Research Article

Emerging Technological Advancements to Safety and Security Systems in Smart Urban Public Spaces

Mamatha P Raj[1], Dakshayini R Patil[1]

1. BMS College of Architecture, Bengaluru, India

This research delves into perceptions of emerging technological tools to suffice safety & security in urban public space formulations in line with the intentions of many cities around the world and as envisioned by CPTED concepts. As cities evolve into technologically advanced hubs popularly termed as Smart cities, enhancing citizen well-being, and promoting sustainable urban living becomes paramount. The study co-relates urban scenarios of pre-smart city eras with post eras in terms of liveability aspects. This technological transformation, while promising, confronts challenges, notably data security concerns and the seamless integration of the physical devices of IoT (Internet of Things) within urban designs. This study addresses the second challenge through the exploration of three aspects of smart systems- intelligent public lighting, smart surveillance, and interactive digital platforms adopting case study method. It attempts to bridge the gap between safety measures and technological interventions with twofold objectives: to understand the role of technology in fostering urban environments, and to propose an integrative framework of digital security systems in the physical public realms. This proposed framework for digital ecosystem intends to create awareness on possibilities and serve as a guide for municipal decisions under architectural and urban design contexts for amicable accommodation of the 'physical components' of such smart systems.

1. Introduction

The world is becoming increasingly urbanized. As per United Nations (UN), more than half of the global population lives in urban areas, while the urban share worldwide is rising from around one third in 1950 to around two thirds in 2050. Emphasis on sustainability and technologically advanced urban development is the primary movement in current times. Urban services are aiming to make lives easier, comfortable, and luxurious, while complexity of the infrastructure is equally increasing relying on information and communication technology (ICT) and digital advancements.

Writer & activist Jane Jacobs was the intellectual pioneer to steer the paradigm on urban planning, architecture, and crime in her seminal book 'The Death & Life of Great American Cities (1961) with the core concepts such as 'Eyes on the Street'. Many theories emerged thereupon by eminent planners, designers, architects, and policy makers in the years to come. One such theory under urban security systems has been Crime prevention through environmental design, popularly termed CPTED, a six-decade-old concept defined as a multi-disciplinary approach to prevent the occurrence of crime in cities through suitable environmental designs (International CPTED Association). It employs elements of design for built and natural environments to enable control of crime and provide safer environments to people in their neighborhoods.

The popular criminologist Professor C. Ray Jeffery coined the name CPTED in his book of 1971. Further this was elaborated by Architect Oscar Newman in his book on Defensible Space in 1972. ICA's (The International CPTED Association) mission is: To create safer environments and improve the quality of life using CPTED principles and strategies (https://www.cpted.net/A-brief-history). The vision outlined that such design strategies deter offender decisions that precede criminal acts. Popularly known as 'designing out crime', it includes aspects of natural surveillance, access control and territoriality. As times progress and human societies evolve, concepts too advance to adapt and reconfigure to suit newer aspirations. Likewise, safety and security designs in cities are becoming smarter, though the question lingers on its long term efficacy, survival and if it all it reinforces the CPTED ideologies. This paper shall understand the fundamental aspects of CPTED, characteristics of smart cities, and exploration of three cases of technological safety systems in cities. It compares the urban scenarios of 'pre-smart' city public spaces to 'smart' spaces under attributes of liveability aspects. The study attempts to fill in one gap in the contemporary times on imposition of technical-smartness and impact on physical realms of urban public spaces.

2. Crime Prevention Through Environmental Design

One of the most important aspects of a good city is the sense of 'safety and security' (Lynch, 1984), and being free of crime or scared of crime. 1st Generation CPTED had 4 components originally- territoriality, natural surveillance, image & milieu, and access control. The 2nd Generation CPTED founded by Cleveland & Saville was introduced formally at the annual conference of the International CPTED Association in 1997 with the reintroduction of social concepts back into CPTED with focus on small-scale environments termed as proximal orientation (Cleveland and Saville, 1997). The development

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of 2nd Generation was a reaction against the target hardening, and the removal of social programming from 1st Generation CPTED (then termed as "motive reinforcement").

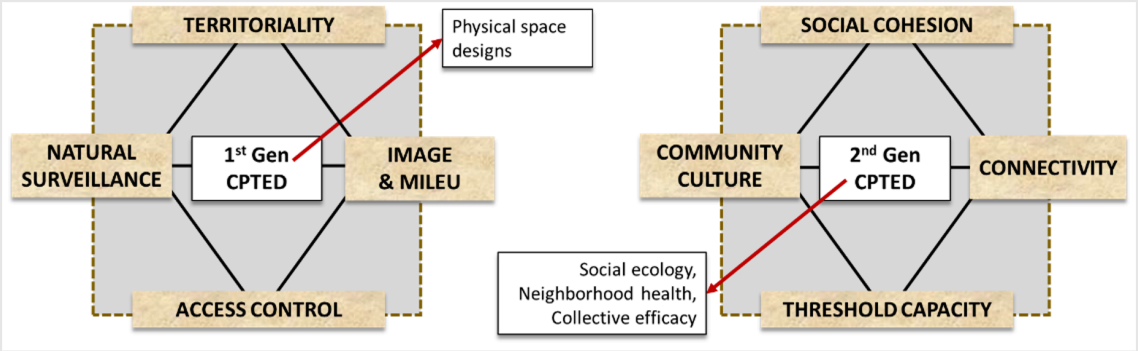

Figure 1. 1st and 2nd Generation CPTED components (Source: https://www.cpted.net/Primer-in-CPTED)

