, thus it is essential to consider the land use distribution along the streets to avoid overpopulation in one focal point. In compact cities, it is needed to reinvent urban spaces vertically and horizontally. Obsolete industrial sites, former landfills, and quarries can be regenerated. In addition, optimizing uses of vacant lands, spaces underground, and under flyovers for compatible uses can help in upgrading land use quality in compact contexts (Hong Kong 2030+ Planning Department, 2016).

3. The Social Dimension

The social dimension is the third section of walkability criteria in the research as illustrated in (Fig.1) and it is studied through two dimensions, which are the perceptual and psychological dimensions.

4. The Perceptual Dimension

The perceptual dimension is analyzed by studying legibility, which is necessary for the user to assimilate and read urban space.

Legibility is an urban quality that helps users easily understand and move in urban spaces, which can be evaluated in multiple ways. One of the evaluation methods is by marking existing paths, nodes, landmarks, edges, and districts on a map and analyzing them to provide recommendations for readjusting the design of those elements in the urban context when possible (Lynch, 1960). There are other indicators for evaluation such as the presence of lighting of roads at night, repeated remarkable signs along the streets, and using the rhythm of trees to

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define the continuity and discontinuity of the road (Nia, 2017). In compact contexts, enhancing legibility can be achieved by simplifying the building facade character, which facilitates the illustration of the full image (Nurgandarum & Anjani, 2020). Grouping similar destination zones whether in form or function helps in the understanding of place (Karssenberg *et al*., 2016). In compact spaces, it is essential to design clear environments to reduce confusion by creating clear connections and using regular shapes in defining boundaries (Shi *et al*., 2014).

5. The Psychological Dimension

The psychological dimension is discussed by studying pedestrian comfort and safety, which affects how a user can feel and experience the pedestrian space.

a. Pedestrian comfort

Pedestrian comfort can be described as a positive emotional reaction to external surroundings, which gives a pleasant experience for the pedestrian (Ovstedal & Ryeng, 2002). Pedestrian comfort is studied using three categories, which are privacy, environmental design, and street design.

First, privacy can be achieved through visual and auditory aspects. Visual privacy can be evaluated by observation of space hierarchy between public and private spaces (Carmona *et al*., 2003) and pedestrian density, which is considered comfortable if the range is from 6 to 12 people per minute per meter (Jacobs, 1996 cited in Matan). Auditory privacy is evaluated by measuring noise level. According to WHO, 45 decibels have been considered the city's safe noise level (Bhat, 2010). Secondly, shades and wind flow affect thermal comfort. One of the indicators that a route has sufficient shade is that pedestrians should be able to walk 20 minutes from origin to destination and 20% to 60% is the shade coverage for a comfortable route (Bork, 2019). To improve wind flow, it is recommended to align the streets in a parallel orientation or up to 30 degrees to the wind direction and to link open spaces where possible in the urban form (Ng, 2010). Thirdly, comfort can be achieved through street design including seat location, access to public transport, footpath design, street slope, curb ramps, and cleanliness. It is recommended to put seats at regular intervals every 100 meters (Ewing, 1999). Moreover, the walking distances from the bus stop to the destination points are acceptable if 1000 meters maximum and it is comfortable if below 400 meters (Burke & Brown, 2007 cited in Tanzil & Gamal, 2021). Footpath width should be from 1.8 to 4.5 m to be comfortable (Ewing, 1999), (Smith *et al*., 1987). It is recommended that the slope (height to length) of a ramp be designed between 1:12 to 1:20 to be comfortable for most users. The slopes between 1:12 and 1:16 can have a maximum horizontal length of 9.14 m without a landing, while slopes between 1:16 and 1:20 can have a horizontal run up to 12.19 m before requiring a landing. These recommended ranges for slopes provide comfort for different types of users, especially the disabled (Maddock, 2020). Curb ramps are recommended to be placed to provide a smooth transition from the sidewalk to the street and crossings for the elderly and disabled with a maximum slope of 1:12, minimum width of 121.9 cm, and overall depths of 121.9, 152.4 cm (Doss, 2023). Street cleanliness is achieved through providing well-distributed dustbins, which enhances users' comfort.

In high densities, the hierarchy of spaces can be achieved through elevating buildings' ground floor or recessing building entrances. Noise can be controlled through sound absorbance, diffusion, and masking (Kahraman & Cubukcu, 2017). Redistribution of land uses in crowded areas is recommended to spread pedestrian density around where more people can comfortably walk and still have space to breathe (Alter, 2020). Making variations in buildings' heights and splitting the large solid building mass into multiple partitions help improve wind flow (Yang *et al*., 2020). It is recommended in residential areas to separate sidewalks and vehicle traffic by a planting strip or an additional buffer zone that ranges between 30 and 60 cm (Aktan & Özyavuz, 2022).

b. Pedestrian safety

Pedestrian safety is the extent to which the pedestrian can walk without the fear of the occurrence of accidents or crimes (Roberts, 2018). Pedestrian safety is measured through some indicators such as traffic signal spacing, crosswalks, stop bars, safety islands, speed limits, and street lighting standards.

Traffic conditions such as vehicle volume and pedestrian crowds can be controlled through regulations such as speed limits, speed bumps, and traffic calming schemes (Liang *et al*., 2023). Traffic signal spacing is recommended to be from 400 to 800 meters, especially in arterial roads, and suburban and developing rural areas, while in downtown areas it is often about 150 meters (Smith *et al*., 1987). According

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to Aberdeen Pedestrian Transportation Plan (APTP), crosswalks should be located with traffic signals, at non-signalized school zones, and uncontrolled intersections with no traffic signals. Crosswalk widths should be 1.8 meters minimum and ideally three meters in downtown areas. In addition, a stop bar should be located at a distance from 4.5 to 9 meters back from the crosswalk to increase visibility (APTP, 2011). Narrowing the crossing distance at street intersections is recommended to facilitate street crossing (Smith *et al.*, 1987). A pedestrian safety island is a solution for wide roads with three or more lanes of traffic (National Association of City Transportation Officials, 2013). On the other hand, speed bumps should be applied on one-lane streets (New York City Department of Transportation, 2020). It is recommended that the safest speed for cars is 30km/h in high pedestrian areas, 40km/h for local roads, and 60km/h or more on arterial roads (Victoria Walks, 2022). It is found that just a 5% cut in average speed can result in a 30% reduction in fatal crashes (Claris *et al.*, 2016). Street light poles standards vary according to street type. Sidewalks standard light poles range from 4.5 to 6m in height. Narrow streets light poles range from 8 to 10m in height while taller poles of height 10 to 12 m are used for wider streets. Moreover, spacing between light poles should be 2.5–3 times the pole height (National Association of City Transportation Officials, 2016).

