Linking Sustainability, Resilience and Liveability with Smart City Development: Modeling Interconnections Using Systems Approach

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Abstract

Smart cities are the solutions to unfathomable urban challenges. However, urban planners skepticize the existing smart cities for not addressing sustainable development through practices of resilience planning and livable transformations. At the embryonic stage, it is vital for cities of today to gain a more consistent understanding on how resilience, liveability, and sustainability can be co-created into the smart city planning model under a unified umbrella. In that respect, this research attempts to understand smart city development through the lens of sustainability, urban resilience and liveability using a systems approach, as cities evolve to achieve the descriptive goal of "Futuristic cities". Causal feedback loop diagrams were used to capture the dynamic interactions among multiple drivers within the urban context under the sustainability, resilience, and liveability models. The proposed feedback structures and interactions can help smart city planners and urban developers to transform the existing smart cities of today to a much aspiring futuristic cities we want.

Keywords
liveability; resilience; smart city; sustainability; system thinking; urban development.

1. Introduction
According to the statistics by United Nations, there has been an increase in the world urban population from 751 million in 1950 to 4.2 billion in 2019, which accounts for around 55% of the global population in 2019 inhabiting the urban area (United Nations, 2019). The United Nations estimate the world population occupying the urban cities to increase by 68% until 2050, thus giving rise to several challenges. Modern cities are up against frontlines of serious urban challenges, most recently, compounding environmental (urban sprawl, overpopulation, land management, waste disposal, climate change and pollution), social (poverty and suburbanization) to economic (outsourcing and economic globalization) challenges (Zander & Mosterman, 2013). These challenges bring the concept of cities as consumers than preservers of urbanism, distorting the ecological balance, thus posing a threat to future sustenance of cities

(Shmelev and Shmeleva, 2018). These threats also raise huge concerns among public authorities and urban planners on how cities can be remodeled to stay safe and secure from unexpected predicaments.

Achieving smartness in cities is of paramount importance (Kutty et al., 2020). Cities hold a crucial role in curbing urban challenges (Curşeu et al., 2021). Modern cities need to device smart technology solutions that are embraced through "smart city initiatives" from public policies and the society to override these urbanization challenges (Shehab et al., 2021). However, smart technologies are not the only answer to our urban problems (Kutty et al., 2020). In order to attain the so called "Future cities", the cities we actually need, smart technologies need to be supported by sustainability, resilience and liveability aspects when attempting to rule out urban predicaments. The smart technologies deployed need to be lean, cost efficient and targeted not only in reducing the CO_2 emissions and refining the energy efficiency of the city, but also on the welfare of the city dwellers, fiscal sustainability, enhanced safety and security, adaption to stress and shocks, economic stability and many more (Shmelev and Shmeleva, 2019; Alsarayreh et al., 2020). The concept of smartness and sustainability in cities can be viewed as a buildout archetype that came into practice in late 20th century in order to respond to the public needs, investigate the growth patterns in the city, to deliver sustainable and smart way of life to the inhabitants and, help cities achieve their competitive advantage (Kramers et al., 2014; Bingöl, 2022; Alagirisamy and Ramesh, 2022). Similarly, resilience planning dates back to the ancient era when flood resilient sewerage network systems were built by Romans in 4th century BC (Galderisi et al., 2020). Liveability dates back to even ancient times back during the time of Plato and Aristotle, with a plethora of conceptualization at different period of time (Yu, 2001). All these concepts are closely interrelated despite several variations in their growth patterns. The consciousness of unsustainable resource usage patterns by humans in the cities integrated with advanced technologies to monitor the resource utilization, quality of growth in the urban ecosystem, knowledge of socio-economic disparities and decision support strategies that aid transformation of cities towards smart, resilient sustainable and livable units have all enabled these concepts to work along the same direction.