Hence, while the 1st Generation aimed at reducing the scope of crime through physical space designs alone, the 2nd Generation identified that social ecology, neighborhood health, and collective efficacy (Fig 1) were prerogative to prevent crime (Mihiniac and Saville, 2019). Research conducted in Australia in the context of a secondary school annual year-end celebration event and prevention of crime revealed that 1st Generation proved ineffective as a stand-alone strategy whereas garnered better results coupled with 2nd Generation tools to foster social cohesion and increased threshold capacity (Letch et al., 2011). Core understanding of the fundamental concepts becomes the foundation to further applications in progressing smart cities safety ideologies (Table 1).

	1st Generation CPTED	**2nd Generation CPTED**
Primary concept	Territoriality	Sense of Community
With focus on	Architecture & physical designs	Social ecology, neighborhood planning & collective efficacy, small-scale environments termed as proximal orientation
Proponents	Ray Jeffrey and Newman & Rand (Defensible theory) as a start-off from Jane Jacob's 'eyes on the street' theory	Greg Saville & Gerry Cleveland
Main components	▪ Territoriality ▪ Natural surveillance ▪ Image and Milieu ▪ Access control	▪ Social cohesion ▪ Community culture ▪ Connectivity ▪ Threshold capacity

Table 1. CPTED components derived from various literature cited in this study

In 2011, a Joint project was presented in Milan by the United Nations Interregional Crime and Justice Research Institute (UNICRI) and Massachusetts Institute of Technology (MIT) *Senseable* City Lab under the UNICRI's Security Governance/Counter-Terrorism Laboratory held to assist effective policy decisions in the field of security (http://www.unicri.eu/news/article/1104-2_urban_security). The MIT Lab researched the security in cities based on green urban design and eco-solutions in cities. It proposed a next Generation CPTED inculcating the evolving digital advancements of modern times. This renewed model termed as 3rd Generation in the report (2011) wished to seek community involvement along with creating better inclusive urban spaces and hosting well-equipped infrastructure to include certain aspects in city designs such as:

- enough urban public spaces for community gatherings
- efficient waste management system adopting the latest technologies
- efficient natural surveillance system – sufficient street light network, active streets, and public spaces always
- robust public transportation
- financial set-up towards the maintenance of civic spaces.

The UNICRI-MIT report concludes with a set of proposals for the 3rd Generation CPTED (http://www.unicri.eu/news/article/1104-2_urban_security) and a broader vision encompassing diverse aspects of urban designs to prevent crime and enhance perception of safety. It introduced additional principles of green environmental design to the core ideas and expanded security perceptions as a global issue with geo-political and socio-cultural divisions. This in conjunction with the era of technological spike and converging with the green objectives of sustainability tended to become synonymous with each other (UNICRI Report, 2011). Originally, the evolution of 3rd Generation CPTED is viewed within the urban planning principle called liveability (Mihinjac & Saville, 2019) which has become one of the most critical aspects of designing urban neighborhoods and streets as better places to live, to use, and to flourish (Appleyard, 1981).

However, as the intent in this study is the exploration of technological aspects to reinforce safety in city space designs, the paper steers in that direction without debating whatsoever the original social systems or CPTED ideologies that have always been self-reliant, cohesive entities to defend crime to maintain secure communities. CPTED becomes a backdrop, whereas given the fact that the ever-evolving human societies either intending to make lives safer or indulge in showcasing dominance via technology, it is imperative that man adopt to these changing times effortlessly. Hence, the study attempts to fill in one gap in the contemporary times on imposition of techno-smartness and impact on urban public spaces.

3. Objectives & Methodology of the Study

This paper takes off from the thought of emerging concepts of technology in designing safety in public realms and qualitative exploration adopting 'case study' methodology. It searches the possibilities of these concepts to induce resilience to crime and enhance the liveability of smart urban spaces and does not necessarily connect this aspect to any Generation CPTED in part or in totality. The main objectives are to perceive in these smart spaces, innovative urban design concepts with the hypothetical proposition: 'Liveability can be enhanced adopting technology towards stimulation of resilience to crime and induction of safety in the design of urban spaces.' Hence, questions raised are-

How and in what ways do technological applications enable creating 'safer and greener' urban spaces?

What are the potentials and issues encountered in digitally equipped 'physical environments' of urban spaces?

To answer these queries, the explorative study adopts a qualitative methodology of case studies of smart urban systems. The intent is to perceive instances where cities have experimented with creative and systematic public space design for better urban experiences. A sample selection of three basic parameters namely- 'lighting, security, and signage' is chosen from the deduced essential design characteristics of urban spaces discussed in the next section.

Thus, the three cases explored include-.

1. Intelligent Lighting Systems
2. Smart Surveillance and Security systems
3. Signage and Interactive Applications

Under each of these three aspects, at least three case studies are undertaken that offer wider perspectives on smart designs & implications.

4. Smart Urban Spaces

A smart city is commonly understood as the application of Information and Communication Technology (ICT) and Internet of Things (IoT) to sense, analyze, and integrate the key information of core systems in the functioning of a city (IBM, 2010). The 'smart' determines how the city optimizes urban functions to promote growth along with improving quality of life (TWI Global).