According to Jane Jacobs, one of the main principles that contribute to crime prevention is to increase activities and "eyes on the street" (Jacobs, 1992). This is achieved in high-density communities through the presence of more mixed land uses that attract people at various times of the day (Matan, 2011). In compact contexts and mixed land-use areas, pedestrian-vehicle crashes may increase because of the increase in the number of pedestrians and cars (Lee *et al.*, 2013).

II. CASE STUDY: ANALYSIS OF WALKABILITY CRITERIA IN SYRIA STREET IN ALEXANDRIA, EGYPT

The morphology of Alexandria has evolved over its long history of 25 centuries. Its planning is based on Hippodamian principles where the streets are laid out in an orthogonal gridiron configuration. The city extends 24 Km from Abukir east to Ras-El-Tin west and 36 Km to the west borders of the governorate till Sidi Kreir, so from east to west the city is approximately 60 Km wide. While it extends from the North to the South for a maximum of only 5 Km for its larger parts (Zahran *et al.*, 1984). Alexandria has limited opportunities for horizontal expansion. Its linear form is caught between the Mediterranean Sea and the Mariut Lake with other water bodies south. Valuable agricultural lands bound the city from the east, while in South-West of the city, various industries are spread out. Alexandria is situated principally along five longitudinal axes: The Corniche Road (Tariq El Guish), the tramline, Abukir Road, Port Said Street, and Al-Mahmoudiah Canal (today an urban expressway). The Corniche Road is one of the most longitudinal and important axis roads in the city. It was developed during the end of the twentieth century from 1998 until 2002 to be widened to at least six lanes and up to ten lanes in some areas to accommodate the growing traffic (Yehia, 2007).

Syria Street in Alexandria is one of the main streets that connects the three main arterial roads, which are Abukir Road, Corniche Road, and Abd-ElSalam Aref Road (the tramline in Roushdy district) (Fig. 3).

Fig. 3. Syria Street in Roushdy district (Source: Google Maps, 2022, edited by researchers).

Syria Street is approximately 750 meters in length and 14 meters in width. It is a busy street with its various land uses, which attracts a variety of users daily. Moreover, the street is located near Stanley Bridge, which is one of the important landmarks and destinations in the city.

The main aim of choosing this location as a case study is that Syria Street can be considered a typical city center street with distinctive features. Its distinctiveness is due to its location, which is near Stanley Bridge, connecting the three main arterial roads of Alexandria, and the presence of a considerable number of historical buildings. Thus, if the streets are categorized in general considering their degree of character and imageability, Syria Street is neither a Local Street with no distinctive features nor what can be called a « Great Street » with outstanding architecture, historic value, tourist attractions, and landmarks. The main reason for

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choosing the case study of this category is that Alexandria includes a large number of similar city center streets that need to be improved and that face the same problems. Hence, the recommendations of Syria Street can be applied to other streets and can help in understanding and analyzing them.

According to the studied criteria, the urban qualities are evaluated to study the strengths and weaknesses related to walkability in the street and provide recommendations. Some qualities are evaluated by comparing the measured value in Syria Street with the standard or Recommended Ranges (RR) of urban indicators, as mentioned in the earlier part of the research. Other qualities are studied through survey, observation, and qualitative analysis of urban indicators of Syria Street.

The studied walkability criteria are analyzed in Syria Street through morphological and visual, functional, and social dimensions.

A. Morphological and Visual Dimensions

Morphological and visual dimensions in Syria Street are analyzed using the urban qualities previously cited and compared with recommended ranges, as explained earlier.

1. Imageability

This quality is evaluated using some recognizable indicators in Syria Street such as the presence of courtyards, plazas, and parks, major landscape features, proportion of historic frontage, presence of buildings with identifiers and non-rectangular buildings, and outdoor dining areas. Through observation, Syria Street contains no plazas nor recognizable courtyards. There are not any outdoor cafés or restaurants on street level. On the other hand, some trees are observed in some zones but no major landscape features are observed in the rest of the rest of the street (Fig.4).

Fig. 4. The presence of trees in some areas of Syria Street and their absence in other parts of the street (Source: The researchers)

The presence of historical frontages increases the imageability of the street, which helps in enhancing walkability. This appears on Syria Street as it contains eight listed buildings. Syria Street can be described as a street that possesses two different characteristics regarding architecture and density. For the most part, the buildings bordering the Street are conventional and characterless, with no particular distinctive architecture. Apartment blocks are rising to 10 to 15 floors and include commercial spaces on the ground floor and the upper first floors. At the same time, other parts of the Street are constituted by villas with gardens. Eight of these villas are listed in the Catalogue of Architectural and Urban Heritage of Alexandria (Governorate of Alexandria, 2007). Under the Unified Building Law 119 for 2008 and the Heritage Conservation Law 144 for 2006, the following map shows Syria Street in red and the other main roads surrounding it in yellow. The buildings highlighted in blue are listed on the « City level » in the Catalogue, which corresponds to level II (in the British System), level I, being the highest exceptional value. The buildings in violet are listed as « Local level ». Most of these villas, which are eclectic in style, were built in the first half of the twentieth century. These buildings of architectural and historic value have a great role in reflecting the sense of place and identity of Alexandria and affect the imageability of the street (Fig.5).

