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Smart neighbourhood

A TISM approach to reduce urban polarization for the sustainable development of smart cities

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Abstract

Purpose – This paper aims to identify the key factors to design efficient, healthy and potentially economical neighbourhood places in the surroundings of smart cities to reduce the urban polarization for the sustainable urban development.

Design/methodology/approach – A two-stage methodology is followed. First, the key factors for neighbourhood are identified from literature studies. The selected factors are validated by sample *t*-tests. Second, the total interpretive structural modeling is used to interpret the complexity of relationships among various factors. Further, cross-impact matrix multiplication is applied for classification analysis to find the most driving factors for neighbourhood design.

Findings – The contribution of this research is to show hierarchical relationships among the various factors to design the neighbourhood places as smart from the perspectives of city planners and decision makers.

Research limitations/implications – The applicability of the research findings is limited to developing countries mainly where population is large and most of cities have high pressure on its infrastructure to fulfil the citizens' demands.

Practical implications – This paper will aid policymakers, city planners and government officials to design a sustainable smart city model in which smart neighbourhood would also be the potential solution to decrease pressure on a city's critical infrastructure especially in developing countries.

Social implications – A smart city could be considered as the centre point of smart initiatives to develop a place smart, and it should continue beyond the city boundaries to enhance the facilities, services, resources utilization and working environment in neighbourhood places also.

Originality/value – The study explores the various literature on neighbourhood planning and then link with smart city development as current need of urban development scenario. The authors propose a hierarchical relation framework to develop the neighbourhood places as smart places to meet the future demand of urbanization in developing countries like India.

Keywords Smart city, TISM, Smart neighbourhood, Urban polarization

Paper type Research paper

1. Introduction

1.1 Urban agglomeration and smart neighbourhood initiatives

Cities are the centre of the economic development in any nation. Advancement in city life, quality of services and future opportunities attract more people in to a city space. This urban transition creates pressure on consumption of city resources, energy supply, public spaces and services. The urban areas are contributing around 60 per cent of gross domestic product (GDP) in India. The United Nations (Habitat, 2016) has projected 300 million new urban residents in India by 2050. Indian urban population was estimated around 0.254 billion, 0.33 billion and 0.42 billion in 1995, 2005 and 2015, respectively. It has been projected

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that Indian urban population would be 0.53 billion by 2025 (Habitat, 2016). It could be seen easily that from 1995 to 2025, Indian urban population would be nearly double. But the level of urbanization in India has not increased at same scale. In 1995, 2005 and 2015, the level of urbanization was 26.6, 29.2 and 32.7 per cent, respectively. It has been projected that by 2025, the level of urbanization would be 37 per cent (Habitat, 2016), merely very less in comparison to increasing rate of urban population. The rapid urban polarization increases strains on energy, transportation, water, housing (Schaffers *et al.*, 2011) planning, development and operation of cities (Cash, 2016). This causes the depletion of city resources at a very high rate (Gu *et al.*, 2015; Qu *et al.*, 2013; Angel *et al.*, 2011). The nature of urbanization depends on different development policies (Pugh, 1995) in a country. The lack of facilities, poor development planning, ignorance from top management (Nam and Pardo, 2011), high poverty level (Bramley and Power, 2009; Mason, 2010), income inequality (Mason, 2010), high wages (Ballas, 2013), quality of life (El Din *et al.*, 2013) and glamour of cities (Ballas, 2013) are the main causes which promote the rural urban migration.

Frankhauser (1998) has defined urban agglomeration as a diffusive and elusive concept. The population growth and migration of people towards the cities are the important reasons for urban agglomeration. The city authorities usually fail to manage planned development due to this agglomeration which create problems like unemployment, congestion, lack of public services (Wu *et al.*, 2015; Bloom *et al.*, 2008), exclusion and rising inequality (Habitat, 2016) among the citizens. In fact, the city planners and governance are not able to resolve the administrative, infrastructure, service delivery and environmental challenges in a city due to the lack of managerial and technical expertise (Montgomery, 2008) which fluctuate the economy (Hayek *et al.*, 2016) of a country. The unplanned land usage, greenhouse emissions, increase commuting time, high living cost, inadequate infrastructure, unemployment and low-quality living are some major outcome of urban sprawl (Habitat, 2016).