While it becomes seamless for developed countries to adopt technology in urban spaces with fewer space-related convolutions to people usage but 'big brother surveillance' raising certain ethical aspects, developing countries rather face the first more severely than the second concern. Cities in richer countries are large as they build 'out' and build 'up' whereas cities in poorer countries become large by crowding 'in' (Jedwab et al., 2021). Consequentially, bleak differences are witnessed in physical environments across cities. The focus here shall remain limited to the aspect of physical space connotations

owing to smart designs. Population, crowding, density resulting as natural surveillance but concerns of clutter due to over-consumption of urban space impacts the public realm.

In the instance of India as well, one of the fastest developing nations in Asia, the smart city mission (SCM) was introduced by the Government in 2015 with the objective of promoting cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment through the application of 'Smart' solutions (SCM, Government of India, 2015). These cities embed physical safety and citizen security, women's safety, crime reduction and smart surveillance tools across urban centers through smart and safe city programs (Rao, BW Smart Cities, 2021). Urban designs are being supported with various technology-based tools introduced for safety designs, monitoring and execution in Smart cities with IoT tools (Fig 2). Smart cities have adopted CPTED strategies as an initiative towards creating safer neighborhoods. While it can be noted that many social concepts of CPTED have always been implanted in Indian traditional settlements since times with cohesive neighborhood designs hosting visible courtyards as centers, but which were lost out due to impacts of modernity & urbanization (Sarangi & Kapoor, 2021). Convergence of traditional ideologies of design and technological safety measures shall ensure a possible renewed holistic safety system in place. Safety schemes include responsive tools such as smart policing, predictive policing, smart stations, resource allocation, and crime management systems.

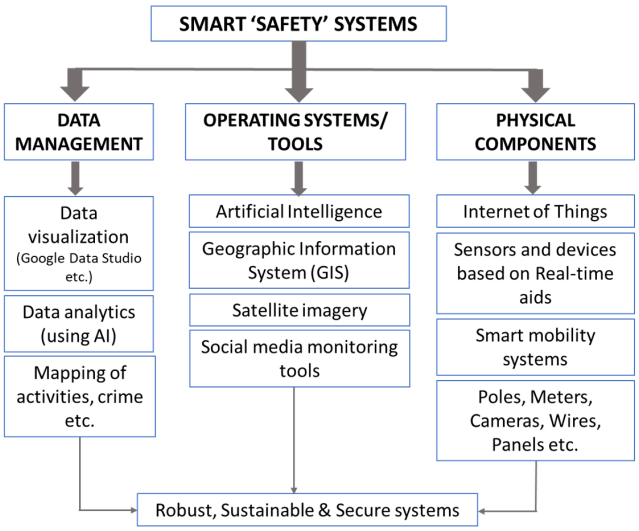

Figure 2. Main aspects of Smart Safety Systems collated from cited literature and Smart City Mission Portal, Government of India

Urban public spaces are one of the most crucial components in any city's spatial layout, that all citizens use and enjoy for various aspects ranging from basic needs of shopping, work, accessing amenities or leisure. Hence, it is understood that these spaces need to be democratic in nature and conducive to use, for which four criteria become fundamental – comfort (Nemanja & Marc, 2010), function (Whyte, 1980), safety, and vitality (Lynch, 1981) (Fig 3).

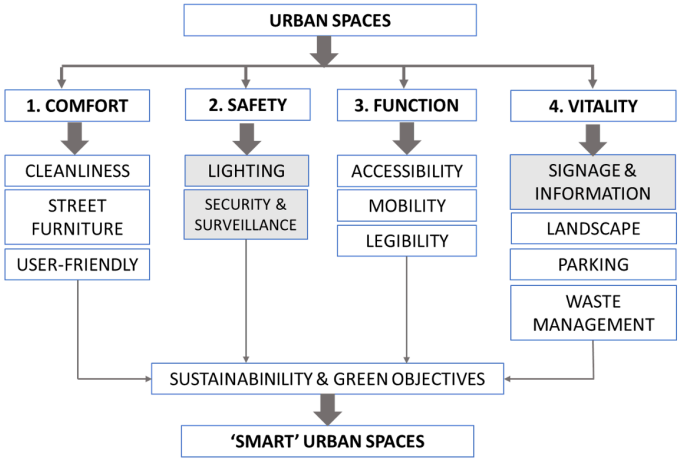

Figure 3. Main design aspects to create Smart urban spaces and selected three aspects for exploration in this study

In this research the sample set for qualitative exploration includes selection of two parameters under 'safety' aspect viz., 'lighting & security' along with one parameter under 'vitality' viz, 'signage' which essentially reinforces the former aspect of 'safety' (Fig 3). Safety & vitality are closely related variables determining secure places because vital spaces are actively used by people thus leading to safe places (Lynch,1981 & Jacobs, 1961). Hence, safety and vitality are chosen to explore with the three parameters under them to initiate correlation equation between public realms & technology in terms of liveability.

