Transitioning Existing Cities' Urban Infrastructure Towards Smart Sustainable Cities

by

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Declaration

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Abstract

Transitioning Existing Cities' Urban Infrastructure Towards Smart Sustainable Cities

Traditionally, the development and management of urban subsystems was seen as a basic engineering and administrative task. The infrastructural system approaches developed throughout the 20^{th} century within the Western context are not adequate to address the current and future challenges that face cities. Smart cities and sustainable cities are urban concepts in their own right, both aimed to address these challenges. Individually both present advantages, shortcomings and discrepancies towards the other. Sustainable cities tend to focus on the resource management of a city, and the sustainability impacts within the city boundaries. Smart cities have the ability to address complex urban challenges, especially related to city infrastructure and its operation and functionality. Recent research has motivated a focus towards amalgamating sustainability and smart city design, giving rise to the smart sustainable city concept.

Cities are complex adaptive and dynamic systems-of-systems with embedded social and technical interdependences, which evolved and developed over many years. It is therefore important to address urban transformation in terms of scale, and linkages across levels, systems and regions. Transformation towards smart sustainable cities requires transitioning and the modernisation of urban infrastructure systems. There is currently an absence in literature of a holistic management framework for smart sustainable city transitions. An extensive literature review is presented investigating important themes, such as the origins, characteristics, benefits, challenges, perspectives, and evaluation of smart sustainable cities. Complex systems theory is explored, whereby a complex adaptive systems perspective is identified as a meaningful way to conceptualise and understand smart sustainable cities and the associated dynamics. Existing approaches and methods regarding city and infrastructure transitioning were also reviewed to draw understanding, requirements and guidelines useful to the design of the framework. The conceptual framework is established through synthesis of knowledge and insight gathered from literature to form a unique solution for the planning, development and management of smart sustainable infrastructure transitions. A collective case study analysis

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is used to validate the theoretical framework, testing twenty foundational aspects of city transitions. Minor adaptations, based on the reflections made regarding the aspects, were made to successfully address any shortcomings. The framework was then also subjected to a validation process testing the appropriateness of the framework's design using a Delphi technique and industry experts. After adapting the framework according to the feedback from experts, all of them were certain the framework would hold up in practice. The framework is intended as a generic guideline useful to municipal managers, city-planners, and project portfolio managers appointed to plan, direct and manage the transition of an existing city towards a smart sustainable city. The framework provides explicit guidelines needed to guide and manage the city transitioning process in practice, and can be adapted to align with the unique context and needs of the specific city it is applied to. The research contributes to knowledge creation at the intersection of three knowledge domains, namely: smart sustainable cities, urban infrastructure transitioning, and complex adaptive systems.

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Uittreksel

Die Oorskakeling van Bestaande Stedelike Infrastruktuur na Slim Volhoubare Stede

Die ontwikkeling en bestuur van stedelike substelsels was tradisioneel beskou as 'n basiese ingenieurs- en administratiewe taak. Die infrastruktuurbenaderings wat gedurende die 20ste eeu binne die Westerse konteks ontwikkel is, is nie voldoende om die huidige en toekomstige uitdagings in stede aan te spreek nie. Slim stede en volhoubare stede is eiesoortige konsepte van stadsontwikkeling wat albei daarop gemik is om hierdie uitdagings aan te spreek. Beide bied voordele, nadele en teenstrydighede teenoor die ander. Volhoubare stede behels 'n fokus op die hulpbronbestuur en volhoubaarheidsimpak binne stede. Slim stede bied die geleentheid om komplekse uitdagings te ondersoek met behulp van intelligente dataversameling, verwerking en bestuur, veral in verband met die funksionaliteit van stadsinfrastruktuur. Onlangse navorsing het 'n fokus op die samesmelting van volhoubaarheid en slim stadsontwerp gemotiveer, wat gelei het tot die slim, volhoubare stad konsep.

Stede is komplekse en dinamiese stelsels-van-stelsels met gevestigde sosio-tegniese interafhanklikhede wat oor baie jare ontwikkel. Dit is dus belangrik om stadstransformasie aan te spreek op verskeie vlakke. Transformasie na slim volhoubare stede vereis oorgangsmodernisering van infrastruktuurstelsels. In die literatuur bestaan daar tans 'n behoefte vir 'n holistiese bestuursraamwerk vir slim volhoubare stadsoorgang. 'n Literatuuroorsig word aangebied waarin belangrike temas ondersoek word, soos die oorsprong, kenmerke, voordele, uitdagings, benaderings en evaluering van slim volhoubare stede. Komplekse sisteemteorie word ondersoek, waardeur 'n komplekse aanpassingstelselperspektief geïdentifiseer word as 'n sinvolle manier om slim, volhoubare stede en die gepaardgaande dinamika te konseptualiseer. Bestaande benaderings ten opsigte van infrastruktuurverandering is ook hersien om insig, vereistes en riglyne te bekom wat nuttig is vir die ontwerp van die raamwerk. Die konseptuele raamwerk word gevestig deur sintese van kennis wat versamel is uit literatuur om 'n unieke oplossing te vorm vir die beplanning, ontwikkeling en bestuur van slim volhoubare infrastruktuuroorgange. 'n Gevallestudie-analise is gebruik om

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die teoretiese raamwerk te verifieer. Aanpassings, gebaseer op waarnemings wat gemaak is uit geïdentifiseerde aspekte, is aangebring om tekortkominge sinvol aan te spreek. Die raamwerk is dan ook aan 'n valideringsproses onderwerp deur multidissiplinêre kundiges te gebruik om die raamwerk te oorsien met behulp van die Delphi-tegniek. Nadat die raamwerk volgens die terugvoer van kundiges aangepas is, was daar konsensus dat die raamwerk in die praktyk geslaagd sal wees. Die raamwerk is 'n generiese gids vir munisipale bestuurders, stadsbeplanners en projek-portefeuljebestuurders betrokke by oorgangsbeplanning vir 'n bestaande stad na 'n slim, volhoubare stad. Die raamwerk bevat riglyne wat nodig is om die proses van stadsoorgang in die praktyk te beplan en te implementeer, en kan aangepas word vir unieke kontekste en behoeftes van verskeie stede.

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List of Publications

Geldenhuys, H.J., Brent, A.C. and de Kock, I.H. (2020). Managing urban infrastructure transitions for smart sustainable cities. *IAMOT 2020: Towards the digital world and industry X.0*. (pp. 546-560). Cairo, Egypt.

Geldenhuys, H.J., Brent, A.C. and de Kock, I.H. (2018). Literature review for infrastructure transition management towards Smart Sustainable Cities. *2018 IEEE International Systems Engineering Symposium (ISSE)*. (pp. 1-7). Rome, Italy.

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"I can do all things through Christ which strengtheneth me."
Philippians 4:13, KJV

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Dedication

This thesis is dedicated to my wife, Joanie. Thank you for our wonderful time together as married students.

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Toewyding

Hierdie tesis word opgedra aan my vrou Joanie en die ongelooflike tyd as getroude studente saam.

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Nomenclature

Variables

kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
TWh	Terawatt-hour

Abbreviations

AI	Artificial intelligence
ANNs	Artificial neural networks
ASCIMER	Assessing smart cities in the Mediterranean Region
AV	Autonomous vehicles
BC	Blockchain
BMI	Body mass index
BSI	British Standards Institution
CAPEX	Capital expenditures
CAS	Complex adaptive systems
CAS	Conventional activated sludge
CBA	Cost benefit analysis
CCTV	Closed-circuit television
CO_2	Carbon dioxide
CPS	Cybernetic physical systems
CREA	Centre for Research on Energy and Clean Air
CVO	Composite virtual object
CVOL	Composite virtual object layer
DL	Deep learning
DLT	Distributed ledger technology
DMC	Domestic material consumption
DMI	Domestic material input
ESs	Ecosystem services

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EIBURS	European Investment Bank (EIB) University Research Sponsorship Programme
EU	European Union
EV	Electric vehicle
FEI	Financial and economic index
GDP	Gross domestic product
GeoICT	Geographic information and communication technologies
ICT	Information and communication technology
IEA	International energy agency
IFC	International Finance Corporation
IoT	Internet of things
IPF	Infrastructure Prioritisation Framework
IPMP	Infrastructure Programme Management Plan
IPP	Independent power producers
IT	Information technology
ITS	Intelligent transportation systems
ITU	International Telecommunications Union
KPI	Key performance indicator
LBS	Location-based services
LCOE	levelised cost of electricity
LocBigData	location-based big data
MFA	Material flow analysis
ML	Machine learning
MLP	Multi-level perspective
NAS	Net addition to stocks
NDP	Net domestic product
NERC	Nigerian Electricity Regulatory Commission
NGO	Non-profit organization
NREL	National Renewable Energy Laboratory
P2P	Peer-to-peer
PCA	Principal component analysis
PFI	Private financing initiatives
PPP	Public-private partnerships
RCEW	Rand Central Electric Works Ltd.
REIPPP	Renewable Energy Independent Power

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	Producer's Programme
RFID	Radio-frequency identification
SAFE	Sustainable assessment by fuzzy evaluation
SL	Service layer
SM	Security management
SNS	Social network service
SOA	Service-oriented architecture
SSC	Smart sustainable city
SSCDI	Smart sustainable cities development index
SSHC	Sustainable smart healthy cities
SSUIT	Smart sustainable urban infrastructure transitioning framework
SUT	Sustainable urban transformation
TA	Transition analysis
UAE	United Arab Emirates
UI	User interface
UK	United Kingdom
UN	United Nations
UPD	Urban population density
UPM	Universidad Politecnica de Madrid
USD	United States Dollar
3D	Three-dimentional
VFP	Victoria Falls Power Company
VOL	Virtual object layer
VR	Virtual reality
WSN	Wireless sensor networks
WWTP	Wastewater treatment plants

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Chapter 1

Definition of the Research

1.1 Background

The current global population for 2022 stands at 8 billion UN-DESA (2022). Currently, rapid urbanisation exceedingly challenges society and the infrastructure supporting it. Urban populations are increasing as millions of people are looking for better opportunities and livelihoods in cities (Zhang, 2016; Das and Angadi, 2021).