For a city to embrace practices of sustainability, resilience, and engagement of urban inhabitants to live with better standards, the city must attempt to remodel its services and management infrastructure, enhance partnerships, adopt a radical reform in its production and consumption practices, generate less waste, and transform all the by-products to useful resources that can re-enter the value chain. This cannot be achieved only by using digital intelligent technologies but requires participatory governance, involvement of multifarious stakeholders and a citizen inclusive ecosystem. This integration would help us not only to attain the Sustainable Development Goal 11 (SDG 11) proposed in the United Nations Development Programme (UNDP), which is to transform cities into being smart and sustainable living units, but also to connect the cities and communities with other SDGs to make cities resilient to shocks and stresses and, livable for present and future communities. The "Future cities we want" need to integrate resilience, liveability, and sustainability with urban smartness under a single umbrella. For the same, it is important to understand how these elements interact in an urban context across several actors using an integrated system-of-system approach. In this research we attempt to bring out possible interactions of various actors under the resilience, livability and sustainability dimensions of future cities which readily applies to the current smart cities, using a systems thinking approach.

2. Research significance

Smart cities are complex urban systems built to offer a dignified standard of living to all it denizens (Mukhlis, 2021). However, smart cities of today pose an enigmatic nature in addressing people concern (Rosati and Conti, 2016). Being platforms to multi-billion investments, smart cities of today lack cohesion due to its silo mode of functioning for business benefits rather than ensuring safety, security, liveability, and inclusive growth in its development. Such business-centered development patterns have ruptured the smart city fabric in delivering the true essence of sustainable development. Pinning patches on the urban fabric to render quality of life with touches of sustainability, urban resilience and liveability requires adopting the idea of having an interconnected nature throughout the city. This can be achieved through a system-of-system approach, where systems thinking helps in identifying leverage points within the complex urban network. Systems thinking in smart cities can interlink the concepts of production and consumption patterns for a sustained future (sustainable development), while delivering quality of life to the urban dwellers of the present (urban liveability), unparalleled by the smooth operating systems that form the nervous system of urban development that can resistant and rebound to shocks with minimal recovery time (urban resilience).

To this end, we use a system thinking approach to close the existing gap in smart city development models from a mere techno-centric perspective to interlinking sustainability (S), resilience (R) and liveability (L), collectively termed as the SRL concepts under a unified umbrella to pave ways for "Futuristic Cities". Causal feedback loop diagrams (CLD) are used to understand the interrelations between several elements that operate in the system across multiple actors that define the corner stones of SRL concepts. Thus, succeeding the Section 1. Introduction and Section 2. Research significance, the remaining Section 3 focuses on developing the causal loop diagrams and highlighting the possible relationships through reinforcing and balancing loops. While, Section 4 explains the dynamic behavior across each loop and Section 5 brings concluding remarks on how to close the existing gaps from a policy perspective.

3. Model development

A causal loop diagram with feedback loops as reinforcing, denoted by **R** and balancing, denoted by **B** is constructed to capture the dynamism across each dimensions of the SRL concept. The causal loop diagrams were built using the Vensim PLE modelling package developed by Ventana Corporation. Under the urban liveability model, the inter-dynamics between the elements in the system is understood across accessibility, community well-being and economic vibrancy; while for the urban resilience model, the key actors were social, economic, environmental, and institutional resilience. The dynamics of urban sustainability in smart cities were explained through climate change, natural and energy resources, safety and security, governance and institution and, society and well-being; the key drivers in fostering a sustainable city. The causalities between the elements under various dimensions of urban liveability, resilience and sustainability model is depicted in Figure 1, Figure 2, and Figure 3 respectively. Table 1, Table 2, and Table 3 shows the respective loops and, their interconnections and feedback mechanisms for the urban liveability, resilience, and sustainability model for the corresponding CLD.