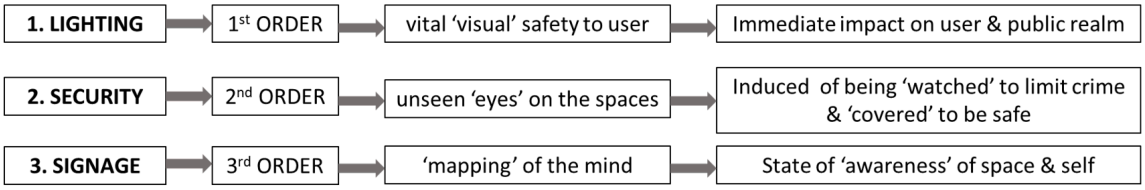

Figure 4. The three parameters of safety

The sample essentially encompasses the most fundamental smart components of digital ecosystem- 1st order of lighting, 2nd order of security/ surveillance systems and 3rd order of signage in hierarchy of safety degree to people in public spaces (Fig 4). Each of these systems involve functioning in terms of backend operation and physical elements in the public realm, it becomes interesting aspects of influence to urban design.

5. Three Cases of Smart Safety Systems

The focus is on examining the smart public space designs for streets, intersections, parks, plazas, and commercial nodes. Though natural vigilance, surveillance, traditional setups, or policing cannot be replaced, technology is envisioned to enable a reinforced system of enhanced safety ecosystem. Smart cities embed this in their overall scheme of planning and design. For CPTED to be popular, it must continually respond to changing times of rapid urbanization, demographic profiles, diversities, evolving lifestyles, emerging crime profiles and newer technologies or products in the market as well (Cozens & Love, 2015). Hence, what are the ways in which technological tools be embedded in public space design, planning, and maintenance?

5.1. Case 1- Intelligent Lighting Systems

Street lighting in neighborhoods is an important factor for a safe urban realm & an evident investment by cities for reducing occurrence of crime (Painter and Farrington, 1999). It has been identified as a key aspect under CPTED core strategies (Robinson, 2013). In recent times, however when viewed with the demands of efficiency or sustainability in design, several factors become crucial such as energy consumption, context-driven detailing and intelligent lighting incorporating LED, solar-powered lights, or sensor-triggered lights.

doi.org/10.32388/MD99FP.5

First case study of innovative safety design is observed in the city of Brussels, Belgium municipality, Molenbeek-Saint-Jean who in collaboration with Sibelga, implemented 'smart lighting' cycling paths in public spaces adopted in 2022. The broad aim was well-being and safety of cyclists coupled with sustainable forms of energy. The design involves a light bubble that follows the cyclist along the path. Similarly, in Woluwe-Saint-Pierre district there are pedestrian crossings equipped with 'presence sensor lights' (The Brussels Times, July 2022).

Second case study in the city of Stonington, Australia involves design strategies for street lighting lamp posts which became creative elements in the urban design framework, with interesting designs and embedded multiple features including cameras, Wi-Fi modems and emergency call-points. Public lights are equipped with sensors to convey real-time data to the municipality through a dashboard for efficient maintenance purposes (Stonnington city web portal). Similar instance is seen in the *LuxTurrim* 5G project undertaken by a consortium of cell phone companies and research universities that devised a smart light pole-based 5G infrastructure with the goal to integrate several smart features (Fig 5). The project aims at technical innovations in conjunction with business opportunities to collate various services in an amicable manner (Varis, 2019).

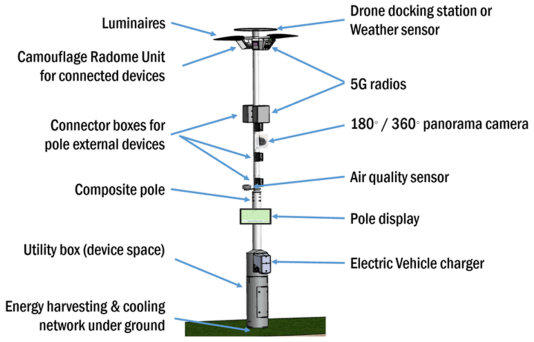

Figure 5. LuxTurrim5G light pole with integrated components of smart features- sensors and cameras (Source: https://ercim-news.ercim.eu/en117/special/luxturrim5g-smart-5g-light-pole-infrastructure-for-digital-service-ecosystems-in-cities)

Third case study refers to one of the features of smart cities in India that envisages additional functions for the illumination of urban spaces to enhance the quality of life, services and experiences for people and sustainability. This vision is taken ahead by various innovators such as Bajaj, Wipro, HPL and Philips Lighting India, which enlists 4 key urban areas of contribution (EPR Magazine Editorial, 2017) (Fig 6). The framework outlines a systematic and hierarchical approach from the scale of urban network up to details on the lighting specifics rendering a complete overview of the lighting ecosystem.