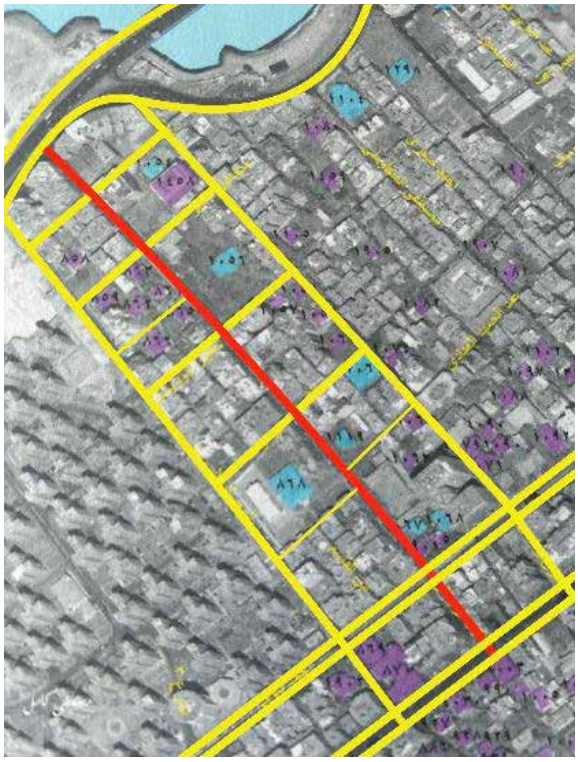

Fig. 5. The buildings in blue are listed on the « City level » in the Catalogue and the buildings in violet *are listed as lesser«* Local level » in Syria Street (Source: based on Governorate of Alexandria, 2007).

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Fig. 6. Qasr El Orouba is an example of listed villas bordering Syria Streets which is architecturally distinctive by its Islamic and Early Modern influences (Source: The researchers).

Among the listed villas bordering Syria Streets, the Palace of Orouba « Qasr El Orouba » is distinctive with its Neo-Islamic eclectic style and Early Modern influences. The Palace code is 1056 in the Catalogue and is classified as « City level » for its unique architectural value (Governorate of Alexandria, 2007, p.142). Unfortunately, the Palace is abandoned. A project of rehabilitation and adaptive reuse could be regenerating Syria Street (Fig.6). As so rightly put by Jane Jacobs, "New ideas must use old buildings » (Jacobs, 1992, p.188). Fig.7 shows the original page of the Heritage Catalogue showing the Data concerning another listed villa (Code 861) located on Syria Street. The following form is an identification of the building code, name, type, address, and the building classification standards, which show that it has a distinctive architectural style.

2. Transparency

This quality is evaluated through indicators such as the proportion of windows at street level, street wall, and active uses of Syria Street. At the ground floor level, commercial spaces with glass transparent windows are observed which enhances the visual connection between pedestrians outside and the inside spaces (Fig.8). The proportion of windows at street level on both sides is assessed to be approximately 65% along the street as blocks lengths on both sides of the street are approximately between 620 and 640 meters and the lengths of the transparent façades on both sides are approximately between 345 and 485 meters.

Fig.7. The page of the Heritage Catalogue showing the data concerning another listed villa (Code 861) located on Syria Street (Source: Governorate of Alexandria).

Fig. 8. Glass facades on the ground floor at Syria Street (Source: The researchers).

On the other hand, the proportion of the street wall is the proportion of the length of the street on both

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sides made up of the street wall. In Syria Street, the proportion of street walls is high because most of the street is lined with buildings on both sides. Active uses can be defined as shops, restaurants, public parks, and other uses that generate activity and provide significant pedestrian traffic. Thus, active uses in Syria Street are considered high because the main land use on both sides of the street is commercial. Except for the fences and blank walls surrounding the gardens of the private villas (Fig. 6 and Fig. 7).

3. The Scale of Enclosure

It is measured through two methods. First, through indicators such as the presence of long sight lines, pieces of street furniture and small planters, and the proportion of windows at street level. Second, through calculation of the ratio between the heights of buildings to the width of the street. Through observation, long sight lines are interrupted along the street due to the presence of obstacles on the sidewalks. Syria Street contains elements of street furniture such as flowerpots, huge banners, street vendors, and pedestrian scale lights but it does not include seats and enough trashcans. These elements contribute to pedestrian comfort and cleanliness, and they need to be upgraded. The proportion of windows at street level is assessed to be approximately 65% along the street, as mentioned before. The height of buildings in the street ranges between 4.5m to 42m and the width of the street is about 14m. This means that the average ratio (H/W) varies between 1:3 and 3:1 (Fig.9).

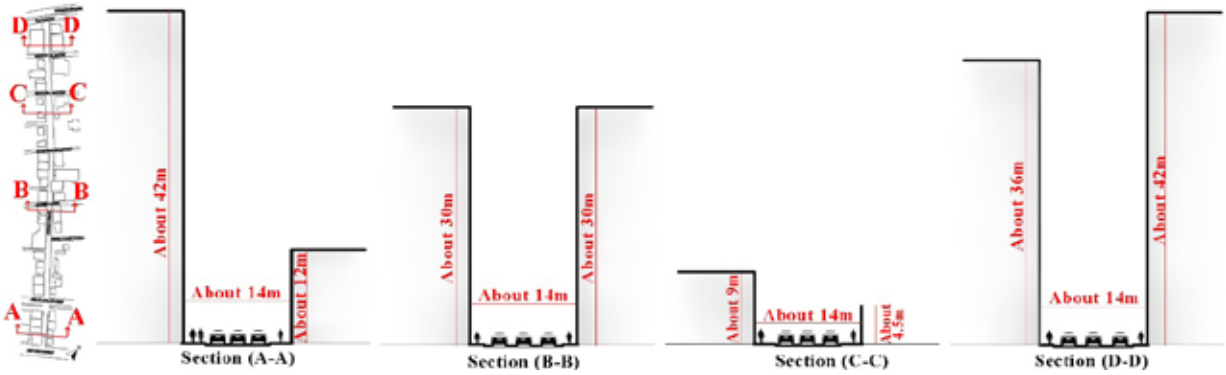

Fig. 9. Enclosure in Syria Street (Source: The researchers).