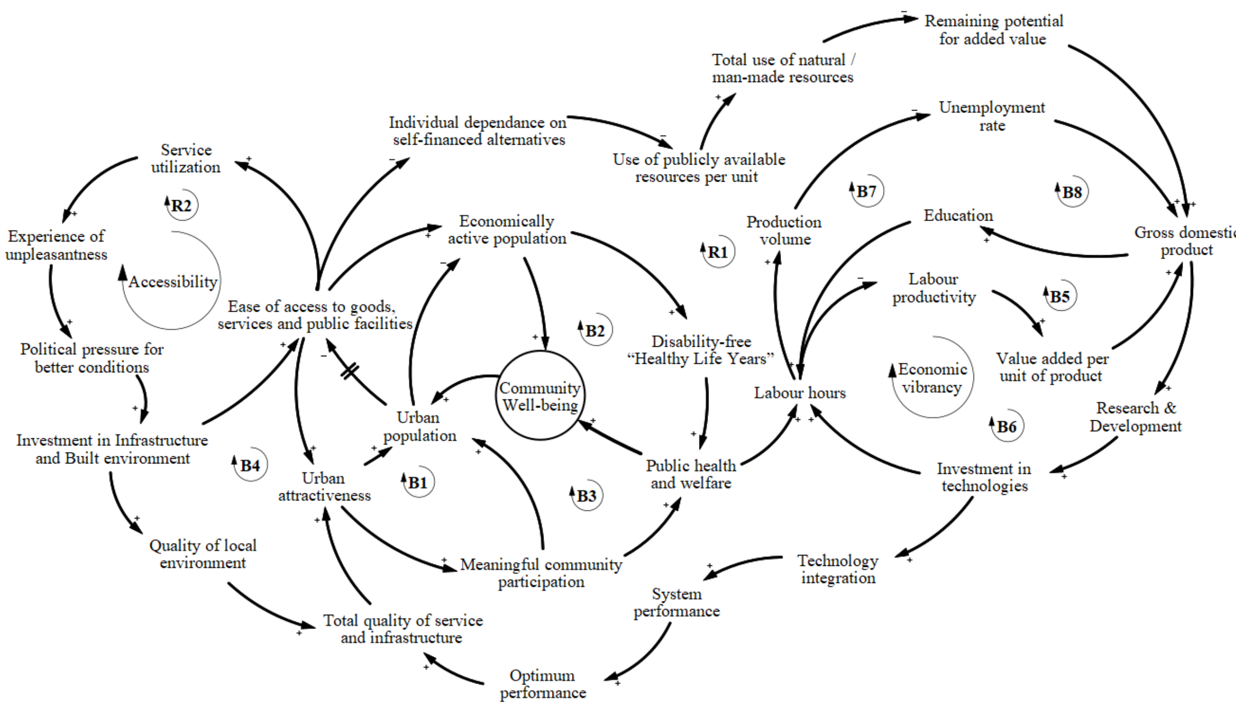

Figure 1. Causal loop diagram for the urban liveability model

Table 1. The causal loops and feedback relations for the urban liveability model

Loops	Interconnections and feedbacks
B1	Urban population – Ease of access to goods, services, and public facilities – Urban attractiveness – Meaningful community participation – Urban population.
B2	Urban population – Ease of access to goods, services, and public facilities – Economically active population – Disability-free "Healthy Life Years" – Public health and welfare – Community Well-being – Urban population.