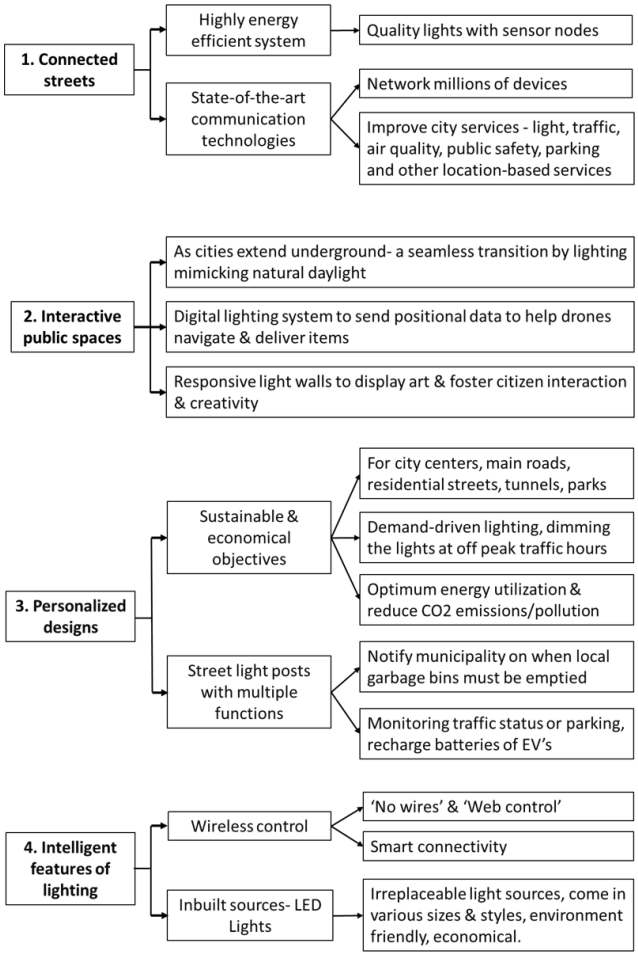

Figure 6. Four aspects of 'Smart City Lighting' in Urban areas (Compiled by Authors based on an article available at https://www.eprmagazine.com/features/powering-the-smart-cities-with-intelligent-lighting/)

Thus, lighting innovations for safety and sustainability can be achieved at different scales of planning and design of public spaces with specific objectives in line with the larger vision and aspirations by the city for its people. Also, light pole designs offer potential of hosting several other smart features pointing at integrated & compact entities.

5.2. Case 2- Smart Surveillance and Security Systems

Video surveillance by installing Closed-circuit television (CCTV) in urban spaces is becoming common in the present times to enable real-time monitoring and reducing patrolling personnel. This technology has been revolutionized with innovations in high computing power, huge memory potential and ample processing capabilities. The system comprises cameras, transmission media, image analysis equipment, monitors, recording and storage systems. Camera resolutions come in varied capacities and quality of capturing the images, hence as per the expected degree of security, the right cameras need to be adopted. Additionally, surrounding lighting, background clutter, crowding of people or objects, day or night etc. impact the system selection, higher the possibilities of crime, higher the expected resolution. Operational attributes, software and hardware components need to be outlined while, sound detection, biometry, and CBRN-E sensors are adopted as per contextual demands (European Commission, Sept 2020).

First case study looks at research that has developed a futuristic urban design tool viz., the *LookCrim* application (Freitas, 2011). This tool gathers geo-tagged information on various locations in the city. It intends to map the four basic CPTED parameters from urban documentations and adopts a spatial-temporal analysis of crime-enabling data organization and apt urban design decisions thereupon. Studies based on this application have been published which revealed its benefits in safety design resolutions.

Second case study is in the case of Detroit smart city, where under the 'Project Green Light' crime was reduced by 50% by the adoption of a network of public and private cameras across the neighborhoods with two main objectives- provide critical evidence for investigations and discourage potential crimes since the cameras came with a green identification light. They are fitted with audio detectors as well to spot adverse noises such as glass-breaking or shouting to enable action before the escalation of crime; the sensors aid the Fire department in spotting fire as in cases of arson as well. Surveillance has been used to prevent railway suicides to a greater extent. However, to keep the security systems themselves protected, physical access control is enabled that includes video capture, QR Codes, visitor badges, and facial recognition to screen authorized personnel access exclusively (Sori; Axis Communications, 2020).

Third case study points at Cell phone applications (Apps) in general that make it inclusive for citizens to have an easy and immediate interface to communicate with respective authorities and be participants in the protection of public spaces (European Commission, 2020). Hence, public spaces are expected to be Wi-Fi enabled, equipped for easy and quick access to required phone services to be used in the case of dire circumstances and report to concerned support lines. It is recommended that every city develops an App with a user-friendly interface for any citizen to use with ease.

Fourth case study looks at the application of Drones or Unmanned Aircraft systems (UAS) considered as technology's latest innovations are being adopted by cities to monitor public space security as in the instance of Turin, Italy. Drones can work in integration with ground surveillance for effective outcomes across smaller sized to large public spaces. In Madrid, Spain drones are extensively used by municipal departments for monitoring and surveillance during daytime and nighttime, public announcements, accident reconstruction and disaster management (EFUS, 2022).

Thus, digital surveillance is going beyond the basics of CCTV applications to innovations with equipping citizens to report crimes, aerial surveillance by drones and software development for prevention of crime or its escalation.

5.3. Case 3- Signage and Digital Interactive Applications

A legible system of urban spaces in a city becomes a step towards a safer city; when a citizen knows his city well and navigates with confidence, he is at ease and the likelihood of being subjected to crime is lesser. Signage aids in wayfinding and supports branding, commerce, and economy as well for businesses to sustain. While static signboards have been around for long, smart cities are embracing innovations in technological tools and designs of signage are now human centered in approach (Sloly, 2023). Digital signage comprises of networked electronic displays in public spaces coupled with interactive features, where displays offer consumers possibilities to interact with the system (Bauer, Dohmen and Strauss, 2011). They provide a range of interactive facilities for information on city services, public transport schedules, local community updates, free public Wi-Fi, emergency warnings, advertisements, green walls, phone charging or game pods (Fig 7) (Smart Cities, Pavegen).