The rate of world urbanisation is more than 50 per cent faster than the rate of global population growth (UN-DESA, 2019*a*,*b*). Urban population grew from 0.75 billion in 1950 to 4.30 billion in 2019, more than five times the initial size. During this time urban populations grew by 2.56 per cent annually compared to the global population growing at 1.62 per cent (UN-DESA, 2019*b*,*a*). Urbanised populations increased from representing 30 per cent of the total global population in 1950 to 56 per cent in 2019 and are predicted to grow to 68 per cent by 2050 (UN-DESA, 2019*b*).

Urbanisation has had an immense effect on how people live and work (Wann-Ming, 2019; Zhang, 2016) and brought significant challenges for the systems and infrastructure supporting this kind of life (Snieška and Zykiene, 2014). Today world cities are challenged by population growth, urban sprawl, resource shortages, air pollution, public safety, traffic congestion, and many other problems (Del Esposte *et al.*, 2019; Wann-Ming, 2019). These urban problems are commonly referred to as "urban illnesses" (Wann-Ming, 2019). According to Litman and Burwell (2006), sustainable development in cities, in comparison to the human body, is equivalent to taking preventative medicine to help sustain health and wellness.

Cities are complex evolving systems (Sorensen and Brenner, 2021). However massive resource consumption and waste flows, exceeding the carrying capacity of the city, are some of the reasons why cities are unsustainable (Chofre *et al.*, 2018; Agudelo-Vera *et al.*, 2011; Batty, 2008). A typical example from history is the Easter Island case where unsustainable development led to

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the fall of an entire civilisation. The resources that sustain human life are limited and should therefore be managed strategically (Chofre *et al.*, 2018; Diamond, 2005; Ponting, 2007; Agudelo-Vera *et al.*, 2011).

Sustainable development was first conceived as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (Brundtland, 1987). In Figure 1.1 sustainable development is illustrated as an integrated balance of social, environmental, and economic aspects for sustained human wellbeing (Cibulka and Giljum, 2020; Litman and Burwell, 2006). From the principles of sustainable development and escalating urbanisation challenges, the concept of sustainable cities emerged (Lee *et al.*, 2021; Perlman and Sheehan, 2007).

1.1.1 Sustainable cities

Sustainable cities typically focus on more efficient resource management and sustainability impacts within the administrative boundaries of the city (Ruan *et al.*, 2020). These two sustainability focuses only partially address issues related to sustainable urban development. Very few cities, if any, are truly sustainable (Höjer and Wangel, 2015). In Pilipczuk (2021) it is stated that for sustainable development to be achieved in a city, a level of environmental balance needs to be managed between the physical space and the city occupants. Historically, for a city to support the life of its citizens, its resources were extracted from a hinterland adjacent to the city where its

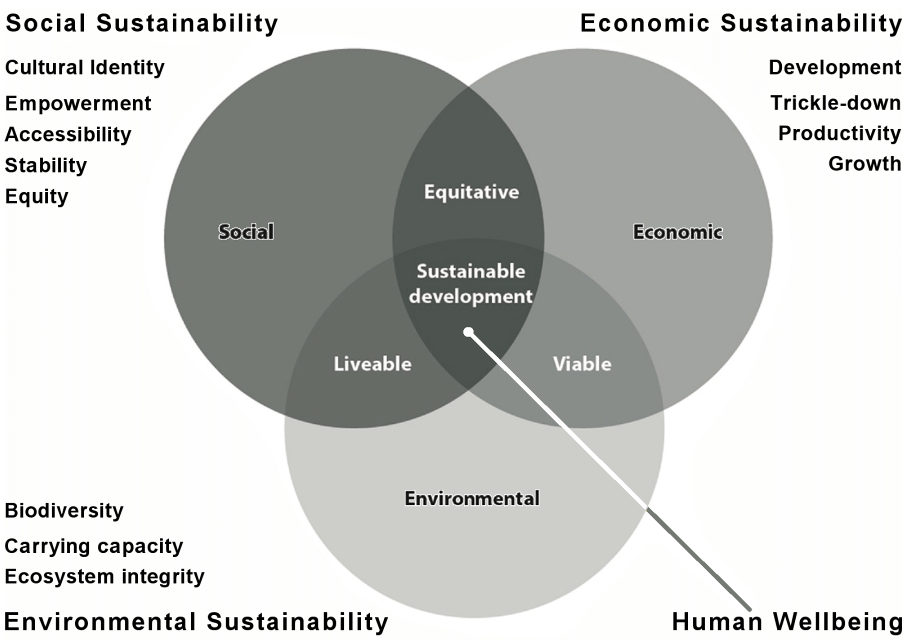

Figure 1.1: Sustainable development illustrated as a balance between social, environmental, and economic aspects (Geldenhuys *et al.*, 2018).

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waste was also disseminated (Höjer and Wangel, 2015). That might have been possible many years ago, but due to industrialisation, urbanisation, and globalisation, very few goods consumed in a city are produced within the city and its hinterland boundaries, but rather further away. This means that it is very hard to conclude what the environmental impact of a city is as its consumption is scattered across the world. This also means that urban metabolisms confined to the city boundaries cannot determine a city's true environmental impact (Höjer and Wangel, 2015).

Information and communication technologies (ICT) come in many forms (services, infrastructures, data analytics capabilities, and applications). Increasingly these technologies supply surpassing ways to solve a range of complex environmental challenges and emerging socio-economic concerns currently facing cities (Thornbush and Golubchikov, 2021). In many parts of the world ICT approaches are already enabling cities to remain sustainable and liveable for citizens (Bibri and Krogstie, 2017). Smart initiatives can be used to support and advance environmental sustainability (Thornbush and Golubchikov, 2021; Kramers *et al.*, 2014).

1.1.2 Smart cities

A smart city has digital components that collect and distribute data across relevant channels to a variety of actors (Bellone and Geropanta, 2019). This manifests as an intangible dimension wherein solutions are developed for challenges in the physical dimension of the city. These challenges generally relate to the organisation, management, and governance of the city, and could also relate to current global challenges like natural resource scarcity affecting cities (Morandi *et al.*, 2016; Komninos, 2014; Fusero, 2009). The intent with a smart city is to approach a city as a complex interconnected system-of-systems consisting of various networks, flows, information, and spaces. Activities and connections enable creative collaborations and collective efforts to address the needs within the city (Healey, 2006).

A smart city can be pictured as a multi-scale collection of instruments connected through multiple networks continuously providing data regarding the flow of materials, people, and decisions regarding the social and physical form of the city (Batty *et al.*, 2012; Ebin *et al.*, 2022). A city can only be considered a smart city if there are intelligent functions that are able to integrate and synthesise city data for some purpose or way of improving quality of life, efficiency, sustainability, and equity (Batty *et al.*, 2012; Boulos and Koh, 2021). Cities will become smarter as they gain the ability to automate routine functions serving buildings, individual persons and infrastructure systems enabling one to monitor, understand, analyse, and plan for a better city (Batty *et al.*, 2012; Yigitcanlar *et al.*, 2020). In Ebin *et al.* (2022) it is stated that the whole process of constructing a city and transforming it into an innovative and smart city is reliant on how people's quality of life and efficiency are improved.

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1.2 Smart sustainable cities

Technology is an integrated part of the social, environmental, and economic sub-systems (Musango and Brent, 2011). Both smart and sustainable cities present significant advantages, but also have their unique shortcomings (Yigitcanlar *et al.*, 2019). The field of sustainable cities is already relatively established and offers a wealth of practically grounded strategies, best practices and policy instruments; as well as sustainable urban models at various spatial levels (e.g., regional, metropolitan, city, community, neighbourhood and building level) (Bibri and Krogstie, 2017).

Smart cities hold great potential for advancing sustainability, despite their current implementation often lacking sustainability considerations. Robust and reliable data are increasingly recognised as fundamental means for sustainable development (Bibri, 2021; UN-DESA, 2015*b*). Integrating data approaches with sustainable development will strengthen sustainability by facilitating evidence-based decision-making. Real-time data is required to prepare and respond faster to economical, natural, political and health crises since most of the current developmental data have two to three years' time lag (Bibri, 2021; UN-DESA, 2015*b*).