B3	Urban population – Ease of access to goods, services, and public facilities – Urban attractiveness – Meaningful community participation – Public health and welfare – Community Well-being – Urban population.
B4	Urban population – Ease of access to goods, services, and public facilities – Service utilization – Experience of unpleasantness – Political pressure for better conditions – Investment in infrastructure and built environment – Quality of local environment – Total quality of service and infrastructure – Urban attractiveness – Urban population.
B5	Labour hours – Labour productivity – Value added per unit of product – Gross domestic product – Education – Labour hours.
B6	Labour hours – Labour productivity – Value added per unit of product – Gross domestic product – Research and development – Investment in technologies – Labour hours.
B7	Labour hours – Production volume – Unemployment rate – Gross domestic product – Education – Labour hours.
B8	Labour hours – Production volume – Unemployment rate – Gross domestic product – Research and development – Investment in technologies – Labour hours.
R1	Ease of access to goods, services, and public facilities – Individual dependance on private mode of transit – Use of publicly available resources per unit – Total use of natural/ man-made resources – Remaining potential for added value – Gross domestic product – Research and development – Investment in technologies – Technology integration – System performance – Optimum performance – Total quality of service and infrastructure – Urban attractiveness – Urban population – Ease of access to goods, services, and public facilities.
R2	Service utilization – Experience of unpleasantness – Political pressure for better conditions – Investment in infrastructure and built environment – Ease of access to goods, services, and public facilities – Service utilization

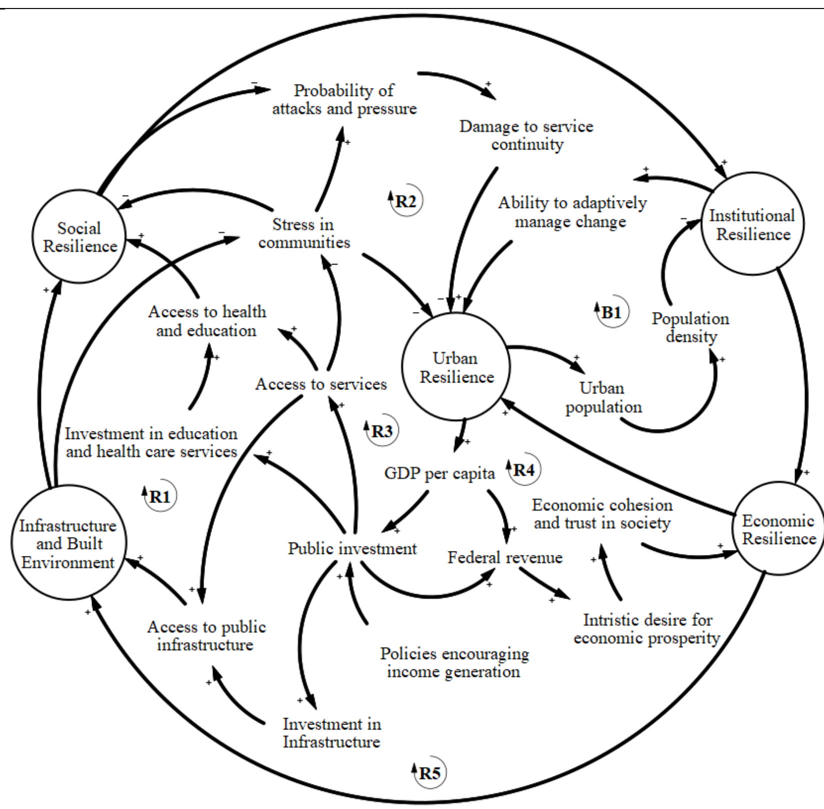

Figure 2. Causal loop diagram for the urban resilience model

Table 2. The causal loops and feedback relations for the urban resilience model

Loops	Interconnections and feedbacks
B1	Urban resilience – Urban population – Population density – Institutional resilience – Ability to adaptively manage changes – Urban resilience.
R1	Urban resilience – GDP per capita – Public investment – Investment in infrastructure – Access to public infrastructure – Infrastructure and Built environment resilience – Stress in communities – Urban resilience.
R2	Urban resilience – GDP per capita – Public investment – Investment in education and health care services – Access to health and education – Social resilience – Probability of attacks and pressure – Damage to service continuity – Urban resilience.
R3	Urban resilience – GDP per capita – Public investment – Access to services – Stress in communities – Urban resilience.
R4	Urban resilience – GDP per capita – Federal revenue – intrinsic desire for economic prosperity – Economic cohesion and trust in society – Economic resilience – Urban resilience.
R5	Economic resilience – Infrastructure and Built environment resilience – Social resilience – Institutional resilience – Economic resilience