First case study looks at the application of kinetic technology to generate energy from people's footsteps and power interactive applications by Pavegen, a UK-based company. This is called 'people power' which envisions in helping society to be sustainable while being progressive and involve fun-filled engagements for the people. Interactive signage adds to the interest level of city designs for residents and visitors alike.

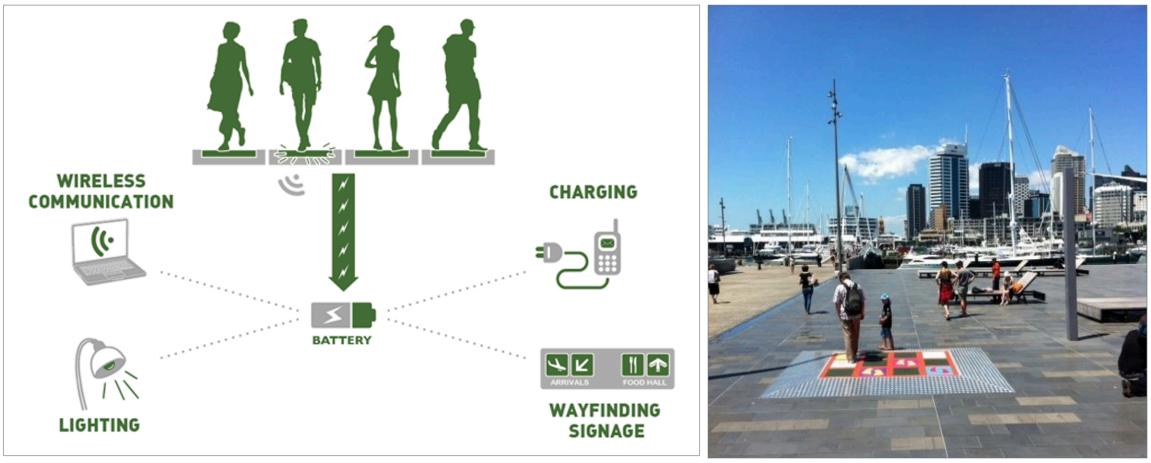

Figure 7. Pavegen Green system installed by Easy Freight in Karanga Plaza, Auckland, New Zealand (Source: https://www.pavegen.com/)

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Second case study highlights a new perspective to interactive signage by a democratic built-in system that gives consumers opportunity of expression of opinion on the sign content. For example, if a person dislikes a 'macabre' in the display or any other discriminating content in the advertisement, he may use his phone to vote on the issue immediately with a simple user interface. The platform provider further collates such votes to enable suitable action on the signage (Bauer, Dohmen and Strauss, 2011). This gives cue to create an easy and quick interface App for the user to contact services instantly with real-time location sensors.

Third case study looks at a project proposal titled *Pointsoft* for the Naples Circumvesuviana in Italy comprising of five crucial railway lines serving over two million commuters (Rocca, 2014). The project involved rejuvenation of the stations with a system of interactive multimedia installations aimed to enhance services, offer required information to commuters about rail schedule, connectivity, emergency numbers, and elevate the perception of safety in the stations and the trains. The interactive screens played videos on history of the place along with primary information. These displays allowed social control, increased sense of security, awareness of place and orientation (Rocca, 2014).

Thus, digital innovation offers wide possibilities of common man-to-technology interface under information signage along with inducing safety strategies from a personal phone App level to a public display interface. They are two-way and interactive in nature making response quicker and efficient by concerned teams.

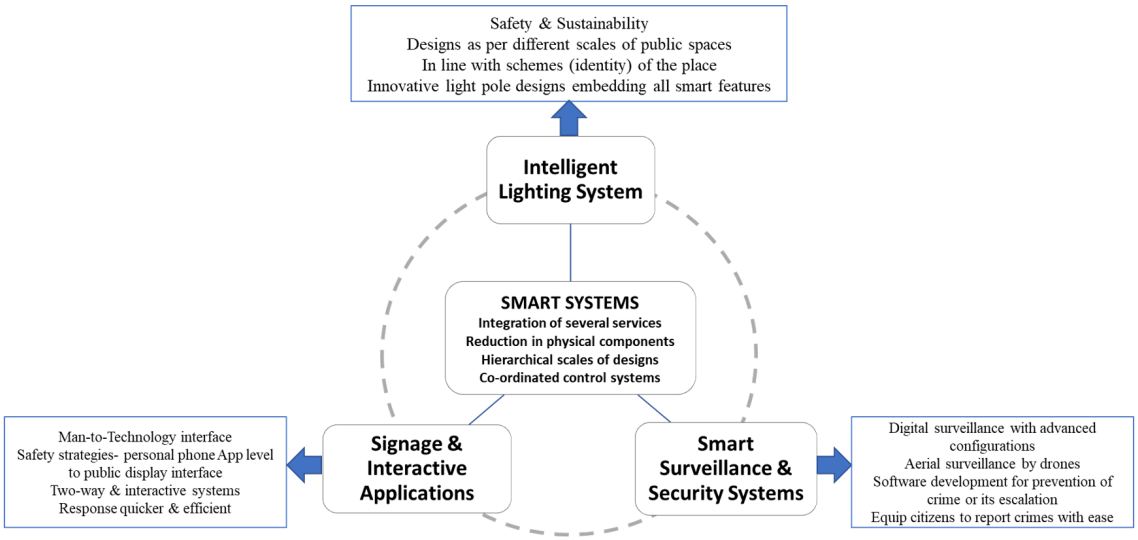

Figure 8. Deductions from Case studies on the three aspects of smart safety measures

The case studies thus present possibilities of innovations across various hierarchies (scales) of planning and urban design with the three cases of smart systems and deductions of salient aspects under each (Fig 8).