An interconnectedness exists between the goals of smart and sustainable cities and an opportunity to incorporate both smart and sustainable city approaches. This could draw upon their multiple benefits and abilities to complement and compensate each other's shortcomings (Yigitcanlar *et al.*, 2019; Ahvenniemi *et al.*, 2017; Bifulco *et al.*, 2016). In order to approach such an amalgamation, it is necessary to understand these strengths and weaknesses. Key discrepancies that are identified between smart and sustainable cities are as follows:

- Sustainable cities are design-orientated (focussed on infrastructure and urban metabolism) but overlook other urban domains where smart solutions can have high influence towards sustainable development (Ahvenniemi *et al.*, 2017).
- Smart cities focus on advanced ICT and solution efficiency but lack design considerations and sustainability contributions (Ahvenniemi *et al.*, 2017).
- Sustainable cities need to incorporate their informational landscapes as a leverage, while smart cities must leverage their physical landscapes towards sustainability (Bibri and Krogstie, 2017).
- There is a lack of understanding regarding the interconnection of the concepts and objectives between smart and sustainable cities (Bifulco *et al.*, 2016).

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According to Jacobs (1961) the most ideal cities are those cities that are open to creative inputs and foster sustainable development. Cities can strive towards this insight by embracing both smart approaches and sustainable development (Strelkova *et al.*, 2020). This corresponds to the concept of a smart sustainable city described by Höjer and Wangel (2015). Figure 1.2 was developed based on Höjer and Wangel (2015)'s theory and the interaction of the three domains (urban development, smart technology (ICT) and sustainable development). Hereby it must be understood that cities can be sustainable without the implementation of smart technology. Smart technology can be implemented in cities without any contribution to sustainability, and sustainable development can utilise smart technology in other contexts than urban planning. But for an entity to be classified as a smart sustainable city (SSC) it must fall within all three domains.

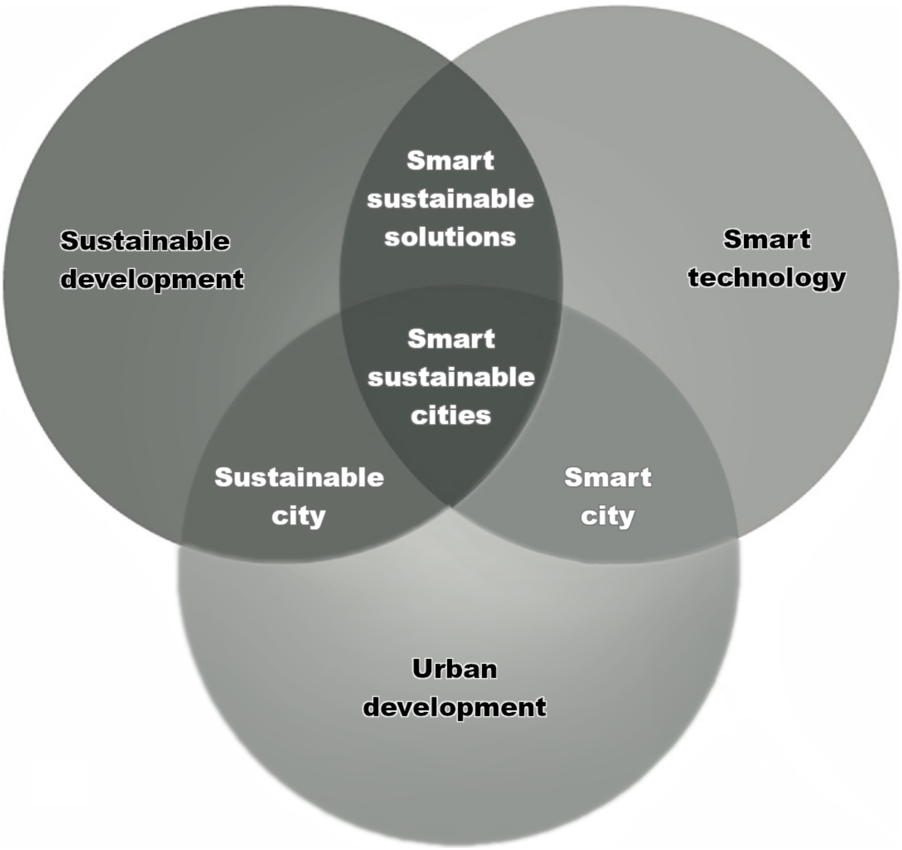

Figure 1.2: The origins of the smart sustainable city concept.

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A smart sustainable city can be defined as a city that (Höjer and Wangel, 2015):

- meets the needs of its current population
- without negatively impacting the ability of future generations or other people to meet their needs, thereby not exceeding the local or global environmental limitations, and
- incorporates, and effectively utilises, ICT technologies.

The challenge, of course, is transitioning cities as we currently know them, to become smart sustainable cities (Hodson *et al.*, 2012*a*; Sorensen and Brenner, 2021).

1.3 Research focus

Cities are of increasing importance in the regional, national, and global economy (Ranđelović *et al.*, 2020; Snieška and Zykiene, 2014). According to Monstadt (2007), a city and region's economic, environmental, and social performance is directly influenced by the critical infrastructure. A series of ecological, economic, institutional and population constraints have brought new challenges and put pressure on urban growth and the management of a city's critical infrastructure (Hodson and Marvin, 2010). Urban infrastructure networks form part of a larger system-of-systems in cities, which comprises of both social and technical components. For a city to address these challenges requires systemic changes of systems (e.g. transport, energy) referred to as *socio-technical transitions*, involving technology, infrastructure, policy, culture, and scientific knowledge (Elzen *et al.*, 2004). Transitions are complex long-term processes with various actors (for example industries, consumers, society, policy makers, researchers, and engineers) that develop, maintain and transform these components (Geels, 2011). The efficient functioning of a city's critical subsystems is very important to support future sustainable urban infrastructure development (Bulu, 2011). In this sense, smart ICT approaches provide efficiency, flexibility and real-time management on infrastructures and the resource flows within it (Dong *et al.*, 2017). It is evident in literature that urban infrastructure transitions are crucial for transitioning a city to both a smart city (British Standards Institution (BSI), 2014*b*,*a*) and a sustainable city (Dong *et al.*, 2017; Höjer and Wangel, 2015). This need for urban infrastructure transitioning transcends to smart sustainable cities, an amalgamation of both smart city and sustainable city aspects, as illustrated in Figure 1.2.

The interdisciplinary literature review conducted by Bibri and Krogstie (2017) demonstrates that research on the multi-disciplinary field of smart sustainable cities is still in the early stages (Umar, 2020). The available

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studies currently have a focus on forming a joint understanding and definition thereof to serve as foundation for further research that determines the required trajectory of smart sustainable urban development and planning.

Recent research in sustainable cities shows an emerging motive for accepting technology as a possible means in helping to achieve sustainability goals (Strelkova *et al.*, 2020; Shruti *et al.*, 2021). Furthermore, governments are slowly applying more pressure on infrastructure projects to also achieve these sustainability goals (Bellone *et al.*, 2022). In turn this might be part of the reason that recent research in smart cities have started to deliberate on the possibility of incorporating green engineering techniques with internet of things (IoT) in smart cities (Gupta and Vyas, 2022).

There is still very few research on the development of smart sustainable cities. The only research efforts that considered the development of a framework for smart sustainable cities are:

- A defining model of the components and aims of a smart sustainable city in Bibri and Krogstie (2020), and an assessment framework focused on the orientation from the field of big data analytics and context-aware computing in Bibri and Krogstie (2017);
- A city readiness roadmap in Ibrahim *et al.* (2018) and Ibrahim (2019) which both gives direction in terms of six main phases involved in urban transformation, but does not provide guidance on the implementation of such a project; and
- A citizen engagement model for designing and planning smart sustainable cities in Al-Nasrawi (2021), focusing on the existing pathways through which citizens can influence the planning process.

Ryan (2017) greatly emphasises the need for systems and management perspectives on sustainable infrastructure transitioning. There is currently an absence of socio-technical transitioning frameworks for smart sustainable cities.

1.4 Research problem and objectives

Smart sustainable cities are an emerging field in response to the current and future challenges facing cities. This requires systemic change of infrastructure through socio-technical transitioning. The available research does not provide a framework to guide the planning, management, implementation and hand-over of large-scale infrastructure transition projects or long-term intervention programs with the aim to change an existing city into a smart sustainable city.

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The research aim is therefore to develop a conceptual framework to guide and manage smart sustainable city transitions and entails the following sub-objectives:

1. Develop an understanding of the concept, models and supporting themes related to smart sustainable cities.
2. Study existing knowledge and approaches available regarding city transitioning and the role of infrastructure in this process and how it can be incorporated and adapted with regards to the development of a holistic framework.
3. Verify and validate the developed framework.

1.5 Research approach

The main research objective, supported by the three sub-objectives, is approached in three phases as shown in Figure 1.3. In the first phase the foundational themes, principles and existing knowledge related to the research problem is explored and investigated. Phase two entails adapting, integrating, and synthesizing existing knowledge, approaches and frameworks in the process to create a framework to guide the planning, management and implementation of smart sustainable city transitions. To ensure the appropriateness of the framework it is verified, validated, and adapted according to feedback obtained in phase three.