Table I shows the urban agglomeration pattern in four metro cities of India, namely, Delhi, Mumbai, Kolkata and Chennai. Based on year 2016 statistics, 6.2 per cent of the total Indian urban population reside in Delhi which was the highest among all cities in India. Mumbai stood second with 5 per cent of the total Indian urban population followed by Kolkata with 3.5 per cent and Chennai with 2.4 per cent . El Din *et al.* (2013) have defined urban planning as a technical and political process. The city planning and community

City	Statistical concepts	City populations (000) 2000	2016	2030	Average annual rate of change (%) 2000-2016	2016-2030	City urban populations/total urban population of India (%) 2016
Delhi	Urban agglomeration	15732	26454	36060	3.2	2.2	6.2
Mumbai	Urban agglomeration	16367	21357	27797	1.7	1.9	5
Chennai	Urban agglomeration	6353	10163	13921	2.9	2.2	2.4
Kolkata	Urban agglomeration	13058	14980	19092	0.9	1.7	3.5

Source: Adopted from United Nations, Department of Economic and Social Affairs, Population Division (2016)

Table I.
Urban agglomeration patterns in four metro cities in India

design influence the development of neighbourhoods (Mason, 2010; Bramley and Power, 2009). In developing countries, the government should try to reduce the gaps between people residing in rural and urban areas by providing quality life and better services in rural areas to decrease the rural urban migration (Habitat, 2016). Moreover, such efforts will also decrease the stress on valuable city resources and mitigating consequences of climate change (Cash, 2016). Hence, there is a strong demand of time to re-look into the policies for city development as well as nearby places too.

In general, the city planning is limited to physical design, land use, facility for basic services, transport and connectivity. Smart cities development are the new initiatives to resolve the existing urban issues in a sustainable manner by integration of ICT to improve the functioning and operation of the city (Schaffers *et al.*, 2011). Smart cities are usually defined as citizen-centric cities (Lee and Lee, 2014) in which people decide and contribute in city development planning. A smart city generally has six major dimensions, namely, smart governance, smart people, smart living, smart mobility, smart economy and smart environment (Giffinger *et al.*, 2007), to live a prosperous, healthy and vibrant life. The success of smart city development lies in understanding the problems and nature of the complexity (Nam and Pardo, 2011) that exist in the city and its nearby places. To preserve the city resources and environment and to facilitate the good services to its citizens, the governments must have to plan to develop the smart and efficient neighbourhood places.

A neighbourhood could be a place which can provide the employment, retail, diverse residential facilities and other services to the citizens. The proper land use, employment opportunities, transportation, street connectivity, public spaces and housing facilities (El Din *et al.*, 2013) in places near smart cities will reduce the urban agglomeration and migration of people to cities. Moreover, multimodal transport, street design (Mason, 2010), energy supply, efficient infrastructure (Bătăgan and Boja, 2012), parks, clean environment (Ballas, 2013), sensors, CCTVs and app-based services would improve the efficiency and incorporate smartness in the functionality of neighbourhood places. Smart cities solutions can only be effective and sustainable, if smart neighbourhood places near smart cities are also developed simultaneously.

2. Literature studies

Cities throughout the world are competing with each other to attract resources to increase their citizens' quality of life (Belanche *et al.*, 2016; Jung *et al.*, 2015). Urban economic development depends upon the rates of interest, tariffs, GDP, exchange rates, fiscal policy coherence, flows of funds and so on (Pugh, 1995). The massive inflow of people from rural and medium-sized cities cause urban sprawl and polarization which create pressure on urban infrastructures (Roy, 2009; Montgomery, 2008; Cohen, 2006), civic services (Otiso, 2003), housing availability and living costs, decreased quality of urban living, poor governance and poor economic performance (Habitat, 2016). The planned smart neighbourhood can solve and manage the high growth rate, slums reduction, mass transit, poverty, inadequate housing, congestion, poor health outcomes and malnutrition, urban sprawl and aging infrastructure.

The smart city initiatives are a new multi-disciplinary approach to enhance the facilities, services, resources utilization and working environment to the global standards. The success of a smart city depends on effective initiatives that must be implemented properly according to the geographical position of city and citizen's requirements. The increasing accessibility to residence, job opportunities, health facilities and various civic services improve the value of neighbourhood places. Mason (2010) was focused on more street connectivity to neighbourhoods via public transports. Lund (2003) has suggested to develop public parks, retails, pedestrian streetscapes in neighbourhood places. A neighbourhood should be efficient to provide social and economic attitudes, lifestyles and institutions (El Din *et al.*, 2013) to its citizens. While designing the neighbourhood places, equal accessibility should be there for all citizens. Nam and Pardo (2011) have raised the issues of digital divide in service accessibility and usability. The waste management, resource utilization, transport adequacy and environment challenges should also be the major concerns for a sustainable neighbourhood development. Rohe (2009) has suggested to work on walkability, mass transit, social interaction, green gas emission and community design (Mason, 2010) in neighbourhood places. Based on the literature studies, some essential factors have been identified (Table II) for neighbourhood design.