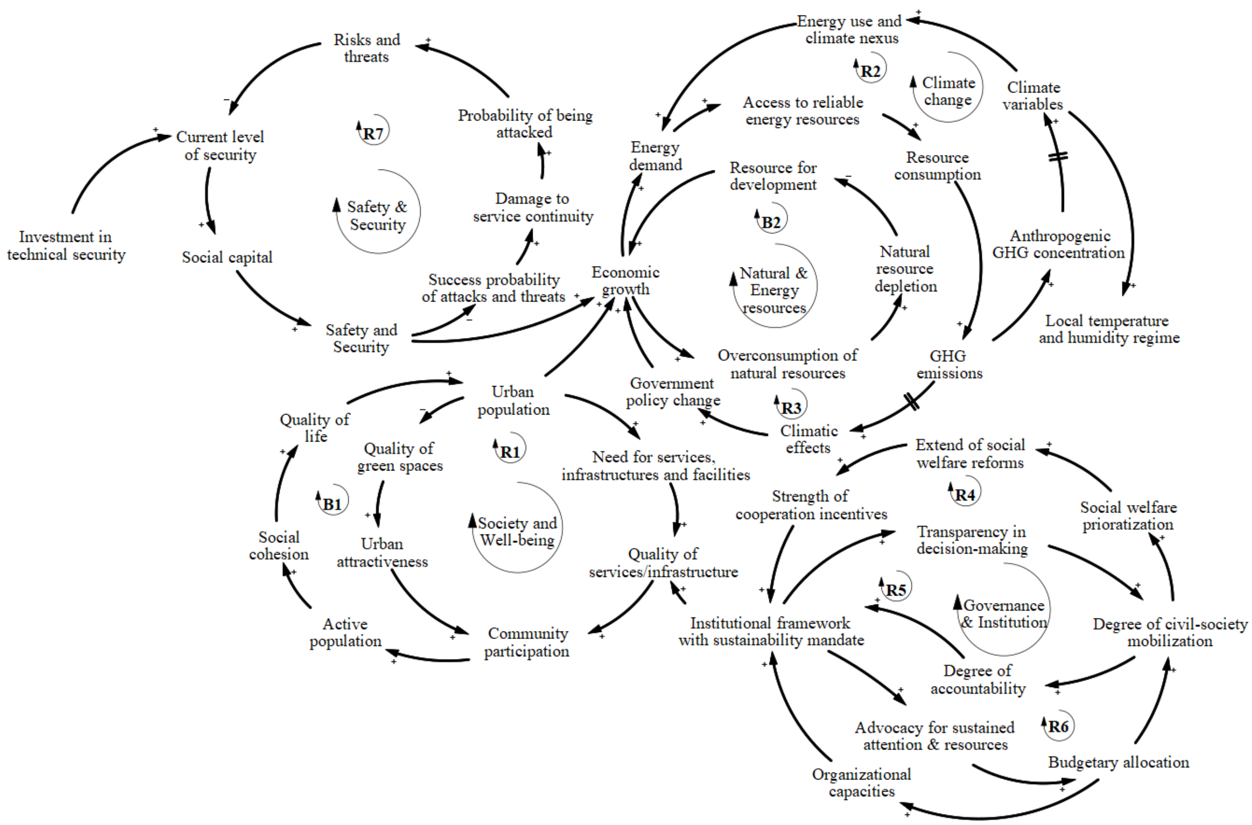

Figure 3. Causal loop diagram for the urban sustainability model

Table 3. The causal loops and feedback relations for the urban sustainability model