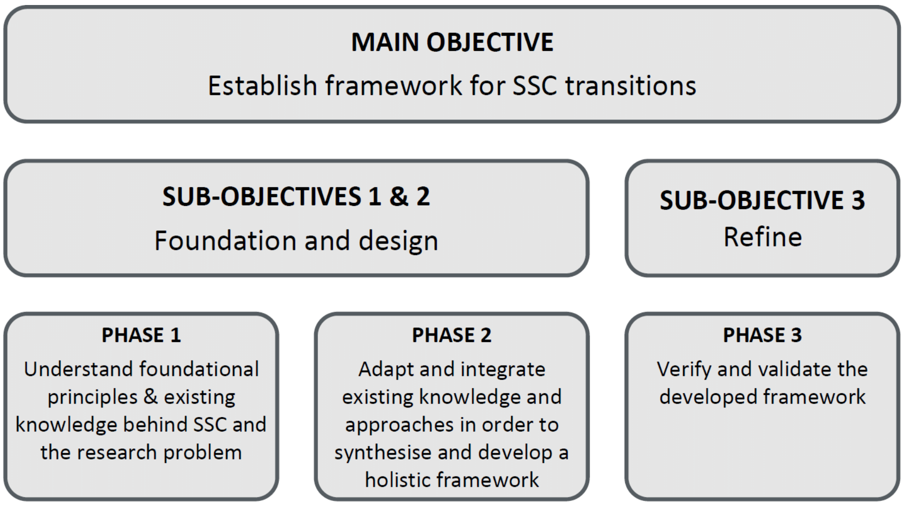

Figure 1.3: Approach followed during the research.

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1.6 Scope and limitations

Urban infrastructure transitions are vast in scale and unfold over numerous years and decades. The complexity of city systems entails those interventions have cascading effects that evolve and are difficult to predict. It would not be viable in this study to fully implement the framework and evaluate its long-term effects. The research consequently delivers a conceptual framework that is generic for the transitioning of an existing city towards a smart sustainable city. It is important to note that all cities are unique and have different requirements. It is advised that the framework be used as a guide and can be adjusted to fit each city's specific context and needs.

The focus of the framework is on managerial and strategic aspects of transitioning a city and not refining theory, indicators or assessment tools in smart cities, sustainable cities and smart sustainable cities. Although there are various types of urban development, the framework will be limited to addressing smart city, sustainable city and smart sustainable city challenges, background, theory and cases.

1.7 Brief overview of chapters

In Figure 1.4 an overview of the chapters of the thesis is provided. In the second chapter of the thesis, the research approach and methodology is explained. Contextualisation of cities in transition and smart sustainable cities is presented in the third chapter. The chapter consists of a review on the nature of the available literature, followed by a conceptual literature review, wherein the existing approaches and theory regarding smart sustainable cities, urban transitioning and complex systems thinking is discussed and investigated to discern how it can contribute to the development of a holistic

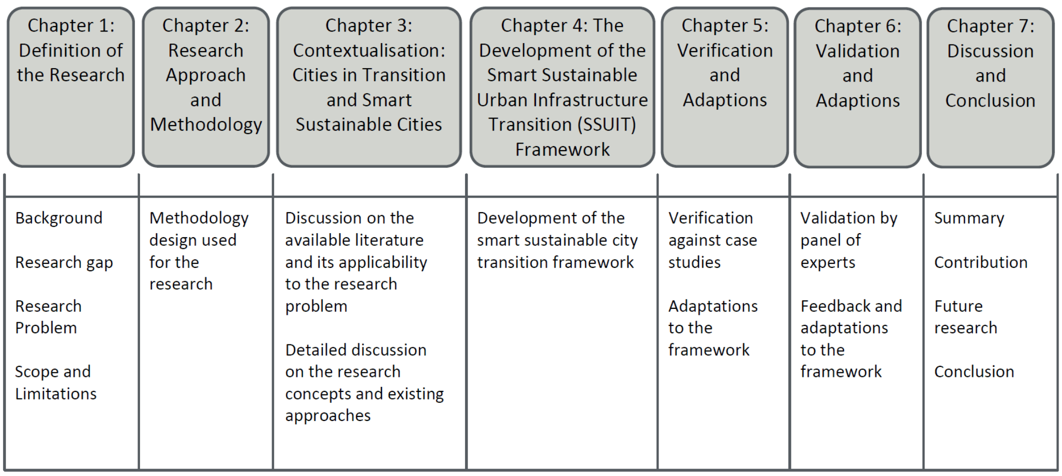

Figure 1.4: Brief overview of chapters.

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framework. In chapter four, the development of the smart sustainable urban infrastructure transition (SSUIT) framework is presented. Chapter five presents the verification through case studies and the resulting adaptations to the SSUIT framework. Chapter six presents the validation by experts, the feedback, and adaptations to ensure the suitability of the SSUIT framework. In chapter seven, the summary of the research along with future research suggestions and the research conclusion is provided.

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Chapter 2

Research Approach and Methodology

This chapter explains the research approach and methodology followed to conduct the research, which entail sub-objectives one, two and three. In Figure 2.1 sub-objective one and two entails the foundation and design of the framework which consists of two phases. Phase one requires understanding the foundational principles and existing knowledge behind smart sustainable cities and the research problem. Phase two involves adapting and integrating existing knowledge and approaches to synthesise and develop a holistic framework. Phase three falls under sub-objective three concerning the verification and validation of the developed framework.

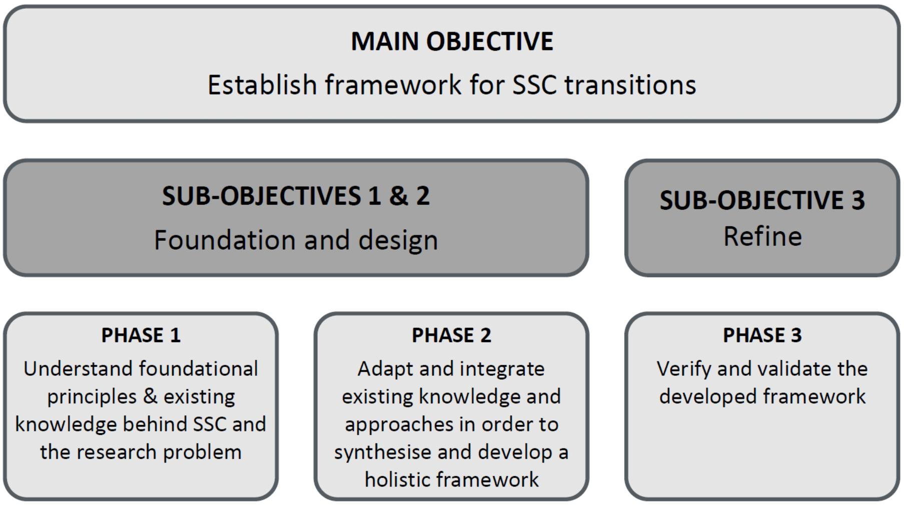

Figure 2.1: Approach followed during the research.

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2.1 Research approach

Knowledge regarding smart sustainable cities is scarce as it is a very young concept. Literature that relates to the components; foundational concepts from which smart sustainable cities developed; approaches and aspects from various disciplines are available yet distributed with limited interconnections made between them. The nature of available literature is investigated in Chapter 3. An exploratory research approach (Abduh *et al.*, 2018; Bryman *et al.*, 2014) was chosen for this study due to the limited direct smart sustainable city literature as well as the diverse, distributed literature which is somewhat indirect/disconnected in its relation to smart sustainable cities. Fortunately, there is an adequate selection of literature to devise relevant and important connections and synthesise a framework to guide urban infrastructure transitioning towards smart sustainable cities. This is because urban infrastructure change, a focal domain of the research question, entails complex dynamics and is comprised of various nested systems-of-systems. Therefore, the systemic interdependencies and interconnections can be identified and assembled to gain a holistic and detailed perspective of a smart sustainable infrastructure transition process.

2.2 Scoping and planning

The following questions and sub-questions helps to better understand the focus of the research and identify the most applicable body of knowledge useful for developing a transition framework for smart sustainable cities.

- What is the available literature on smart sustainable city transitions and what is the knowledge gap?
- What are smart sustainable cities?
  - What is the definition of a smart, sustainable, and smart sustainable city?
  - What are the main purposes or goals of these three types of cities?
  - What are the key characteristics and components of these respective city types?
- How can we better understand the research question from a systems perspective?
  - What are the main schools of thought regarding systems theory?
  - How are cities conceptualised in terms of systems theory?
  - How are transitions understood and guided by systems thinking?

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- How can an existing city be transformed to a smart sustainable city?
  - What existing approaches or frameworks are used to plan and guide the development and transitions of cities?
  - What are the requirements to develop a transition framework?

2.3 Conceptual framework development

The process that was followed to develop the framework is illustrated in Figure 2.2. A systematic literature review was conducted which explored the existing knowledge landscape regarding smart sustainable cities and urban transitioning. The findings were used to determine the direction of the research, which is to develop a holistic framework to guide urban planners and city councils with the planning, development, and management of smart sustainable city infrastructure transitions. Important themes, such as the origins, characteristics, benefits, challenges, perspectives, and evaluation of smart sustainable cities were investigated in a conceptual literature review. Complex systems theory was explored, since a complex adaptive systems perspective (Deljoo and Janssen, 2013) was identified as a meaningful way to conceptualise and understand smart sustainable cities and the associated dynamics. Existing approaches and methods regarding city and infrastructure transitioning were also reviewed to draw understanding, requirements, and guidelines useful to the design of the framework. The conceptual framework is established through the synthesis of approaches, theory and insight gathered from literature to form a unique solution for the planning, development, and management of smart sustainable infrastructure transitions.