Smart neighbourhoods must be designed in an efficient, healthy and economical way to live, work, shop and grow. The neighbourhood urban infrastructure has attributes like land use, housing, quality life, access to services, safety, education, diversity, cultural uniqueness (El Din *et al.*, 2013), waste management, environmental protection law, infrastructure services (Pugh, 1995) clean air, drinking water, sewage treatment, transportation and renewable energy sources. The resources must be used in a sustainable manner to make a viable neighbourhood. The factors identified from literature were shown to expert group (Appendix 2) and further discussed. Some factors with related contexts were merged and some factors were discarded by experts. The final list of factors is shown in Table III.

To develop a digitally enabled neighbourhood place, innovative planning and solutions are required to integrate with city systems to improve the critical urban infrastructure. Apart from planning, adequate financing capacity, effective partnerships with all relevant stakeholders (Habitat, 2016) and technological capability are also needed to develop a green neighbourhood economy. The government should focus on people-centric development and priority-based services to the citizens. The prime focus must be on efficient transport, reducing waste, energy consumption and pollution control. Sanitation should also be a critical priority for a clean neighbourhood place. Crime should be controlled by integration of ICT technologies to make the citizens more secure and safe in neighbourhood places. A well-designed and well-maintained smart neighbourhood could be a centre for citizens to transform their standard of living.

Factors	Sources
Green urban planning	Kabisch *et al.* (2016), Pulighe *et al.* (2016) Pietrzyk-Kaszyńska *et al.* (2017)
Employment opportunities	Bolay and Rabinovich (2004), Mason (2010)
Affording opportunities	Mason (2010)
ICT infrastructure	Mason (2010), Bătăgan and Boja (2012)
Citizens co-production and feedback	Linders (2012), Picazo-Vela *et al.* (2012), Baud *et al.* (2015)
Mass transit	Rohe (2009), Mason (2010)
Affordable housing	Chegut *et al.* (2016)
Education facilities	Ballas (2013)
Health amenities	Mason (2010), Nam and Pardo (2011), Ballas (2013)
Efficient mobility	Giffinger *et al.* (2007)
Shopping facility	Rabbiosi (2015)
Urban quality of life	El Din *et al.* (2013)
Sports and entertainment	Ballas (2013)
Congestion levels	Bătăgan and Boja (2012)
Physical beauty of place	Ballas (2013)

Table II. Factors identified from literature on neighbourhood design

F_Code	Factor	Description
V1	Green urban planning	Government planning and policies for land, green belts, water supply, electricity, gas supply, food, waste management, sanitation, use of renewable energy sources, emission reduction, pollution control, sewage treatment, basic civic services and amenities
V2	Employment opportunities	Jobs, business opportunities, research facility, incubation centre, industrial development, agri-businesses, SMEs platforms, promoting local industries
V3	ICT infrastructure	Broadband deployment, Wi-Fi, Sensors, CCTVs surveillance, Mobile app-based services, integration of municipalities services, online payments and banking
V4	Citizens coproduction and feedback	Citizens' engagement to decide the priorities of the development and their participation in planning and policies execution
V5	Affordable housing	Rent/house facilities for citizens at reasonable price
V6	Education facilities	Schools, colleges, universities, open education, smart learnings over internet
V7	Health amenities	Hospitals, medical support, health-care facilities, telemedicine, online consultation
V8	Efficient mobility	Multimodal transport facility, real-time traffic information, freight logistic, traffic diversion, end point connectivity
V9	Shopping facility	Shopping malls, open market fair, community centres
V10	Sports and entertainment	Games, multiplex theatres, clubs, party halls

Note: F_Code denotes factor code

Table III. The description of chosen factors

3. Methodology

3.1 Questionnaire survey and factors validation

The questionnaire was developed on the basis of literature review and expert discussion. Initially, a pilot phase was conducted. The questionnaire was emailed to people ranging from highly experienced city planners, mayors, policymakers, government officials, CEOs smart city, private society builders and academicians in India to get the holistic view of the neighbourhood design while developing the smart cities. We have contacted some experts (Appendix 2) personally to discuss the influencing factors in details and to build structural self-interaction matrix for total interpretive structural matrix process.

The questionnaire was circulated to 103 people; however, 38 responses were obtained in which only 33 were complete responses and 5 were incomplete. During the pilot phase, we asked the respondents to rate the identified factors on a five-point Likert scale (1 – Not Important, 5 – Extremely Important). The data obtained from the survey were analysed by single sample *t*-test. Results of this analysis are provided in Table IV. All the factors are significant at $p < 0.01$.

3.2 Total interpretive structural modeling

Total interpretive structural modeling (TISM) is a mathematical process to interpret complex relations in the form of nodes (to address "what") and links (to address "how and why"). The relationships may be available from existing theories or can be obtained from field understanding. The TISM process (Sushil, 2016, 2012) can facilitate to integrate multiple pair-wise comparisons in the form of a hierarchical model using the basic technique of interpretive structural modelling proposed by Warfield in 1974 (Sushil, 2012).