Loops	Interconnections and feedbacks
B1	Quality of life – Urban population – Quality of green spaces – Urban attractiveness – Community participation – Active population – Social cohesion – Quality of life.
B2	Resource for development – Economic growth – Overconsumption of natural resources – Natural resource depletion – Resource for development.
R1	Urban population – Need for services, infrastructures, and facilities – Quality of services/infrastructure – Community participation – Active population – Social cohesion – Quality of life – Urban population.
R2	Energy demand – Access to reliable energy resources – Resource consumption – GHG emissions – Anthropogenic GHG concentration – Climate variables – Energy use and climate nexus – Energy demand.
R3	Economic growth – Energy demand – Access to reliable energy resources – Resource consumption – GHG emissions – Climate effects – Government policy change – Economic growth.
R4	Institutional framework with sustainability mandate – Transparency in decision-making – Degree of civil-society mobilization – Social welfare prioritization – Extend of social welfare reforms – Strength of cooperation incentives – Institutional framework with sustainability mandate.
R5	Institutional framework with sustainability mandate – Transparency in decision-making – Degree of civil-society mobilization – Degree of accountability – Institutional framework with sustainability mandate.
R6	Institutional framework with sustainability mandate – Advocacy for sustained attention and resources – Budgetary allocation – Degree of civil-society mobilization – Degree of accountability – Institutional framework with sustainability mandate.
R7	Safety and security – Success probability of attacks and threats – Damage to service continuity – Probability of being attacked – Risks and threats – Current level of security – Social capital – Safety and security.

4.Results and discussion

The dynamics of urban livability in smart cities is explained through accessibility, community well-being and economic vibrancy; the key drivers in fostering a livable city. Ideating public participation into the urban planning model fosters sociability when urban attractiveness is made apparent in the design conditions of the city (Guedoudj et al., 2020). Ease of socio-cultural and economic pursuits in urban areas spur urban attractiveness (Correia et al., 2020), which results in people moving into cities. Such ease of access to services and public facilities create a "Disability-free community" comprised of active population with sound health and welfare, a key driver to community well-being (Buch et al., 2014). Enhanced urban attractiveness is a key determinant for migrants moving into cities (Stead, 2003). The community well-being dynamics is captured well in the balancing loops **B1, B2,** and **B3**. Do, (2008) identifies a positive correlation between the ease of access to available services in cities with service utilization. However, as services become easily accessible to anyone-anytime-anywhere, an experience of unpleasantness creep as an enduring problem (Di et al., 2021). This can cause pressure to the municipal planning authorities to bring better conditions into the city, thus demanding further investments in the area of infrastructure and built-environment. Such investments can boost the quality of dwelling units, which in turn increases the urban attractiveness, leading to migrant in-flow (see loop **R2** and **B4**). To continue, a vibrant economy is a productive, progressive, and prosperous economy with successful value addition to the services offered to its inhabitants. Loops **B5** through **B8** captures the dynamics of economic vibrancy. As the economy booms, a change in the volume of production in goods and services is seen to meet the growing population demands (Li, 1996). This in turn has a direct influence on the unemployment rates. Studies show a significant decline in unemployment rate as production volume increases (Kreishan, 2011). Furthermore, an economy that aspires to deliver better health and welfare conditions to its labor force produces a productive work force with efficient use of labor hours (Tsoukatou, 2019). Labour productivity is closely linked with value addition per unit of goods produced which holds a positive impact on the GDP growth rate (Mourre, 2009). In addition, education, and investment in alternative technologies through R&D initiatives increases economic growth, henceforth leading to a stable economy. Similarly, the accessibility-economic vibrancy nexus is captured in the reinforcing loop **R1.**