Thus, only some areas in the street are within the recommended ranges, as in section C-C (in Fig.9). The ideal recommended (H/W) street ratio is 1:1 and the minimum ratio is 1:2, according to Jacobs (1996) as cited in Ewing (1999). The ratio of 1.5:1 between the height and width of the street creates claustrophobic space based on Hedman and Jaszewski's (1984) (Kahraman & Cubukcu, 2017).

4. Complexity

It is evaluated through indicators such as the number of visible buildings on both sides of the street within the study area, basic and accent building colors, the presence of outdoor dining area, and public art pieces such as monuments, sculptures, murals, and any artistic display in Syria Street. Through observation and survey of Syria Street, the average number of visible buildings is about 7 buildings of different design facades. This is considered a good degree of complexity. Variable basic and accent building colors are observed in the street. Syria Street contains no outdoor dining areas or public art pieces. Thus, outdoor dining areas and public art pieces should be added to enhance complexity.

5. Connectivity

It is evaluated in the case study using the third method by calculating the ratio between links to nodes which is the most suitable method of evaluation of connectivity of the case study because the other two methods are used for measuring connectivity of streets with multiple start points and particular destination or for larger scales than one street. Link is defined to be the pathway segment between two nodes. From the analysis of the connectivity map of Syria Street and surrounding streets, as shown in (Fig.10), it is illustrated that the Link-Node Ratio = 62 links /34 nodes = 1.8. This is considered an acceptable ratio for connectivity of a walkable community because the minimum required ratio of a walkable community = 1.4 (Clos, 2013).

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Fig. 10. Connectivity and legibility existing map for Syria Street (Source: Google Maps 2022, Osama 2017, AlZuabi, 2018 and edited by researchers).

Another factor that affects connectivity in the street is the presence of obstacles on footpaths, such as elements that are not placed in appropriate places, which affects the pedestrian walking experience. For example, light poles, huge advertisement banners, outdoor merchandise of shops, parked motorcycles, and ATM kiosks, as several banks are located on the Street (Fig.11).

Fig. 11. Different kinds of obstacles on sidewalks of Syria Street (Source: The researchers).

a. The Functional Dimension

The functional dimension in the case study is illustrated by studying the diversity of land uses, which is a main urban quality that is achieved through land use mix in urban space, which enhances walkability and pedestrian experience. Illustrating land uses of the street on a land use map is the selected method of evaluation in the case study because this specifies types and distribution of land uses along the street, which achieves efficient analysis of land uses of Syria Street. Moreover, measuring land uses on the scale of a street is easier to illustrate on a land use map, and the formula mentioned before is needed to measure land use mix for larger scale neighborhoods.

Fig. 12. Land use map for Syria Street, Alexandria City (Source: Google Maps 2022 edited by researchers).

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From the land uses map of Syria Street (Fig.12), it is clear that there is a variety of land uses including residential buildings, shops, schools, and medical and administrative buildings. This mix of land uses attracts more users and enhances walkability in the street.

b. The Social Dimensions

Social dimension is studied in the case study through two dimensions as illustrated before, which are the perceptual and psychological dimensions.

1. The Perceptual Dimension

Perceptual dimension is studied in Syria Street through studying main urban quality, which is legibility that helps users understand the urban space better and move easily from one place to another without confusion.

Legibility is measured through a qualitative method that depends on observation and site analysis of Syria Street to define strong and weak points. It can be assessed by marking existing paths, nodes, landmarks, edges, and districts on a map, and analyzing them helps to suggest recommendations for readjusting the design of those elements in the urban context. Furthermore, some other indicators help in the evaluation of legibility such as the presence of lighting of the roads at night, the presence of repeated remarkable signs along the streets, and using the rhythm of trees to define the continuity and discontinuity of the path. From the legibility map of Syria Street (Fig.10), it is observed that in each of Syria, AlMoaaskar Alromani, Roushdy streets, an extra intermediate landmark, and more nodes can be added especially in the distance between Abdel Salam Aref and Al Corniche roads. Hence, it is recommended to visually connect between those arterial roads that are already considered reference points or landmarks. Besides, lighting in the street needs to be upgraded and added, as some areas are dark at night (Fig. 13).

Fig. 13. Light pole locations through Syria Street (Source: Google Maps, 2022 and edited by researchers).

Moreover, some trees and planters are observed in some zones and missing in other parts of the street, and there are street name signs and traffic signs.

2. The Psychological Dimension

The psychological dimension in the case study is analyzed in Syria Street through studying two main urban qualities, which are pedestrian comfort and safety, which upgrades walkable spaces and pedestrian experience.

a. Pedestrian Comfort is studied through the evaluation of several indicators such as the hierarchy of spaces, pedestrian density in space, city's noise, percentage of shade coverage, buildings' orientation and wind movement, seat position, access to public transport, footpath width and slope, cleanliness, and curb ramp. Through observation, it is observed that there is a hierarchy of spaces in Syria Street; for example, entrances of residential buildings are recessed to create a transitional space between public and private zones (Fig.14).

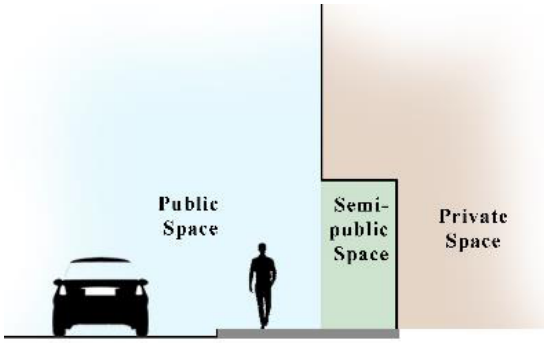

Fig. 14. Showing hierarchy of spaces in the street from public to semi-public to private spaces through recessed entrances (Source: The researchers).

Moreover, pedestrians have been counted several times per minute per meter for every

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100 meters using a stopwatch on both sides of the street day and night during weekdays and weekends (Fig.15). The average number of pedestrians is approximately 6 to 7 persons per minute per meter at day during both weekdays and weekends, which is within the recommended ranges because the common appropriate level is between 6 and 7 people per minute per meter (Jacobs, 1996, Whyte, 1988 cited in Matan, 2011). It is observed that the number of pedestrians is higher during the day than at night because the average number of pedestrians is approximately 2 to 3 persons per minute per meter at night. This occurs due to the absence of restaurants and cafes along the street and the closing of shops at night. The main active point at night is at the beginning of the street from AbuKir Road due to the presence of a shopping mall in that area. Furthermore, it is observed that pedestrian density increases in commercial zones of the street.