The various steps involved in TISM are as follows:

- Identifying the factors which are relevant to the problem. This could be done by literature studies, survey or group problem solving techniques.
- Establishing a contextual relationship between factors by pair-wise comparison.
- Developing a structural self-interaction matrix (SSIM) for factors. This matrix indicates the pair-wise relationship among selected factors. The matrix could be developed through the expert opinion or survey method.
- Developing an initial reachability matrix from SSIM. This matrix should be checked for transitivity and final reachability matrix must be developed.
- Partitioning of final reachability matrix into different levels.
- Converting the reachability matrix into conical form.
- Drawing digraph based on the relationship given in final reachability matrix and remove transitive links except those which have distinct interpretation.
- Converting the resultant digraph into a TISM-based model by replacing element nodes with the statements and links as interpretation relations.

The complete details of TISM for this study are given in Appendix 1. The final digraph from the modelling has been shown in the Results section (Figure 1).

4. Results

4.1 TISM model

The contextual pair-wise relationships were made among the factors to develop the SSIM matrix (Figure A1). SSIM matrix was used to develop the initial reachability matrix (Figure A2) and final reachability matrix (Figure A3). Level partitioning was performed to get the hierarchy among the factors (Table AI). A conical matrix was designed (Figure A4) from the partitioning process. A digraph was generated from the conical matrix to visualize the factors and their interdependencies in terms of nodes and edges. The TISM model has been developed (Figure 1) by replacing nodes of the factors with statements. In normal circumstances, the feedbacks and cycles should be eliminated to get a digraph with minimum edges.

4.2 Cross-impact matrix multiplication applied to classification analysis

Matrice d'Impacts croises-multiplication appliqúe an classment (cross-impact matrix multiplication applied to classification) (MICMAC) is used to conduct to get the new insights

Factor	SD	*t*	*N*	Mean
Green urban planning	33	4.42	0.751	33.830
Employment opportunities	33	4.76	0.561	48.742
ICT infrastructure				
Citizens co-production and	33	4.33	0.816	30.488
feedback	33	4.15	0.870	27.400
Affordable housing	33	4.48	0.755	34.122
Education facilities	33	3.73	0.839	25.509
Health amenities	33	3.82	0.727	30.174
Efficient mobility	33	4.27	0.719	34.135
Shopping facility	33	2.70	0.684	22.652
Sports and entertainment	33	2.39	0.998	13.778

Table IV. Factors validation through single sample *t*-test

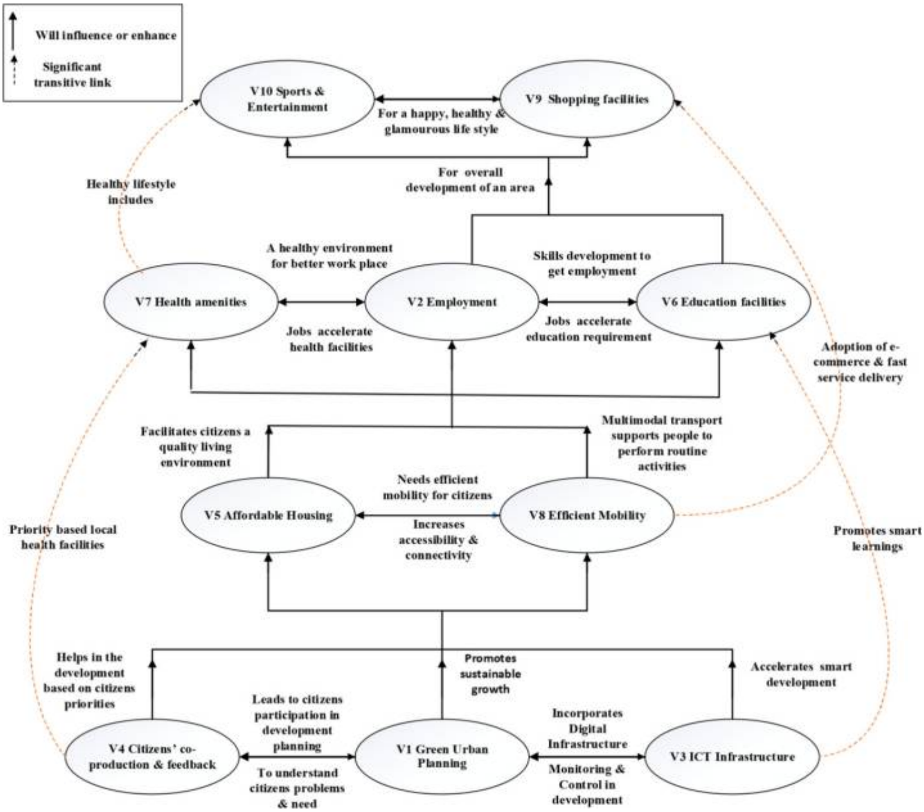

Figure 1.
TISM for smart neighbourhood design

into dependencies among the factors in the development. The methodology was developed by Duperrin and Godet in 1973 (Hu *et al.*, 2009). The method enables a systematic analysis of the factors based on their driving power and dependence. All the factors have been clustered into four quadrants, namely, autonomous, linkage, dependent and independent based on their driving and dependence power (Figure 2).