While understanding urban resilience through systems thinking (see Figure 2.), it is seen that an increase in per capita GDP increases the aggregate demand which holds a positive impact on the citizen spending and federal revenue through increased taxes in the latter case and better employment opportunities in the former (Yin, 2009). Public investments provide access to multitude of services to urban inhabitants which impacts the quality and standard of living (Chakraborty and Dabla-Norris, 2011), thus alleviating urban stress and improving product level accessibility. This is evident from the reinforcing loop **R3** in Figure 2. Public investments has enormous potential to bring prolonged benefits to the cities and urban inhabitants (Czudec and Zając, 2021). With public policies encouraging income generation, investments in education, health care services, public infrastructure, capacity building, carbon-neutral transition and investments tailored to harmonize socio-economic growth in an inclusive manner can shield cities from possible socio-environmental threats and improve service continuity (loops **R1** and **R2**). This can support the social system to collectively built tolerance, adaptively manage to change, and sustainably cope with unplanned stress and shocks accompanied by urban sprawl (loop **B1**). Furthermore, a possible impact on the annual revenue levels can exert an upward push to the economy, leading towards prosperity, thus bringing in an economic upheaval and a path for higher economic growth (Abdel-Razek, 2021). Economists identify such growth in the size of economy as a “long-term phenomenon” due to its ability to suppress challenges and return to a stable operating state (Mele, 2021), thus leading to urban resilience due to a strengthened crisis repellent economy (**R4**).

Moving on, we attempt to understand the dynamic interactions of all the elements under various dimensions of urban sustainability through the causal loop diagram presented in Figure 3. Smart cities of today are criticized for their ambiguous growth patterns that lack cohesion between entrepreneurial mind-sets and social progress (Jonek-Kowalska, and Wolniak, 2021). However, smart cities are no exception in providing a dignified standard of living to all the inhabitants including migrants that seek quality in life. Enhanced quality of life boosts the inflow of working-age immigrants to cities in search of jobs (Mubangizi, 2021). As the urban population increases, there is a huge market for the economy to progress in terms of innovation and technological advancements, thus increasing competition at the same time risk of security (Abdella et al., 2019; Ullah et al., 2021; Abdella and Shaaban, 2021). Such breach in security levels can damage the service continuity in smart cities that are driven on ubiquitous data from sensors and tech-driven platforms. Investments in technical safety can increase the social capital, thus increasing resilience to threats and adaption capacity to insecurities (Andrade et al., 2020). The dynamics is represented in the reinforcing loop **R7**. When exploring the society and well-being dynamics (loops **R1** and **B1**), an increase in population can trigger a demand for better services, infrastructures and facilities in cities which hold a positive impact on quality of service to be offered (Kutty et al., 2020a; Kutty et al., 2020b). Howard-Grabman et al., (2017) using the “Research Evidence framework” identified service quality as a key facilitator for effective community participation, which in turn generates an active and socially cohesive society. Factors that seek to enhance social cohesion hold a positive correlation on the quality of life (Paramita et al., 2021). Furthermore, as population increases, the physical and physiological accessibility to green urban areas are compromised, which hinders community participation (Menconi et al., 2021). Community participation positively predicted better quality of life when a pool of active population in a socially cohesive environment was put under study by Chen and Zhang, (2021). When understanding the dynamics of natural and energy resources in smart cities, studies over the years show a significant correlation between economic growth and energy demand (see . A positive impact is observed on the variables ‘access to reliable energy resources’ due to the demand generated, which in turn affects the consumption of available resources. Excess consumption can result in depleting the current sources, that are the anticipated resources for future developments in cities (Kucukvar et al., 2016; Kucukvar et al., 2019). The natural and energy resource utilization dynamics is depicted in loops **B2** and **R3**. While, over resource consumption leads to resource depletion, an optimal amount to meet the increasing demand can also lead to emissions related to the use of resources (Abdella et al., 2020; Abdella et al., 2021). This can create a concern for the government to instill sustainable behavior in the consumption and resource utilization patterns for the economy to thrive. At the same time, if unattended, this can result in climatic changes that can alter the balance in the energy-climate nexus as in loop **R2** (Kucukvar et al., 2016; Kucukvar et al., 2018). Smart cities of today are power houses of greenhouse gas (GHG) emissions due to the increased energy consumption while assimilating data from sensors that run 24/7 to improve its core functions, including reducing the environmental impacts of our cities. An increase in urban population can actually create the possibility for a better quality life and a lower carbon footprint through more efficient infrastructure and planning (loop **R1**) (Spanos et al., 2021). An equitable balance need to be maintained in terms of the resources available for consumption, as smart cities of today face numerous sustainability challenges along with climate change (Kucukvar et al., 2021). For the same, an 'institutional framework with sustainability mandate' is essential for transparent decision making in civil society, which prioritizes social welfare through strengthened cooperation incentives (see loop **R4**). Such frameworks hold potential in harnessing the growing power of "social mobilization", an important means to bring responsiveness and accountability when addressing people concern (loop **R5**).