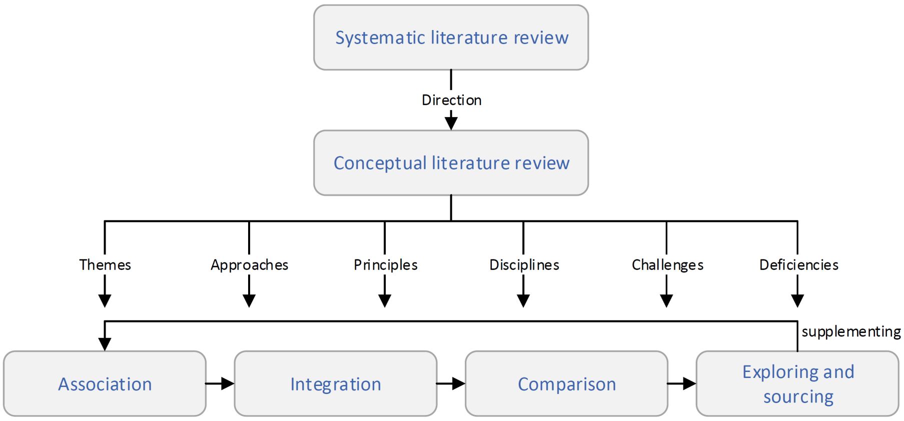

Figure 2.2: Research process followed to develop the framework.

The process followed to develop the framework was an iterative process that entailed four components. The themes, approaches, principles, perspectives from multiple disciplines, challenges and deficiencies regarding

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existing methods and implementations, were reviewed. Similarities and relations became observable between various parts of information and thereby associations and linkages identified were used to group information and aspects. Secondly, these aspects and information were integrated into a draft framework having been placed relative to the guidelines, linkages and relations to each other and their purpose within the whole of the framework. Thereafter other frameworks (Fu and Zhang, 2017; Kivilä *et al.*, 2017; Peprah *et al.*, 2019; Malekpour *et al.*, 2017; Cooper *et al.*, 2009; Ibrahim *et al.*, 2018; Boyko *et al.*, 2005; Haasnoot *et al.*, 2013; Goodman and Hastak, 2015; Gibson Jr *et al.*, 1995; Akande *et al.*, 2019; Boorsma, 2017; Harris *et al.*, 2013; Mendizabal *et al.*, 2018; Göpfert *et al.*, 2019) were studied and compared with the draft framework to determine whether there are important components or aspects that are relevant, yet lacking. Where necessary the needed information was sourced through an exploratory process. The information found was then adapted and added to the framework. These four components of the framework's development were repeated until there were no further amendments.

The existing approaches, models, roadmaps, and frameworks investigated are diverse as they use different theoretical lenses, focal points, contexts and applications. The existing approaches and frameworks also differ regarding the levels at which they are focussed, because urban transformations entail multidisciplinary components and processes, various dimensions and consist of multiple nested levels. The collective knowledge and insights drawn from the various approaches and frameworks are sufficient to guide the construction of a smart sustainable city transitioning framework.

2.4 Framework refinement

Due to the long-time frames that urban transitions span and the limited duration of this study, it is not practical to refine the framework by implementation. This limitation was also encountered by other researchers regarding the smart sustainable city's transformation roadmap in Ibrahim *et al.* (2018).

The approach followed to refine the conceptual framework (which was developed from literature) is shown in Figure 2.3. It entails two processes, namely verification followed by validation.

2.4.1 Verification approach

The verification of the developed framework was done against documented reflections and case studies of past and existing city projects. This was done to test whether the developed framework comprises of the necessary components and construction for its intended purpose it was designed for. This also submits the framework to a comparison against real-world occurrences

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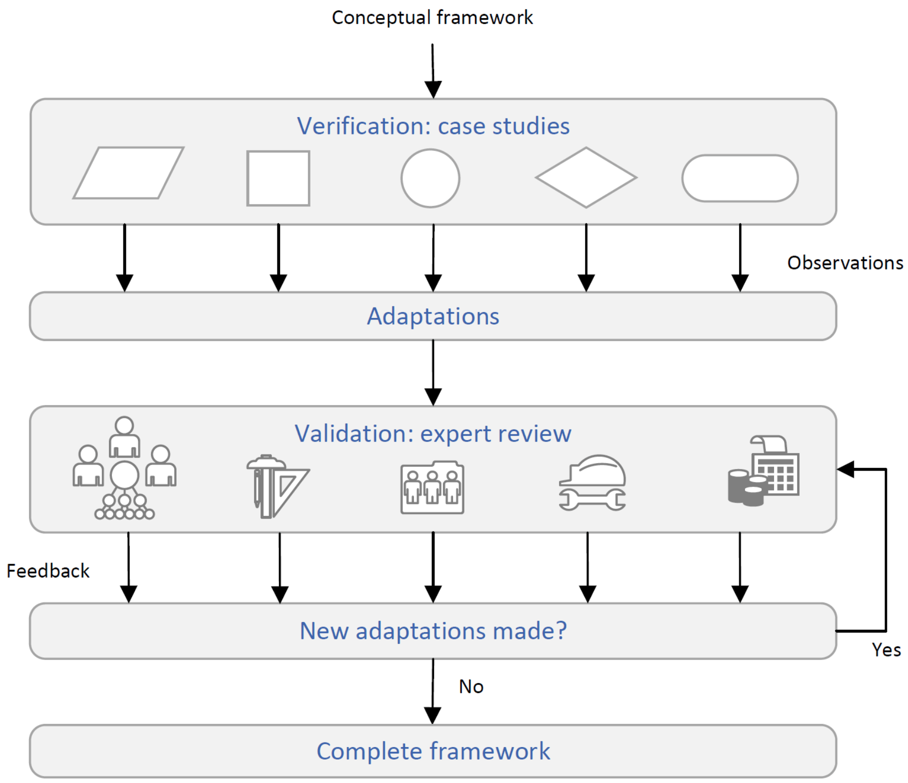

Figure 2.3: Approach designed to refine the conceptual framework through verification and validation.

to identify necessary enhancements that were overlooked or absent in the literature available. The selection of case studies that were used, are of a heterogeneous nature, symbolised by the different shapes in the verification block in Figure 2.3. Using diverse examples can lead to a more comprehensive verification, and test the framework on unique cases, as it is in practice - each city and project has unique properties.

2.4.2 Validation process

For models that are difficult to validate on actual case studies, the Delphi approach is extensively employed in social and urban studies (Okafor *et al.*, 2021; Perveen *et al.*, 2017; Muse *et al.*, 2020; Chan and Lee, 2019; Chowdhury and Dhawan, 2017), including smart sustainable cities (Ibrahim, 2019). Accordingly, a Delphi approach was chosen to be used in creating a data gathering instrument for the purpose of validating the framework. This approach is widely used to validate conceptual frameworks and models (Abduh *et al.*, 2018; Ibrahim, 2019).

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2.5 Verification by case studies

2.5.1 Case studies selection

A search was done in Google and Google Scholar with the selection setting to include Stellenbosch University access results. The search terms were: "smart city", "sustainable city", "lessons learned", "best practise", "challenges", "barriers", "transition", "transformation", "urban change", "case studies", "cases", "project".

Case studies and documents were selected according to relevancy from the search results. After which they were opened and scanned to evaluate their quality, authors, focus, context, and design. The main documents selected were evaluated by reviewing important aspects regarding their relevance to the study. Factors that were investigated were:

- Publishers and authors context, expertise and motive.
- Focus of the case study (barriers, success factors, implementation challenges, best practise and understanding context).
- Feasibility of use within the scope of the study (time limitations, completeness achievable, quality of insights achievable relative to intensity of effort and time to extract data).
- Information usefulness and quality.
- Findings and conclusions.
- Structure of the information.
- Richness and clarity of information.

The retrieved sources were then screened and sorted into groups based on their adequacy. The case studies that stood out as main bases of information were prioritised, and the rest were kept for the purpose of fact checking and inconsistencies detection, as a means of triangulation of information between the various sources (research articles, industry reports, city information, observations, expert opinions etc.).

It was observed that there weren't conclusive distinctions on the smart or sustainable city status of cities. Most have features of both urban forms, due to the complimentary benefits or strategic gains. *Copenhagen example excerpts, sustainable for climate goals, smart motivated for its benefits for sustainability.

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2.6 Expert review using Delphi technique

The validation process followed for this research is illustrated in Figure 2.4. The process in Figure 2.4 kicks off by setting up the open- and closed-ended questions for the validation of the research. Thereafter the experts that will participate in the validation need to be selected and contacted to see if they are willing to participate. When contacting an expert, the aim and scope of the validation activity is briefly described along with what is required of the expert, such as how much time the study will require. Not all experts will be able to make room in their schedules for the validation and therefore this process is repeated until there is sufficient participants for the validation.