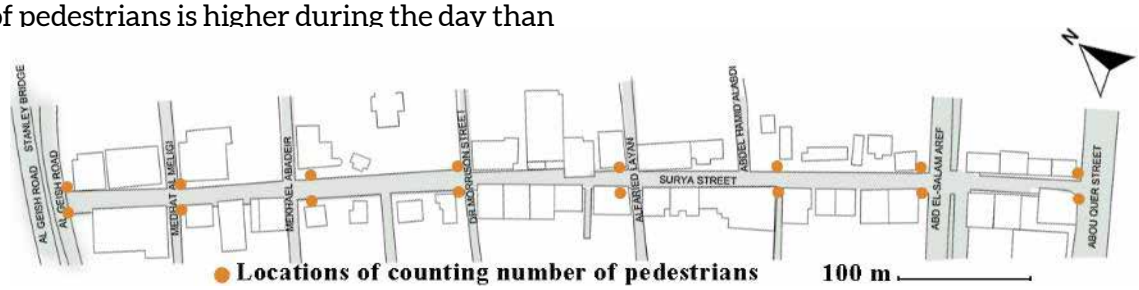

Fig. 16. Wind movement direction with Syria Street orientation (Source: Windy.App 2022, edited by researchers).

Good shading is observed in regions with trees and high-rise buildings, and it decreases in regions with low-rise buildings and no trees. Furthermore, buildings are nearly parallel to the wind direction, which allows the wind to flow along the street (Windy.App, 2022) (Fig.16).

Fig. 17. Public transport locations (Source: (Google Maps, 2022 and edited by researchers).

Another indicator is that the access to public transport is straightforward and the furthest point to public transportation stops is 325 m (below 400 m), which is a comfortable distance for walking. As explained in the map below, the public transportation means are located in Al Corniche such as bus stations and microbus stops, besides Abdel Salam Aref, which includes the Tramline (Fig.17).

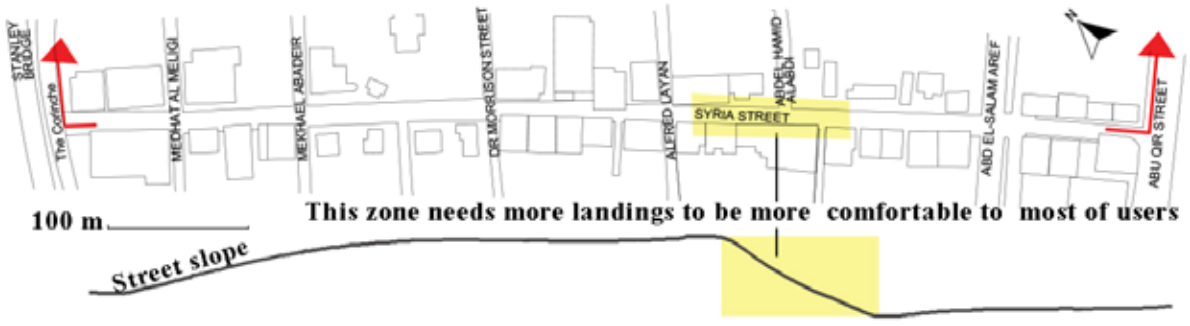

Fig. 18. Syria Street slope (Source: Google Earth and edited by researchers).

In addition, footpath width ranges from about 1.8m to 2.7m, which is considered within the recommended ranges. Through analysis of Google Earth, it is shown that the slope of the street is almost flat except in two areas. The slope of the yellow zone as shown in (Fig.18) before Alfred Layan Street is in the recommended range but needs more landings to be comfortable. The slope (H/W) of the zone at the end of the street near Al Corniche Road is more than 1:20, which is comfortable for walking.

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Moreover, the street needs more dustbins to enhance cleanliness in the street and make it easier and more convenient for users. Curb ramps are observed on some sidewalks and missing on others. There is a total absence of seats along Syria Street, which significantly undermines the quality of the street, in terms of comfort, especially for the elderly and the persons with reduced mobility.

b. Pedestrian Safety is studied through analysis of indicators such as traffic signal spacing, crosswalk locations and widths, stop bar, safety island locations, narrowing crossing distance at street intersections, speed limit in built-up areas, and light pole height. In Syria Street, there are three traffic signals located on the three arterial roads and one between Abdel Salam Aref and Al Corniche roads. This means that the distance between the first two signals is about 150 m, the second is about 250 m and the third distance is about 400 m. The recommended range for traffic signal spacing is 400 to 800 m in arterial roads, suburban and developing rural areas, and 150 m in downtown areas. Thus, one more traffic signal is recommended along the street in the distance between Abdel Salam Aref and Al Corniche roads. There are no crosswalks, stop bars, or safety islands observed on Syria Street. Moreover, no narrowing crossing distance at street intersections is observed to make pedestrians' crossing easier. The speed of vehicles is assessed through survey and observation. It is evaluated by using two methods. First, through observation and recording of car speed while riding several times through the street with the same speed as other cars and the second method is by using the equation of (Speed= distance/time). Therefore, the time taken by a car to travel a certain known distance is calculated using a stopwatch and then the speed is calculated.

The average speed of vehicles during the day in the street is approximately between 30 to 40 km/h and during heavy traffic speed can be less. This speed lies within the recommended ranges because 30 km/h is recommended in high pedestrian areas and 40km/h in local streets. Light poles on sidewalks of the street are about 4.5 m to 5 m in height, which is within the recommended ranges (4.5 to 6m on sidewalks, 8 to 10m on narrow streets, and 10 to 12m on wider streets). In addition, the spacing between poles is about 15 m, which is about 3 times the height of light poles as in the recommended ranges (National Association of City Transportation Officials, 2016). However, some areas need more light poles.