6. Challenges to Smart Safety Systems in cities

Crime detection, prevention, and people protection components of tech-enabled CPTED propose a fool-proof security system yet accompanied with certain challenges to be addressed to make the spaces liveable as well. They are meant to induce safety to common public and not intimidate with complex user interfaces nor bulky equipment occupying public spaces. Smart security systems in cities face two main challenges – firstly, concerns regarding breach of information confidentiality as data is on the global network, secondly the accommodation and integration of the physical components of the systems in the public space design. The study addresses the second concern as a scope under this research. For example, in the context of Indian cities which are in most cases highly populated, demographically diverse with urban spaces becoming zones of high activity, crowding and multiple stakeholders, urban spaces become contested spaces for several entities vying for space. The streets are occupied with- people, vegetation, vehicles, hawkers, stray animals, signage & hoardings, waste dumps, shop spillovers, private encroachments by residents and commercial shop owners and infrastructure elements such as utility units and poles (Patil & Raj, 2019).

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Figure 9. Sidewalks cluttered with multiple components including utilities & their physical units impacting liveability in terms of safe pedestrian navigation in public spaces (Date of capture- October 20, 2017, 11 AM, Basavanagudi, Bangalore)

To compare the scenarios of urban spaces before and after smart city implementations, a study is referred to here- doctoral research conducted by authors during the pre-smart city implementation period in the city of Bangalore (capital of Karnataka state, India, and a globally progressive metropolitan city). The research developed a methodology to audit neighborhood streets & public spaces for elderly walkability. Results showed that the infrastructure elements accounted for nearly 80% of the barriers to walkability in the surveyed four neighborhoods. These overground utility units comprising of electrical transformers, light poles, cables, manholes, or control units for electricity, telecommunication & water supply services were observed to be placed and spread randomly occupying much of the sidewalks along the streets in an uncoordinated manner leading to discontinuous pedestrian paths forcing pedestrian to get down to traffic laden roads proving unsafe causing accidents (Fig 9 & 10). Hence, it was observed that the utility or infrastructure elements impacted adversely the urban place-making and on the overall liveability (Patil & Raj, 2019).

Figure 10. The clutter of utility elements- poles, control units, signage, traffic police/control units (Date of capture- September 2, 2023, 10 PM, Bangalore city center)

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One definition refers to smart city as - an instrumented, interconnected, and intelligent city (IBM, 2008); 'instrumented' pertaining to the modes of capturing and integrating real-time data using sensors, meters, appliances, and a range of other devices (Praharaj & Han, 2019). Embedding these physical components of the security devices into the architecture of urban space becomes critical for better designs that keep up the aesthetic value of the place and be user-friendly to all citizens. Right placement of equipment- light posts, surveillance cameras, cables, sensors, and access boxes in a manner as to:

- not hinder people's movement or comfortable usage of the public space
- not ruin the aesthetical realm
- not add to unsightly clutter & perils of crowding
- not hamper routine/regular maintenance of devices by personnel
- not to be impacted by weather forces
- not easy to be destroyed/ vandalized
- not economically demanding nor environmentally harmful in any way.

The case studies under intelligent lighting presented scope of design for compact physical units embedding various smart security features to combat the concerns of bulky, multiple-unit components and space-consuming infrastructure. This poses as a potential advantage especially in dense city center public spaces to resolve clutter and thereupon enhance the public realm for walking, smooth access, aesthetics, and overall ambience while being well equipped to be smart places. This elevates the degree of liveability factor of the city.

7. Proposed Framework

From general understanding, it is observed that four aspects ensue safety in cities- urban governance (policies), police force, urban planning & design strategies, and technological adaptations. The last two being focus here, the study hypothesized that liveability can be enhanced adopting technology towards stimulation of resilience to crime and induction of safety in the design of urban spaces. Under the scope of the study, was the concern pertaining to accommodation of the physical components of the smart systems in the public space designs.

From the case studies it is noted that smart systems of lighting, surveillance, and signage have created innovative solutions, one of the important outcomes being integrated and compact physical modules (Fig 8). While the research conducted in pre-smart city scenario showed adverse impact on public reams, on liveability aspects with unsafe and barrier laden sidewalks due to independent services and their corresponding physical components being spaced out or strewn in the public spaces. Thus, technological advancements which converge various security systems and services aid towards creating amicable and user-friendly public realms in cities. Hence, proving the hypothetical assertion of smart urban spaces paving way for liveable conditions to an extent.