5. Findings and discussions

The results (Figure 1) were shown to experts and discussed to validate the findings. The green urban planning is crucial while making policies for the development of a smart neighbourhood. It incorporates the sustainability in the development. The green urban planning focuses on maintaining the natural aspects and biodiversity of that place. It also includes the strategic planning for clean air, drinking water supply, use of renewable energy sources, reduction of waste, sustainable drainage system and recycling processes to develop a green belt. Ballas (2013) has also discussed about the clean environment in his study. Pietrzyk-Kaszyńska *et al.* (2017) have studied urban green spaces in three Polish cities with the use of public participation geographic information science tool approach to link information on citizens' preferences, uses, perceptions and values with specific, spatially explicit locations. Citizens' co-production and feedbacks are essential at planning phase to set the priorities for the development. Citizens' participation in planning and decision process

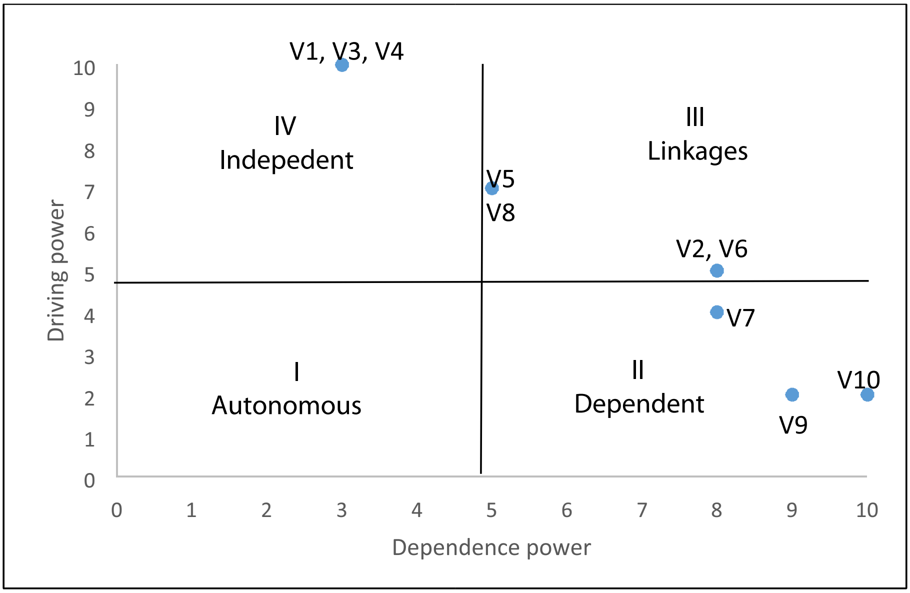

Figure 2.
MICMAC analysis illustrating driving power and dependence power of each factor

will enhance the government capability and functionality for the sustainable development. Baud *et al.* (2015) also have argued the citizens' feedback in interactive monitoring process in government planning. ICT infrastructure introduces the smartness in the development process. Integration of all the public services and municipalities' functionality into city's digital space are required. Establishing high speed broadband network, Wi-Fi network, city cloud, communication hub, CCTVs and sensors network throughout the places will increase the government capability to develop a smart neighbourhood. More opportunities can be created through the digitization and digital databases based on ICT systems (Baud *et al.*, 2015). ICT also enhances the smart education and learnings to make the people smart. Green urban planning, citizens' participations and ICT infrastructure promote the need and development of affordable housing and efficient mobility in neighbourhood places.

Efficient mobility enhances the accessibility of services in a short span of time. To achieve this, a multimodal quick public transport system, real-time traffic information and route diversions information in case of congestion are required to increase the reachability to neighbourhood places. The street networks, roads and train network can be designed based on vehicle load and people to and fro movement. Mason (2010) has stated the influence of the local government on the outcomes in their communities through zoning for streets, sidewalks and parks. Rohe (2009) has also supported to work on walkability and mass transit in neighbourhood places. The street must be pedestrian-friendly to walk. Affordable housings for the citizens near to their workplace or neigbourhood places where citizens can also access facilities and services for their daily life, will reduce the daily commute in cities. Chegut *et al.* (2016) have argued to build affordable housings and buildings by investing in energy efficiency techniques. The cost of living must be minimized by promoting the access to affordable housing, services and facilities. A proper settlement help people to focus on other areas of life and to live a quality and joyful life. The mobility and adequate housing influence the employment, education and health opportunities in neighbourhood places.