TABLE I
EVALUATION OF WALKABILITY CRITERIA USED IN THE CASE STUDY (SYRIA STREET, ALEXANDRIA) (Source: The researchers)

Urban Dimension	Urban quality	Evaluation of Syria Street
Morphological dimension	Imageability	
	Transparency	
	Scale of Enclosure	
	Complexity	
	Connectivity	
Functional dimension	Land use Mix	
Social dimension (Perceptual)	Legibility	
Social dimension (Psychological)	Pedestrian comfort	
	Pedestrian safety	

From the evaluation of the urban dimensions and qualities in Syria Street (Table I), The outcomes are that the land use mix is satisfying, which helps in encouraging walkability. Moreover, transparency, connectivity, and legibility are good but can be upgraded. On the other hand, imageability, scale of enclosure, and complexity are rather sufficient to sustain street safety and public contact but can also be improved. Yet, the street is poor at pedestrian comfort and safety, which are critical and need serious improvement to increase walkability. These lacks are a handicap and have badly undermined the street convenience for pedestrians. Some of the qualities included are evaluated through qualitative and quantitative indicators together and other qualities are evaluated through either qualitative or quantitative indicators. For instance, measuring imageability is qualitative, measuring connectivity is quantitative, and measuring comfort is both qualitative and quantitative.

III. RECOMMENDATIONS

According to the previous evaluation of Syria Street, some recommendations are provided to enhance walkability as spatial features are thought to have an impact on a person's decision to walk. Some recommendations can be easily applied while others are difficult to implement and can be considered a long-term goal.

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Recommendations that can be easily applied for the short term:

- Attention to detail and careful coordination between traffic engineers and planners are prerequisites to creating pedestrian-friendly streets, especially considering the importance of providing a good mix of land uses and connectivity.
- Greater consideration must be given to street furniture: renovating and designing more adapted pavement and curbs, greenery, especially trees, and seats (preferably shaded). Some elements must be added and increased such as the number of trashcans.
- Crosswalks must be added to the street to increase the degree of safety. Marked crosswalks are most effective as motorists and pedestrians can identify them easily.
- Removing all obstacles on the sidewalks such as parked motorcycles, and merchandise in front of shops, and designing appropriate locations for ATM distributors, planters, streetlights, and huge street-level advertising billboards. Placing the advertising poles in appropriate locations and reducing their large number would improve the flow of pedestrians. It is also possible to combine lighting and advertising poles in one element.
- Disposing of all debris or elements obstructing the flow of pedestrians on the sidewalk is the responsibility of Municipal Governments that must apply fines for irregularities, especially concerning occupying public roads and sidewalks.
- Upgrading the ground floor design of the street, in terms of functions and activities, to achieve a vibrant experience for users at eye level and considering the activities at night, not only by day. Restaurants, cafés, or theatres would enable the street to be more vibrant at night.
- Adding an intermediate landmark in the distance between Abdel Salam Aref and Al Corniche roads to visually connect between arterial roads that can be considered as reference points.
- The sloped part before Alfred Layan Street needs more landings to be added to make it smoother for walking.
- Adding crosswalks, stop bars in the street, and more lighting in the observed dark zones at night and providing narrow crossing distances at street intersections to improve safety.
- Expanding the width of sidewalks by minimizing on-street parking, when opportunities arise.

Recommendations for long-term goals:

- Increasing intermodal networks and cycling lanes in the neighborhoods and on the border scale of the city.
- Introducing guidelines in policies to encourage people to use public transit in their commute. These guidelines must be included in local planning documents.
- The Government must encourage public-private partnerships, which can contribute to enhancing the quality of the physical street environment. This can be done through renewal and renovation projects. For instance, the Governorate could provide incentives for developers to renovate pavements and pedestrian amenities to enhance the street comfort, safety, and image.
- Providing incentives for developing vacant lots towards an urban green network accessible to all residents complemented by a network of squares and other small outdoor places for active living in the streets.
- The Governorate and Planning Authorities should be working with investors to develop strategies concerning the adaptive reuse of abandoned listed villas in efficient ways to explore a variety of pedestrian-friendly approaches and land-use mixed developments on the scale of the neighborhood.
- Planning policies must strengthen public awareness to promote walking.

IV. CONCLUSION

The present research has shown that people's willingness to walk depends on accessibility to nearby transportation, compact development with varied destinations, path quality, safety, attractiveness of the built environment, and sense of comfort and convenience. The research also confirmed the fact that a dense concentration of people is one of the necessary conditions for flourishing city diversity

(Jacobs, 1992, p.205). To deepen the understanding of the urban qualities and their indicators explained in this research, the walkability criteria were classified into morphological/visual, functional, and social dimensions. Each dimension included a number of urban qualities. In addition, each urban quality was studied by stating its definition, measuring methods, and demonstrating how this quality works in high-density communities. The case study of Syria Street was selected to represent a typical city center street in Alexandria that includes a mix of listed villas and conventional common apartment buildings. This is the case for most streets in the city centers of Alexandria. The walkability criteria are then applied to the street. Thus, the strong and weak points of the street are analyzed. This is illustrated through the findings provided from the case study, which clarify that the land use mix is satisfying in the street. While transparency, connectivity, and legibility are good and can be enhanced. Imageability, scale of enclosure, and complexity need improvement. On the other hand, after studying pedestrian comfort and safety in the street, those two criteria are critical and need to be seriously addressed.

According to this analysis, some recommendations were provided to enhance walkability conditions. How people perceive and experience the local environment is significantly impacted by their walking conditions. Therefore, to reclaim the city for people, the Government must focus on the dimensions that encourage people to traverse a city on foot. Local authorities need to acquire the necessary knowledge of planners and urban designers to support the decision-making process so each city and even each street can create its own solutions.

References

[1] M. Tobin *et al.*, "Rethinking walkability and developing a conceptual definition of active living environments to guide research and practice," *BMC Public Health*, vol. 22, no. 1, 2022, doi: 10.1186/s12889-022-12747-3.

[2] R. Wang, Y. Wang, and Y. Zhang, "International Methods and Local Factors of Walkability: A Bibliometric Analysis and Review," *J Urban Plan Dev*, vol. 148, no. 4, 2022, doi: 10.1061/(asce)up.1943-5444.0000872.