2.6.1 Participant selection

The participants for the expert panel are selected on a basis of their experience, and the collective diversity of expertise relevant to the framework and urban transition process. Two options were considered, the first being to use an international conference to interact and invite participants to review the conceptual framework. The latter to invite industry experts by using personal networks to find appropriate and willing candidates. The contacts from the conference did not consist of adequate participants due to most being inexperienced or of a field that is not relevant enough to the research problem. Some of the experts considered for the study were not available to be able to take part.

As transitioning a city towards a smart sustainable city is multi-disciplinary oriented (Bibri and Krogstie, 2017), therefore experts were chosen accordingly to represent a wide variety of fields collectively in stead of a single niche competency. Participants were identified according to the skill contribution they can fulfill in the group. A group of five multi-disciplinary experts participated in the validation process for the proposed novel framework. The selection of experts were a result of their availability to participate in the validation, and contribution of industry experience in terms of years and depth of exposure to diverse projects relevant to smart or sustainable infrastructure development.

During the validation in Chapter 6, each participant was asked to rate their level of skill according to eighteen domains related to smart sustainable city transitions. These participant ratings can be found in Figures 6.2 to Figures 6.6 in Chapter 6. Figure 2.5 is a representation of the skill-set levels of the group collectively by considering the highest skilled candidate level present per domain. This gives a representation of the strengths and weaker domains in the group. From the eighteen domains listed in Figure 2.5, all of the domains were at least represented by a skilled level in the group of which twelve of the domains were represented by highly skilled participants.

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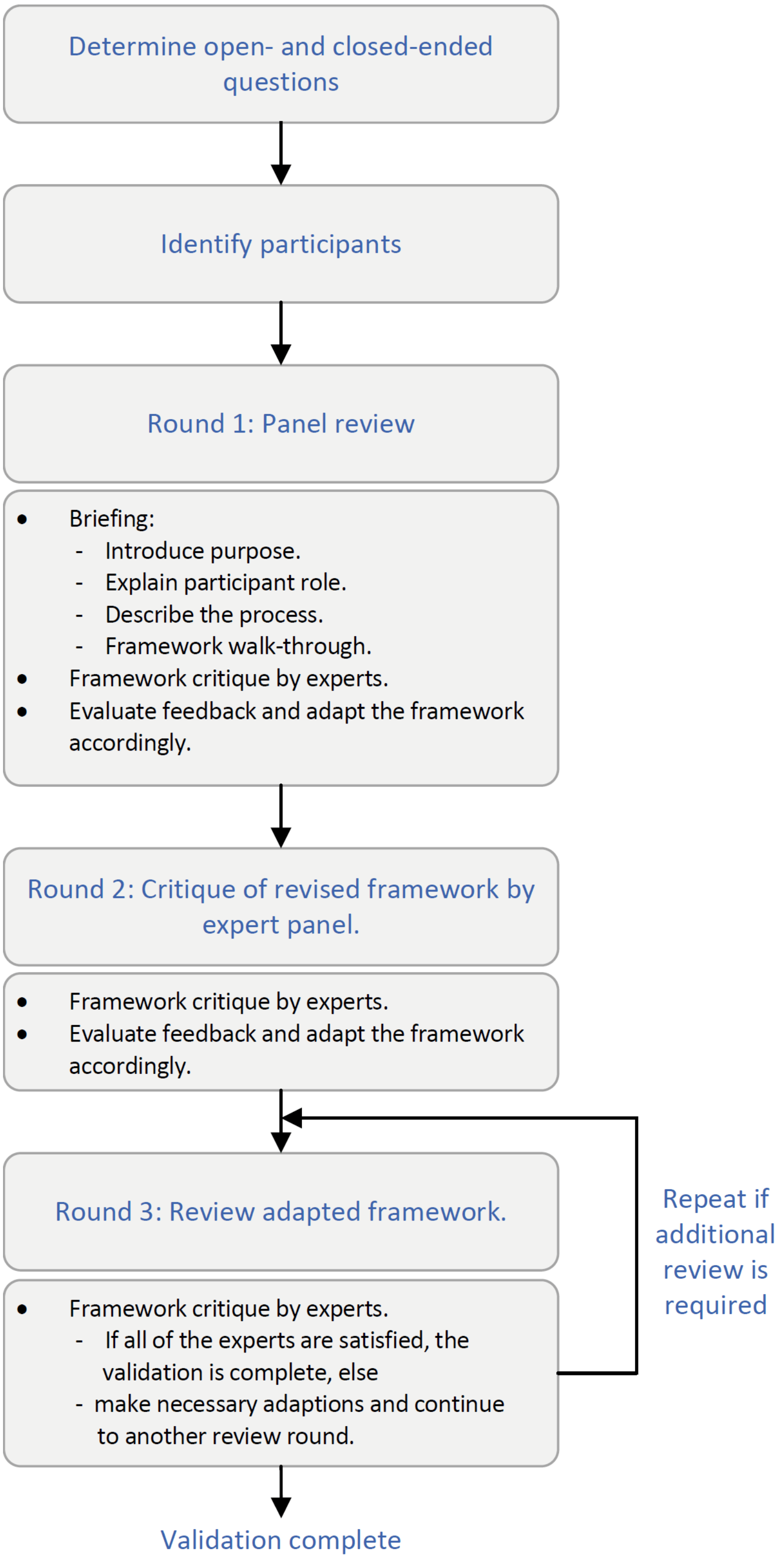

Figure 2.4: The validation process followed using the Delphi technique.

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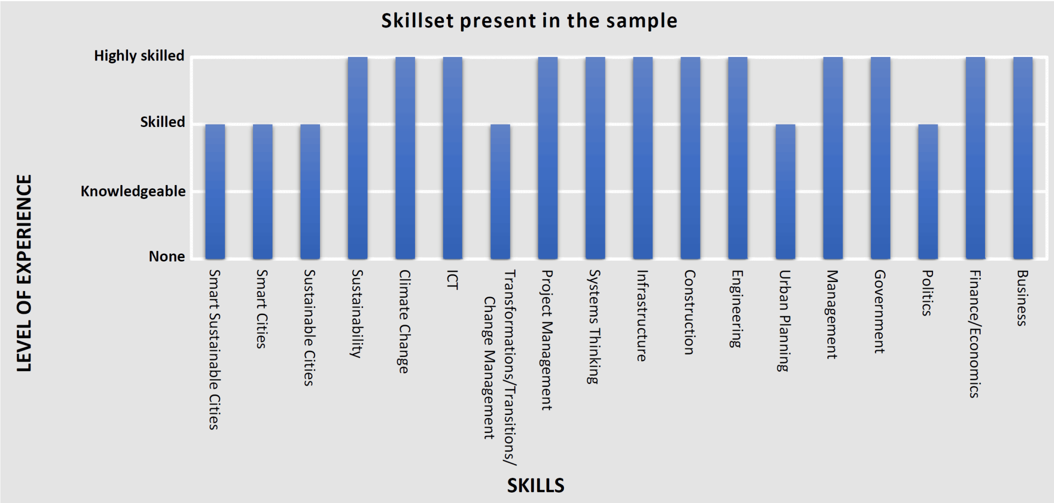

Figure 2.5: The combined skillset of the five validation participants.

Figure 3.9 in Chapter 3 represents the subject fields of each of the papers selected in the literature review. In Figure 3.9 it can be noted that the literature available is most dominant in urban studies, ICT and sustainability, of which are lower represented by the skillsets of the participants. Figure 3.8 in Chapter 3 show that policy development is the strongest aim of the literature selection, and research funded by governmental organisations were most dominant in number as illustrated in Figure 3.7. Some of the scarcer fields shown in Figure 3.9 for the available papers are well represented by the skillsets of the survey participants. The smart, sustainable and smart sustainable city skill levels were only represented by skilled levels in the group, this correlates to the observation from that there are not many experts in practice in these fields, and none that were available at the time to participate on this study.

Finally, although only five participants was used for the validation, significant number of years experience were present. The total years of experience present in the group was 119 years, with an average of 24 years per participant with the two highest being 39 and 38 years. The group is not only diversely represented by the different years of experience brackets, but each participant also offer an unique viewpoint based on their background and field of work.

2.6.2 Delphi technique

During Round 1 of the validation, the five participating experts were asked to complete open-ended questions about their specific experience in practice. Open-ended questions create the opportunity for the facilitator to gain information which could have been absent or overlooked as with closed-ended questions on topics such as the framework stages or steps and expert experience. Closed-ended questions were also set to gain a

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better insight on the specific knowledge each participating expert has in each of the eighteen selected domains relating to the developed framework. These domains are: smart sustainable cities; smart cities; sustainable cities; sustainability; climate change; ICT (information and communication technology); transformations/transitions/change management; project management; systems thinking; infrastructure; construction; engineering; urban planning; management; government; politics; finance/economics; and business.

These closed-ended questions on the eighteen domains made use of a 4-point Likert scale. A 5-point Likert scale offers the benefit of providing respondents with a neutral option, but a 4-point scale was chosen to avoid respondents from clustering their choices in the centre or neutral group (McMillan and Schumacher, 2014) For each domain the participant had the following 4 possible options to choose from:

- 1 = 'None' (no prior knowledge on the subject matter),
- 2 = 'Knowledgeable' (knowledgeable on the subject matter),
- 3 = 'Skilled' (skilled on the subject matter), and
- 4 = 'Highly skilled' (highly skilled on the matter).