The employment opportunities in a city attract unskilled migrants from surrounding sub areas and rural areas. Bolay and Rabinovich (2004) have considered the two main reasons for the growth of cities: rural population usually move into cities to gain access to modern services and infrastructure and to gain employment opportunities and better quality of life in a healthier environment. If the employment opportunities are in plenty in neighbourhood places, then massive population growth, traffic congestion and pressure on city infrastructure could be reduced. The employment opportunities promote the development of education, health, sports, entertainment and shopping facilities and vice versa in neighbourhood places to make the citizens better skilled, healthy and happy people. The neighbourhood places accomplished with the global standards education facilities for primary, secondary, higher education and research will make the people highly skilled and innovative to develop the higher societies. Education enhances the employment opportunities and influences the development of hospitals, shopping malls, multiplex, sports facilities and vice versa. A healthy environment makes people to work efficiently. The affordable housing, job opportunities and education facilities accelerate the demand for sanitation facility, hospitals, health centres, good number of beds in hospitals, online appointments of the doctor, health card to citizens, online consultation for remote areas and emergency services like ambulance from nearby hospitals in case of accidents or natural calamities. A healthy lifestyle influences sports and entertainment activities.

The shopping malls provide the quality public places and glamour in living places and facilitate essential services to a large number of people at a single place. The development of shopping malls depend on the people communities living in that area. Lund (2003) has also suggested to develop public parks, retails, pedestrian streetscapes in neighbourhood places. If the mobility is efficient and people are skilled, having good earnings and living in a healthy environment, the demand for opening shopping malls, multiplex, party halls, water parks, club or gaming zones will be high. The outdoor games will require the good playgrounds while developing the neighbourhood places. Ballas (2013) has supported the improvements in quality of life by natural amenities, i.e. climate, physical beauty of place and human-created amenities like education, health and entertainment opportunities.

The independent factors have strong drive power and weak dependence power. The factors with a very strong driving power are called the "key factors". The green urban planning (V1), ICT infrastructure (V3) and citizens co-productions and feedbacks (V4) in planning and decision-making have been found as the most driving factors (independent) in developing the smart neighbourhood (Figure 2).

The autonomous factors (Figure 2) have weak driving power and weak dependence. They are relatively disconnected from the system, with which they have few links, which may be very strong. No selected factor in this study was found suitable for this category. Linkage factors have strong driving power and strong dependence. These factors are unstable as any action on these factors will affect other factors and also a feedback effect on itself. Employment opportunities (V2), affordable housing (V5), education facilities (V6) and efficient mobility (V8) are found linkage factors for neighbourhood development. Dependent factors have weak driving power but strong dependence. Health amenities (V7), shopping facility (V9), sports and entertainment (V10) have weak driving power and strong dependence in the neighbourhood design.

The city authorities and planners are required to focus on citizen-centric urban planning, economic development, affordable housing, quality life style, energy efficiency, efficient transport infrastructure and ecological connectivity while planning and developing the neighbourhood places to a smart city.

6. Conclusions

The paper suggests a development framework for city planners and policymakers to design smart neighbourhood places surrounding to the smart cities. The study explains development of smart neighbourhood in the form of step-by-step hierarchy of all the influencing factors. The citizens' participation could be focused in developing the local infrastructure based on citizens' priorities. The adequate use of technology will support the city planners to develop digital infrastructure for an area to accomplish smart cities mission. The green urban planning and incorporation of ICT would enhance the quality of life, fast service delivery and new developments in an organized and balanced pattern in a living area. The availability of the critical resources, efficient transport and connectivity, job opportunities, health and education facilities are some key drivers for the sustainable growth of neighbourhood places in terms of economic, social and environment. The efficient urban management can also support for further widespread adoption of more sustainable urban practices. The benefits of urbanization should not be limited to large cities only but to their neighbourhood places also while executing smart cities mission to accomplish the goal of becoming a smart nation in near future.

7. Limitations and further research

There might be some more factors to address the urbanization issues. Adding or subtracting the factors can change the hierarchy. The multiple interpretations might be made by different users. The determination of the ranks of the sub-elements from the TISM process is difficult. To identify the most important and least important factors with priority, analytic hierarchy process or analytic network process can be used further. In future studies, the privacy and security issues can also be considered in digital infrastructure for the sustainable growth of the neighbourhood.

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Appendix 1

1. Development of structural self-interaction matrix (SSIM)

SSIM was developed based on the pair-wise relations among the selected factors. Experts were asked to suggest "leads to" or "'influences" type relations.