5. Concluding remarks

This paper is an attempt put forth to investigate the possible interactions in cities through the lens of sustainability, urban resilience, and liveability, so as to broaden the concept of the existing smart cities to a sustainable, resilient, and livable dwelling unit. "Systems thinking" as a qualitative tool is used in understanding the complex interactions. Systems thinking through causal loop diagrams help in unwinding complexities in systems (Onat et al., 2017). The authors highlight that the cities we want are not just cities with digital innovation and smart solutions, but an ecosystem with high grade of complexity that is capable to effectively rebound post stress, bring harmony and cohesion in living with elevated standards and, sustainable in the production, consumption and utilization patterns all made up of multiple partners including city residents, government bodies, corporate firms and industries, and social groups working towards achieving a desired outcome. These desired outcomes can vary from technology, productivity, governance, intelligence, sustainable urban development, climate mitigation, accessibility, policy, and many more to a much broader concept based on the targets set by the city to be accomplished in light of city development.

The authors further comment that smart cities of future must hold several key features addressed under the SRL concept across numerous segments of economy, policies and administration, society and urban environment namely: (a) Integration of Information and communication technologies (ICTs) with the public services and enhancing the accessibility of these services swiftly through several digital platforms and strong internet connectivity; (b) Adequate social infrastructures (which includes proper health care facilities like hospitals, clinics, dispensaries etc.; educational institutions like schools, universities, nurseries and research centers ; recreational areas like parks, playgrounds and ball fields) which are well equipped and efficient; (c) Proper safety and security of the inhabitants; (d) Sufficient finance and funding for social inclusive technology based sustainable development; (e) Effective public services (which includes timely waste collection, utilization and management of non-renewable resources etc.) that are more accountable, accessible, reasonable and transparent for the public; (f) Efficient transportation network made accessible to citizens by promoting increased usage of public transport and discouraging private owned modes of transportation, encouraging alternative mode to commute within the city and its outskirts (which includes embracing practices of urban sharing like ride sharing, carpooling and other peer to peer car sharing services) and effective traffic planning to avoid traffic congestion using digital intelligent solutions; (g) Aligning the socioeconomic and environmental sustainability aspects with the city development goals to promote sustainable development.

When analyzing the strand of sustainable development under the UNDP 2030 agenda vis-à-vis smart cities, one must take into consideration all the sustainability, resilience and liveability aspects leading to urban development and growth. All these aspects required for urban development and advancement including resource utilization, establishment retrofitting, technological advancement, etc. needs to be consistent to meet the needs of the present and future generation. The development should be structured with an equilibrium between the dimensions of environment, social, institutional, and economic under the resilience aspect; accessibility, economic vibrancy, and community well-being under the liveability aspect; and, safety and security, societal well-being, natural and energy resources, climate change, and, governance and institution under the sustainability aspect. All the aspects should be in line with the smart city agenda aimed at enhancing the quality of life and livelihood of the inhabitants, implementing unique architectural language to enhance and diversify the economy and attaining city specific goals to meet the alarming demand of sustainability adopted through digital intelligent solutions.

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