The open-ended questions also provided a chance for each expert to elaborate on closed ended questions and provide further details on the number of years experience they have in certain fields.

2.7 Conclusion

This chapter explained the process followed to conduct this study with the aim of developing a framework that guides urban infrastructure transitioning of existing cities to become smart sustainable cities. A systematic literature review is followed by a conceptual literature review to understand various facets of the research problem. The framework is developed by synthesising existing knowledge, approaches, frameworks, and insights gained from relevant literature. The framework is then verified against case studies to ensure it contains the necessary components. The validation approach entails an expert review of the framework by means of a questionnaire and gathering their opinions regarding the design of the framework. Adaptations are made to the framework until the experts are satisfied with the result. This is done to ensure the framework is adequate for its intended use. Table 2.1 summarises the main research activities and characteristics of the data gathered for the study. In the next chapter the framework design is presented and discussed.

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Table 2.1: Characteristics of the research activities.

Research phase	Literature (synthesis)	Verification (components)	Validation (user context)
Domains	SSC, sustainable and smart	Smart and sustainable cases	Diverse industry experts (functional roles)
Source of data	Academic research	Real projects (consulting organisations, industry & city reports, R&D firms)	Delphi review rounds
Type of data	Peer-reviewed, mixed data	Secondary data	Primary data
Scope of data	Multi-disciplinary	Multiple cases & contexts	Multi-disciplinary

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Chapter 3

Contextualisation: Cities in Transition and Smart Sustainable Cities

During the first part of the literature review, a systematic literature review was conducted where important literature was sifted and short-listed to better understand and refine the knowledge gap to be addressed. A systematic review helps to ensure that all appropriate literature relating to the transitioning of cities to smart sustainable cities forms part of the literature study. The literature review focuses on the main research question: How can the process to transition a city to become a smart sustainable city be planned, implemented, and managed? This forms part of phase one, under sub-objectives one and two of the research, as illustrated in Figure 3.1.

The second part of the literature review consists of a conceptual literature discussion. During the conceptual literature discussion the first and second

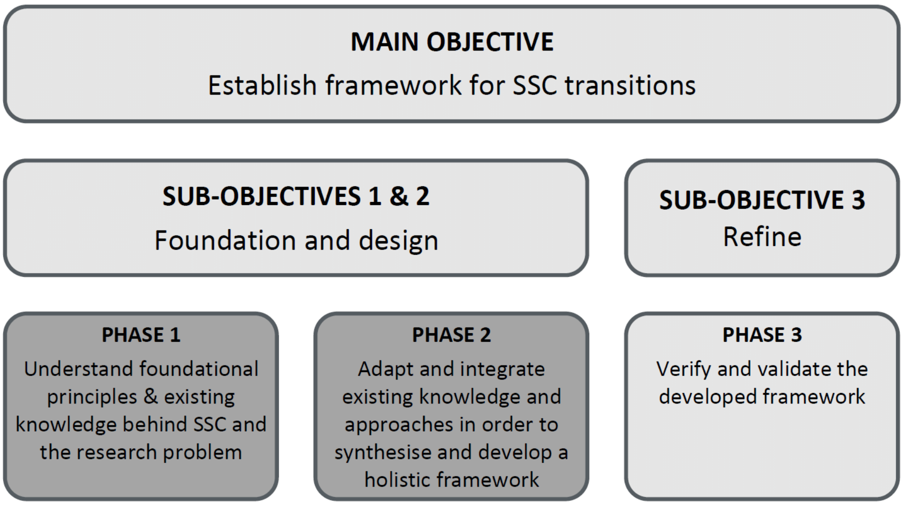

Figure 3.1: Approach followed during the research.

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sub-objectives on foundation and design are addressed as illustrated in Figure 3.1. Sub-objectives one and two are made up of two phases. In phase one, existing knowledge and the foundational principles behind the research problem and smart sustainable cities are examined. In phase two, the existing knowledge and approaches are integrated and adapted to develop a holistic smart sustainable city transformation framework.

3.1 Search and identification

Many sources were used for obtaining information throughout the thesis, with the primary source being Scopus due to its vast collection and relevancy of content. Scopus was used for the literature search. Snowballing was also allowed where literature cited by relevant articles pointed to potential articles that could be included in the collection. In 2020, Scopus' database included 5000 international publishers and almost 78 million items of which 40 percent was made up by the following publishers: Elsevier; Springer; Taylor & Francis; Wiley-Blackwell; Sage; Oxford University Press; Wolters Kluwer; Cambridge University Press; Emerald; Inderscience Publishers; Bentham Science; and IEEE (Scopus, 2020).

During the search and identification stage different concepts relating to the research topic were formulated into combinations of search strings using boolean operators 'AND', 'OR' and 'NOT' and proximity operators 'pre/n'. Scopus has accented character and lemmatisation functions that group accented and inflected forms of a word such as "City", "city" and "cities" to be analysed as a single term. Parentheses help to form compounded searches by grouping related or similar terms together. The proximity operator 'pre/n' was used to indicate that one term must be within 'n' terms from another. It is also worth noting that using the boolean operators 'AND' and 'AND NOT' as an argument to a proximity expression is not supported in Scopus.

In Figure 3.2 the identification stage consists of three independent search queries: n_1, n_2 and n_3 with their results updated in January 2020. From multiple search attempts over a period of two years these searches in Figure 3.2 proved to deliver the most relevant literature with regards to the research problem. Each of the queries, n_1 to n_3, delivered 58, 180 and 264 results respectively. These results were inspected by hand for duplicates and retracted articles and thereafter screened by title and abstract for relevance to the research topic. This delivered 100 articles that were regarded as very relevant and 112 articles that were regarded as good secondary literature. During the second screening of the relevant literature, only articles in English were included and accordingly books and chapters excluded to deliver a total of 90 papers. During the eligibility phase only 62 papers were found available in full text. From the twelve unavailable papers the only one that was directly related to smart sustainable cities was in Agrawal (2017). Agrawal (2017)

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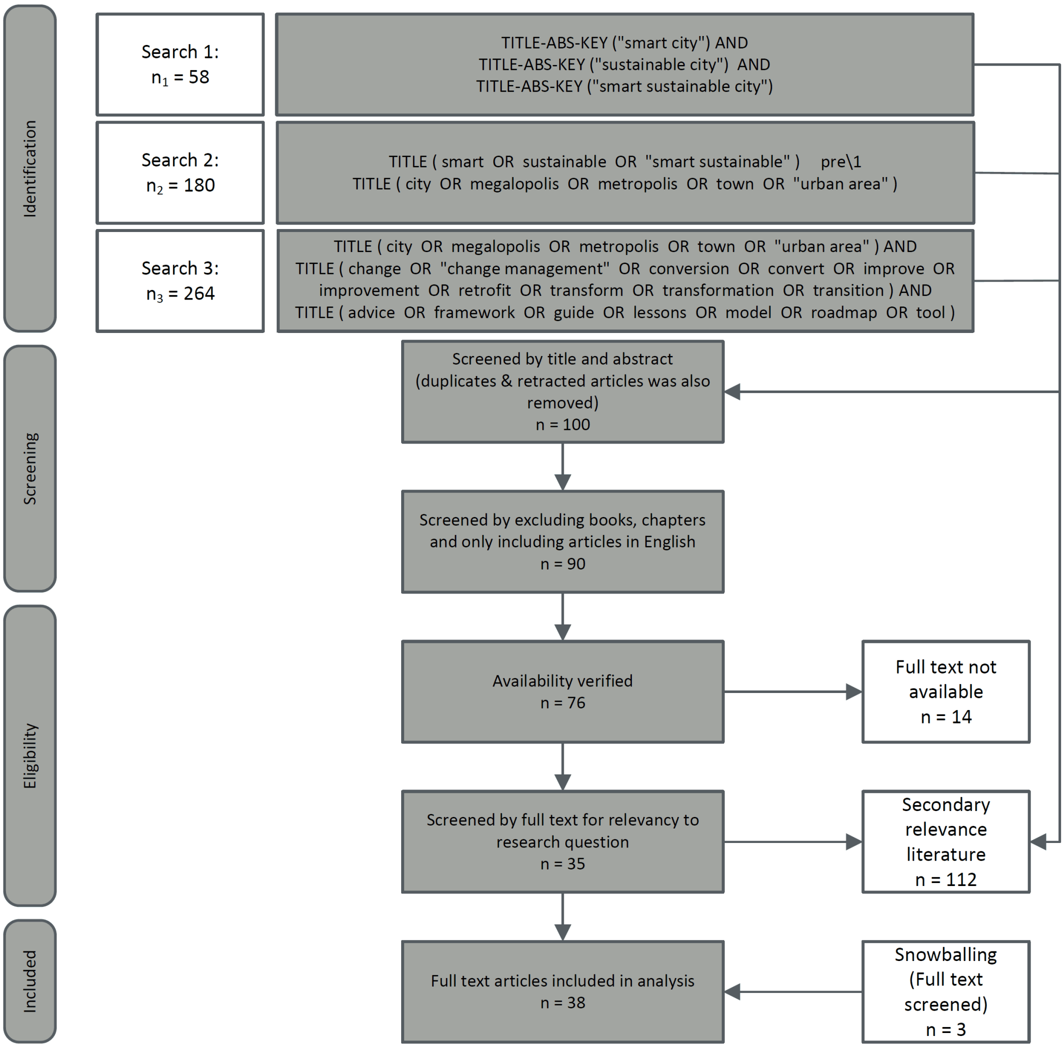

Figure 3.2: Systematic search process.

focused on a law and policy approach by studying Indian judiciary to help secure the rights of pedestrians for smart sustainable cities. During the next step in the eligibility phase, papers were screened by their full text to verify their relevancy to the research questions, leaving 35 relevant papers. While inspecting the papers the snowballing technique was also used to gain more literature. The snowballing technique entails discovering relevant literature that have cited or have been cited by a selected paper or by following up on a relevant source of publication to look for other possible papers. The papers identified with the snowballing technique were also screened in full text and delivered another 3 papers that were included to obtain a list of 38 papers.