The following four symbols were used to denote the direction of relationship between two factors (*i* and *j*):

(1) *V* for the relation from factor *i* to factor *j* (i.e. factor *i* influences factor *j*);

(2) *A* for the relation from factor *j* to factor *i* (i.e. factor *i* would be influenced by factor *j*);

(3) X for both direction relations (i.e. factors *i* and *j* influence each other); and
(4) O for no relation between the factors (i.e. barriers *i* and *j* are not related).

Based on the contextual relationships, the SSIM was developed (Figure A1).

2. Development of initial reachability matrix

After making SSIM, an initial reachability matrix was developed (Figure A2). For this, symbols V, A, X or O of SSIM were substituted by 1s or 0s by applying following rules:

- If the (*i*, *j*) entry in the SSIM is V, then the (*i*, *j*) entry in the initial reachability matrix becomes 1 and the (*j*, *i*) entry becomes 0.
- If the (*i*, *j*) entry in the SSIM is A, then the (*i*, *j*) entry in the initial reachability matrix becomes 0 and the (*j*, *i*) entry becomes 1.
- If the (*i*, *j*) entry in the SSIM is X, then the (*i*, *j*) entry in the initial reachability matrix becomes 1 and the (*j*, *i*) entry also becomes 1.

	V10	V9	V8	V7	V6	V5	V4	V3	V2	V1
V1	O	O	V	O	O	V	A	X	V	-
V2	V	V	A	O	X	O	O	O	-	
V3	O	V	V	V	V	O	X	-		
V4	O	O	V	O	O	V	-			
V5	O	V	X	O	O	-				
V6	V	O	A	X	-					
V7	O	O	A	-						
V8	V	V	-							
V9	X	-								
V10	-									

Figure A1. Structural self-interaction matrix

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
V1	1	1	1	0	1	0	0	1	0	0
V2	0	1	0	0	0	1	0	0	1	1
V3	1	0	1	1	0	1	1	1	1	0
V4	1	0	1	1	1	0	0	1	0	0
V5	0	0	0	0	1	0	0	1	1	0
V6	0	1	0	0	0	1	1	0	0	1
V7	0	0	0	0	0	1	1	0	0	0
V8	0	1	0	0	1	1	1	1	1	1
V9	0	0	0	0	0	0	0	0	1	1
V10	0	0	0	0	0	0	0	0	1	1

Figure A2. Initial reachability matrix

- If the (*i*, *j*) entry in the SSIM is O, then the (*i*, *j*) entry in the initial reachability matrix becomes 0 and the (*j*, *i*) entry also becomes 0.

Transitive links of the contextual relation also were checked in initial reachability matrix which states that if factor (A → B) and (B → C), then necessarily (A → C). 1* entries have been filled in initial reachability matrix to incorporate transitivity. As a result, a final reachability matrix (Figure A3) was obtained. The driving power and dependence have been calculated for each factor from final reachability matrix. The driving power of a factor is the sum of ones in the rows and its dependence is sum of ones in the columns. The ranks of driving power and dependence were given based on maximum number of ones in rows and columns, respectively.

3. Level partitions

To place the factors level-wise in a hierarchy, the reachability set and antecedent set were derived for each factor from the final reachability matrix. In case of a factor, if intersection of the reachability set and the antecedent set were same as the reachability set, then the factor was considered at the top level.

The top-level factors usually do not lead the other factors. The top-level factors were removed from the iterations. The process was continued till all the factors get the levels. In this study, it took four iterations to get the levels for all factors (Table AI).

Table AII illustrates the final iteration results and level of each factor in top to bottom order in a hierarchy.

4. Development of conical matrix

Conical matrix (Figure A4) was developed by clustering such factors which were at the same level during the partitioning process. The preparation of the lower triangular reachability matrix is optional. The digraph can be developed directly from the final reachability matrix.

5. Digraph formation

A digraph is a visual representation of the factors and their interdependencies in terms of nodes and edges. A preliminary digraph including transitive links was developed from the conical form of reachability matrix. After removing the indirect links, a final digraph was developed. Only

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	DR
V1	1	1	1	1*	1	1*	1*	1	1*	1*	10
V2	0	1	0	0	0	1	1*	0	1	1	5
V3	1	1*	1	1	1*	1	1	1	1	1*	10
V4	1	1*	1	1	1	1*	1*	1	1*	1*	10
V5	0	1*	0	0	1	1*	1*	1	1	1*	7
V6	0	1	0	0	0	1	1	0	1*	1	5
V7	0	1*	0	0	0	1	1	0	0	1*	4
V8	0	1	0	0	1	1	1	1	1	1	7
V9	0	0	0	0	0	0	0	0	1	1	2
V10	0	0	0	0	0	0	0	0	1	1	2
DP	3	8	3	3	5	8	8	5	9	10	