Given the scope to collate safety systems/services and reduce complexity in urban design, led to conceptualizing proposal for an 'integrated, inclusive, and collaborative' system of IoT with a proposed network called as 'mesh of smart safety ecosystem' concept in city designs (Fig 11). Such a coherent system that integrates all services and security measures leads to effective utilization of the valuable open spaces in the city for better socially enriched spaces creating walkways, public seating, parklets, or amenities. While the software and hardware of the ecosystem become the backdrop, physical components become of immediate concern to architecture & urban design schemes with experiential attributes to users. Smart physical units can integrate- intelligent lighting, smart surveillance cameras, Wi-Fi, digital parking, environmental monitoring (pollution), a public information system for the visually challenged, charging points, fire safety measures, smart direction systems, interactive maps, and emergency calling stations (Colclough, 2021).

The proposed smart ecosystem involves five broad criteria- Core safety & security measures, Response, Legibility, Amenities and Management (Fig 11). Such a system relies on principles of innovative, collaborative, integrative, advanced, inclusive, and participatory methodologies for a wholesome and efficient functioning to mitigate noted issues.

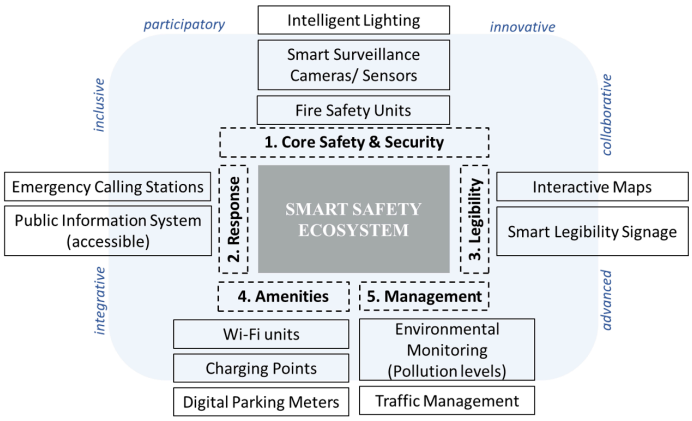

Figure 11. Mesh of Smart Safety Ecosystem

This framework shall enable resolutions under the twofold objectives of technology to foster urban environments and a system for amicable public realms. The smart ecosystem enabled with the two main aspects of physical designs and systems management lead towards a liveability anchored in safe and conducive public spaces in cities proving the hypothetical assumption (Fig 12).

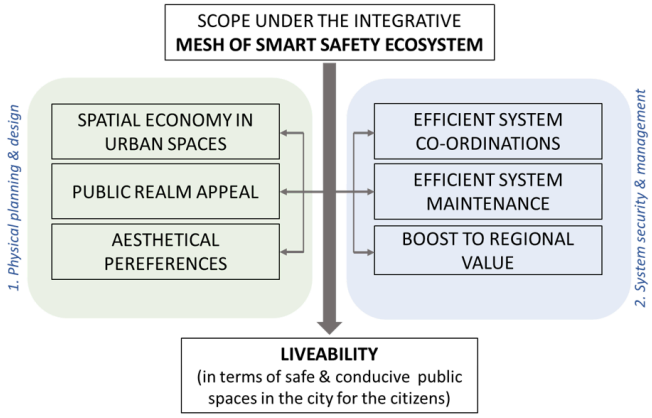

Figure 12. From Smart systems to Liveability- Resolution & mitigation under physical space planning and system security management

Firstly, it is realized that to achieve a coordination between the physical components innovation of system designs to consume less space with the right choice of devices is fundamental. Secondly, though not in the scope of this study, assumption points at a collaborated ecosystem to reduce vulnerabilities of the systems with a single control/operational point and specific sub-points while dispersing such elements in the public spaces (this needs substantiation). The study proposes to initiate further research on this second aspect and explore smart urban space designs addressing each specific utility system in the available spatial and contextual typologies. The qualitative assessment in the second phase of study in the upcoming research shall include people-based opinion surveys in selected neighborhoods to reinforce the case study analytical results. However, a robust people-centric approach to techno-safety designs of urban spaces becomes necessary for architects and designers in conjunction with CPTED strategies.

8. Conclusions

The research highlights qualitative explorations of emerging concepts with the adoption of technology in designing public realms in cities as possibilities to induce resilience to crime while enhancing liveability as well, with a focus on nascent smart urban spaces. The study attempted to fill in one gap in the contemporary times on imposition of technical-smartness and impact on physical realms of urban public spaces. This was conducted by way of case studies under three parameters, deducing that smart security features are collaborative in nature with multiple attributes acting towards a wholesome

doi.org/10.32388/MD99FP.5

system of functioning. And a comparative analysis of pre-smart era and current smart scenarios was undertaken, that showed that in the first case infrastructure remained independent creating overtly laden sidewalks and public spaces impacting liveability in terms of public realms.

It concludes with a proposed ideology of a 'mesh of smart safety ecosystem' as an integrated mechanism. This further leads the way to develop in the Indian urban contexts with the impending complexities and multiple components in public realm, architectural and urban design guidelines imbibing essential principles of CPTED for effective and progressive safety systems.

The study proposes to further the research in terms of qualitative assessment involving people perspectives based on age-based user group opinions with on-field surveys to substantiate the learnings from case studies and arrive upon context-specific attributes to the CPTED principles of safety designs.

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Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.