[3] X. Li, "Study Of Environmental Variables Affecting Walkability: Learning From Main Street In Downtown Fort Worth," Master of Landscape Architecture, University of Texas at Arlington, 2015.

[4] M. Rosenberg, "What Is Population Density and Where Is It Highest?" 2019. [Online]. Available: https://www.thoughtco.com/population-density-overview-1435467

[5] SEDAC, "Gridded Population of the World (GPW), v4 | SEDAC." 2020. [Online]. Available: https://sedac.ciesin.columbia.edu/data/collection/gpw-v4#

[6] T. Udell, M. Daley, B. Johnson, and R. Tolley, "Does Density Matter? The role of density in creating walkable neighbourhoods," Melbourne, 2014. [Online]. Available: https://irp.cdn-website.com/541aa469/files/uploaded/Discussion_paper_Does_density_matter-the_role_of_density_in_creating_walkable_neighbourhoods.pdf

[7] J. Kent, "Higher-density living can make us healthier, but not on its own." Jul. 2015. [Online]. Available: https://theconversation.com/higher-density-living-can-make-us-healthier-but-not-on-its-own-34920

[8] E. Dawodieh, "The Impact of high population density on the built environment and the behavior of individuals in Amman," *Global Journal of Researches in Engineering*, vol. 17, no. 1, 2017.

[9] M. Carmona, *Public places urban spaces: The dimensions of urban design*. 2021. doi: 10.4324/9781315158457.

[10] Michael T. Ang, C. Taclendo, and A. C. M. Robles, "A Model Walkability Index for Sustainable Urban Mobility of a Region: The Case of Soccsksargen- A Transdisciplinary Research Approach," *Global Sustainability Research*, vol. 2, no. 4, 2023, doi: 10.56556/gssr.v2i4.604.

[11] R. Ewing and S. Handy, "Measuring the unmeasurable: Urban design qualities related to walkability," *J Urban Des (Abingdon)*, vol. 14, no. 1, 2009, doi: 10.1080/13574800802451155.

[12] D. R. Tobergte and S. Curtis, *Streets as Public Spaces and Drivers of Urban Prosperity*. 2013.

[13] F. Tibbalds, *Making people-friendly towns: Improving the public environment in towns and cities*. 2001. doi: 10.4324/9780203469521.

[14] K. Lynch, *The Image of City*. 1960.

[15] R. Ewing and R. Cervero, "Travel and the Built Environment," *Journal of the American Planning Association*, vol. 76, no. 3, pp. 265–294, Jun. 2010, doi: 10.1080/01944361003766766.

[16] "Comprendre la marchabilité Comment évaluer la place du piéton dans les espaces publics ?" Cerema, 2021. [Online]. Available: https://www.cerema.fr/system/files/documents/2021/12/livret_marchabilite2.pdf

[17] I. M. Sulaiman, "Walkability in Different Contexts in Neighbourhood Planning: An Overview," *Architecture Research*, vol. 2020, no. 1, 2020.

[18] O. Clemente, R. Ewing, S. Handy, and R. Brownson, "Measuring Urban Design Qualities an Illustrated Field Manual of the," *Growth Lakeland*, 2005.

[19] R. Ewing and O. Clemente, *Measuring urban design: Metrics for livable places*. 2013. doi: 10.5822/978-1-61091-209-9.

[20] "Planning and Urban Design for a Liveable High-Density City." 2016. [Online]. Available: https://www.pland.gov.hk/pland_en/p_study/comp_s/hk2030plus/document/Planning%20and%20Urban%20Design%20for%20a%20Liveable%20High-Density%20City_Eng.pdf

[21] United States. California. San Jose, "Downtown Design Guidelines," California, 2004.

[22] S. Shi, Z. Gou, and L. H. C. Chen, "How does enclosure influence environmental preferences? A cognitive study on urban public open spaces in Hong Kong," *Sustain Cities Soc*, vol. 13, 2014, doi: 10.1016/j.scs.2014.04.011.

[23] A. B. Jacobs, *Great Streets*. The MIT Press, 1995.

[24] R. Ewing, "Pedestrian- and transit-friendly design," 1996.

[25] E. Duygu Kahraman and E. Cubukcu, "Developing The Standards For Sense of Enclosure : An Experimental Study in Virtual Environments," *CPUD '17 / II. International City Planning and Urban Design Conference*, no. October, 2017.

[26] C. Harrouk, "Psychology of Scale: People, Buildings and Cities." Jul. 2020. [Online]. Available: https://www.archdaily.com/950321/psychology-of-scale-people-buildings-and-cities

[27] H. Karssenberg, J. Laven, M. Glaser, and M. Hoff, Eds., *The City at Eye Level. Lessons for street plinths*. Eburon Academic Publishers.

[28] R. Kaplan and S. Kaplan, "The experience of nature: a psychological perspective," *The experience of nature: a psychological perspective*, 1989.

[29] "Safe speed." 2022. [Online]. Available: https://www.victoriawalks.org.au/safe_speed/

[30] H. A. Elfouly, "Adapting a composite street connectivity index as a spatial tool for approaching informal settlements in Egypt; Applied to Giza City," *The International Journal of Development*, vol. 6, no. 8, 2017.

[31] ONESTL, "Connectivity Indexes (Transportation Network Design)." Accessed: Feb. 17, 2021. [Online]. Available: www.onestl.org

[32] WSDOT, "Mix Land Uses." Jul. 2022. [Online]. Available: http://www.transportationefficient.org/mix-land-uses/

[33] C. Garau and A. Annunziata, "A method for assessing the vitality potential of urban areas. The case study of the Metropolitan City of Cagliari, Italy," *City, Territory and Architecture*, vol. 9, no. 1, 2022, doi: 10.1186/s40410-022-00153-6.

[34] S. Mavoa *et al.*, "Identifying appropriate land-use mix measures for use in a national walkability index," *J Transp Land Use*, vol. 11, no. 1, 2018, doi: 10.5198/jtlu.2018.1132.

[35] L. D. Frank, T. L. Schmid, J. F. Sallis, J. Chapman, and B. E. Saelens, "Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ," in *American Journal of Preventive Medicine*, 2005. doi: 10.1016/j.amepre.2004.11.001.