Notes: DR= Driving power; DP = Dependence

Figure A3.
Final reachability matrix

F_Code	Reachability set (RS)	Antecedent set (AS)	AS ∩ RS	Level
Iteration 1				
V1	1,2,3,4,5,6,7,8,9,10	1,3,4	1,3,4	
V2	2,6,7,9,10	1,2,3,4,5,6,7,8	2,6,7	
V3	1,2,3,4,5,6,7,8,9,10	1,3,4	1,3,4	
V4	1,2,3,4,5,6,7,8,9,10	1,3,4	1,3,4	
V5	2,5,6,7,8,9,10	1,3,4,5,8	5,8	
V6	2,6,7,9,10	1,2,3,4,5,6,7,8	2,6,7	
V7	2,6,7,10	1,2,3,4,5,6,7,8	2,6,7	
V8	2,5,6,7,8,9,10	1,3,4,5,8	5,8	
V9	9,10	1,2,3,4,5,6,8,9,10	9,10	I
V10	9,10	1, 2,3,4,5,6,7,8,9,10	9,10	I
Iteration 2				
V1	1,2,3,4,5,6,7,8	1,3,4	1,3,4	
V2	2,6,7	1,2,3,4,5,6,7,8	2,6,7	II
V3	1,2,3,4,5,6,7,8	1,3,4	1,3,4	
V4	1,2,3,4,5,6,7,8	1,3,4	1,3,4	
V5	2,5,6,7,8	1,3,4,5,8	5,8	
V6	2,6,7	1,2,3,4,5,6,7,8	2,6,7	II
V7	2,6,7	1,2,3,4,5,6,7,8	2,6,7	II
V8	2, 5,6,7,8	1, 3,4,5,8	5,8	
Iteration 3				
V1	1,3,4,5,8	1,3,4	1,3,4	
V3	1,3,4,5,8	1,3,4	1,3,4	
V4	1,3,4,5,8	1,3,4	1,3,4	
V5	5,8	1,3,4,5,8	5,8	III
V8	5,8	1, 3,4,5,8	5,8	III
Iteration 1				
V1	1,3,4	1,3,4	1,3,4	IV
V3	1,3,4	1,3,4	1,3,4	IV
V4	1,3,4	1,3,4	1,3,4	IV

Table AI. Partitioning the level

Factors	Code	Level
Sports and entertainment	V10	I
Shopping facilities	V9	I
Employment opportunities	V2	II
Education facilities	V6	II
Health amenities	V7	II
Efficient mobility	V8	III
Affordable housing	V5	III
Citizens co-production and feedback	V4	IV
Green urban planning	V1	IV
ICT infrastructure	V3	IV

Table AII. Final iteration results

significant transitive links are shown in final TISM digraph (Figure 1). In this development, the top-level factors were positioned at the top of the digraph, and second level factor was placed at second position and so on, until the bottom level factor was placed at the lowest position in the digraph.

	V9	V10	V2	V6	V7	V5	V8	V1	V3	V4
V9	1	1	0	0	0	0	0	0	0	0
V10	1	1	0	0	0	0	0	0	0	0
V2	1	1	1	1	1*	0	0	0	0	0
V6	1*	1	1	1	1	0	0	0	0	0
V7	0	1*	1*	1	1	0	0	0	0	0
V5	1	1*	1*	1*	1*	1	1	0	0	0
V8	1	1	1	1	1	1	1	0	0	0
V1	1*	1*	1	1*	1*	1	1	1	1	1*
V3	1	1*	1*	1	1	1*	1	1	1	1
V4	1*	1*	1*	1*	1*	1	1	1	1	1

Figure A4.
Conical form of final reachability matrix

Appendix 2

The profile of experts who participated in subject study are as follows (names, organization details and contact details are not provided for data and information privacy concerns).

Experts	Expert profile/designation	Experience	Category
Expert 1	Professor, Strategic development	>20 years	Academician, Delhi, India
Expert 2	Professor, e-Governance	>20 years	Academician, Delhi, India
Expert 3	Associate Professor, City Competitiveness	>10 years	Academician, State University, India
Expert 4	Senior adviser (Smart city, mGovernance)	>20 years	Industry, Government of India
Expert 5	MD and CEO, Planning and IoT	>20 years	Industry, Pvt Ltd, India
Expert 6	Solution Architect, Smart cities and clean energy technology	>18 years	Industry, Government of India
Expert 7	Mayor and politician	>15 years	Government Official, City in State, India
Expert 8	Chief Development Officer	>13 years	Government Official, India
Expert 9	CEO, Smart city project, Urban design	>18 years	Government officials, India
Expert 10	Managing director, Smart city application development	>12 years	Industry, Pvt Ltd, India
Expert 11	Cyber Expert, ICT planning	>23 years	Government Officials, India
Expert 12	Town planning officer	>17 years	Government Officials, India
Expert 13	Public works department officer	>14 years	Government Officials, India

Table AIII.
List of experts

About the authors

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