[36] H. E. Christian *et al.*, "How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 8, 2011,

doi: 10.1186/1479-5868-8-55.

[37] B. Moghimi, "Urban legibility, analyzing urban elements," *European Online Journal of Natural and Social Sciences*, vol. 6, no. 1, 2017.

[38] D. Nurgandarum and C. F. Anjani, "Legibility of Building Facades and Imageability of Historical City Center, Case Study: Bukittinggi City Center," in *IOP Conference Series: Earth and Environmental Science*, 2020. doi: 10.1088/1755-1315/452/1/012158.

[39] L. Ovstedal and E. O. Ryeng, "Understanding pedestrian comfort in European Cities: How to improve walking conditions?," in *European Transport Conference*, 2002.

[40] A. Matan, "Rediscovering Urban Design through Walkability : An Assessment of the Contribution of Jan Gehl," *Thesis*, vol. 19, no. 1, 2008.

[41] S. Bhat, *Natural Resources Conservation Law*. SAGE Publications Ltd, 2010.

[43] B. K, "Shade and Thermal Comfort." 2019. [Online]. Available: https://azmag.gov/Programs/Transportation/Active-Transportation/Active-Transportation-Plan/Active-Transportation-Toolbox/Pedestrian-Infrastructure/Shade-and-Thermal-Comfort

[42] E. Ng, *Designing high-density cities for social and environmental sustainability*. 2009. doi: 10.4324/9781849774444.

[44] M. Burke and A. L. Brown, "Distances people walk for transport," *Road and Transport Research*, vol. 16, no. 3, 2007.

[45] Y. T. Tanzil and A. Gamal, "Elements identification for pedestrian comfort," in *IOP Conference Series: Earth and Environmental Science*, 2021. doi: 10.1088/1755-1315/673/1/012026.

[46] S. A. Smith, K. S. Opiela, L. L. Impett, M. T. Pietrucha, R. Knoblauch, and C. Kubat, "Planning and implementing pedestrian facilities in suburban and developing rural areas - research report," 1987.

[47] M. B., "Ramp Slopes Dimensions & Drawings | Dimensions.com." 2020. [Online]. Available: https://www.dimensions.com/element/ramp-slopes

[48] "Curb - Ramp, Parallel Dimensions & Drawings | Dimensions.com." 2023. [Online]. Available: https://www.dimensions.com/element/curb-ramp-parallel

[49] L. Alter, "Urban Design After the Pandemic." 2020. [Online]. Available: https://www.treehugger.com/urban-design-after-coronavirus-4848013

[50] J. Yang, B. Shi, G. Xia, Q. Xue, and S. J. Cao, "Impacts of urban form on thermal environment near the surface region at pedestrian height: A case study based on high-density built-up areas of Nanjing City in China," *Sustainability (Switzerland)*, vol. 12, no. 5, 2020, doi: 10.3390/su12051737.

[51] T. Özcan Aktan and M. OZYAVUZ, "Criteria of Walkability: As a Sense of Urban Experiment," *Tekirdag Namik Kemal University Institute of Natural and Applied Sciences*, 2022, doi: 10.55848/jbst.2022.10.

[52] J. Roberts, "Urban Safety Project, Urban Safety and Security in Myanmar," San Francisco, California, 2018. [Online]. Available: https://asiafoundation.org/wp-content/uploads/2018/07/Myanmar_Urban-Safety-Brief-Series_ENfullSeries.pdf

[53] Z. LIANG, H. K. LO, and K. F. NG, "Towards Walkability Enhancement: A Systematic Review and Future Directions," *SSRN Electronic Journal*, 2022, doi: 10.2139/ssrn.4013437.

[54] "Aberdeen Pedestrian Transportation Plan & Aberdeen Bicycle Transportation Plan," 2011.

[55] National Association of City Transportation Officials, "Urban Street Design Guide," New York, 2013.

[56] New York City Department of Transportation, "Street Design Manual," New York, 2020.

[57] S. Claris, C. Luebkeman, D. Scopelliti, and J. Hargrave, "Cities Alive: towards a walking world." ARUP, 2016. [Online]. Available: https://www.arup.com/globalassets/downloads/insights/cities-alive-towards-a-walking-world.pdf

[58] National Association of City Transportation Officials, "Global Street Design Guide: Global Designing Cities Initiative," New York, 2016.

[59] J. Jacobs, "The Death and Life of Great American Cities (New York, 1961)," *P-393*. 1982.

[60] J. S. Lee, P. C. Zegras, and E. Ben-Joseph, "Safely active mobility for urban baby boomers: The role of neighborhood design," *Accid Anal Prev*, vol. 61, 2013, doi: 10.1016/j.aap.2013.05.008.

[61] Zahran M., "The Comprehensive Planning of Alexandria 2005, The Final Report, the Governorate and the University of Alexandria," Alexandria, 1984.

[62] M. Yehia, "In Search of a Local Architectural Language, The Case of Alexandria, Egypt," Doctoral dissertation, Faculty of Engineering, University of Alexandria, Alexandria, 2007.

[63] "Google Maps," Google.

[64] Egypt. Governorate of Alexandria, "Catalogue of Conservation of Heritage Building for the Governorate of Alexandria ," Alexandria, 2007.

[65] O. O, "Enjoy the rain on Alexandria's Stanley Bridge." Jul. 2017. [Online]. Available: https://www.egypttoday.com/Article/6/37689/Enjoy-the-rain-on-Alexandria%E2%80%99s-Stanley-Bridge

[66] "TOLIP Hotel Alexandria." 2018. [Online]. Available: https://www.tripadvisor.co.uk/Hotel_Review-g295398-d4722224-Reviews-TOLIP_Hotel_Alexandria-Alexandria_Alexandria_Governorate.html

[67] W. H. Whyte and P. Underhill, *City: Rediscovering the center*. 2008.

[68] Windy.App, "Alexandria, Egypt: weather forecast and live wind map," Windy.App. Accessed: May 22, 2022. [Online]. Available: https://windy.app/forecast2/spot/132024/