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3.2 Nature of existing research

The thirty-eight papers that were identified in Figure 3.2 is the most relevant to the research problem. The broad characteristics of the literature selection were investigated to understand the composition and type of content available to address the research problem.

3.2.1 Geographic analysis

Geographic attributes of the literature are presented in Figure 3.3 and Figure 3.4. These figures show the authors' country of affiliation and the geographic area that was focused on by the studies in the literature selection respectively.

In Figure 3.3 it is observed that two thirds of the authors that produced the selected papers are affiliated with European universities and institutions. Researchers in the United Kingdom, Norway, Sweden, and the Netherlands make up the most prominent part of the representation. Other European countries represented include Finland, Germany, Switzerland, Italy, Portugal, Spain, Serbia, Latvia, Slovakia, and Hungary. Asian affiliation constitutes fourteen per cent of the research with contributors from Japan, Indonesia, Taiwan, and India including Russia. Sixteen per cent of the research is from the Arab states Lebanon, with the involvement of a co-author in the United Kingdom (UK), as well as researchers from Egypt, Saudi Arabia, and Bahrain. One Egyptian affiliate collaborated with Norway to identify failure and success factors from smart city and sustainable city examples in the United Arab Emirates (UAE), China and South Korea. South America, North America, and Africa each have the smallest representations at three per cent. A Brazilian study focused on smart sustainable city residence satisfaction evaluation, the North American study on smart sustainable city infrastructure resilience and the South African research on general urban transitioning from a complex adaptive systems perspective.

There is a slight correlation between the compositions of geographic affiliation of the researchers shown in Figure 3.3 and the geographic focus of the papers shown in Figure 3.4. However, forty-two per cent of the research does not focus on any specific country, but rather on definitions, concepts, generic models, tools, and frameworks related to smart sustainable cities. The rest of the literature is comprised of studies that incorporated data, case studies and surveys from existing cities to investigate hypotheses, identify trends and drivers, challenges, success factors, to build theory and in some cases with the intent to reflect on past projects, evaluate current interventions and inform future planned projects. Almost a quarter of the studies relate to Europe, focussing on the UK, Netherlands, Norway, Sweden, Italy, Germany, Spain, Serbia, Romania, Latvia, Slovakia and most often Europe in general. Thirteen per cent of the studies looked to Asia (Japan, Indonesia, Taiwan, South Korea,

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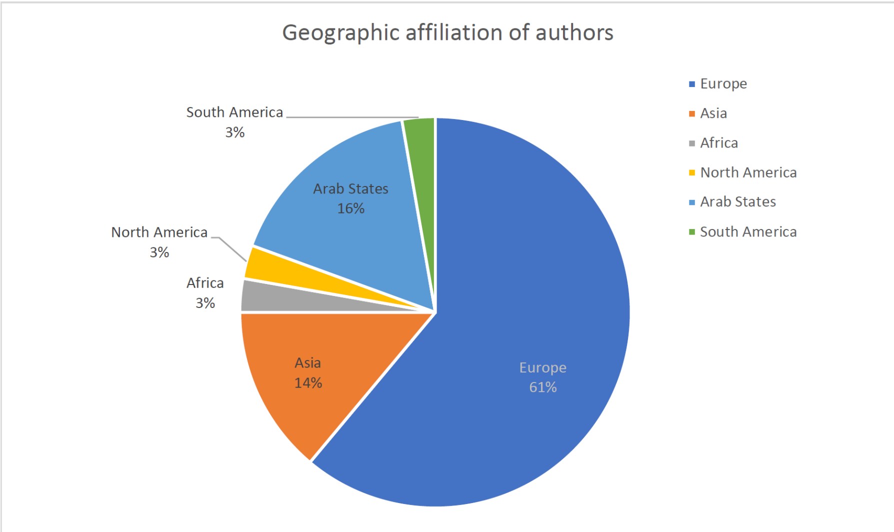
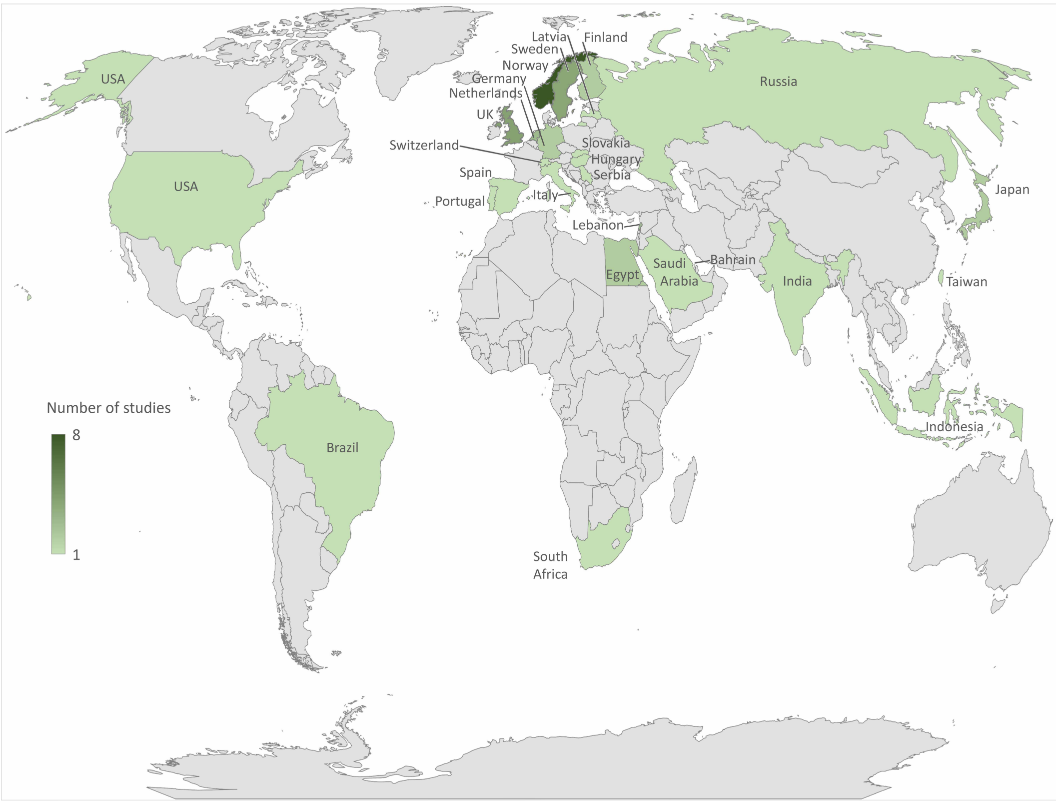


(a) Geographic grouping of academic authors under the world regions.



(b) Geographic map of academic authors.

Figure 3.3: Geographic affiliation of academic authors.

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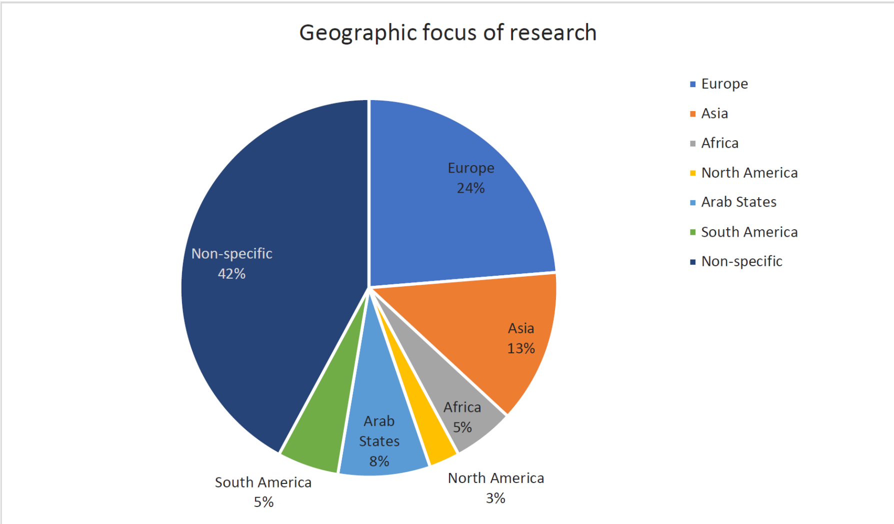
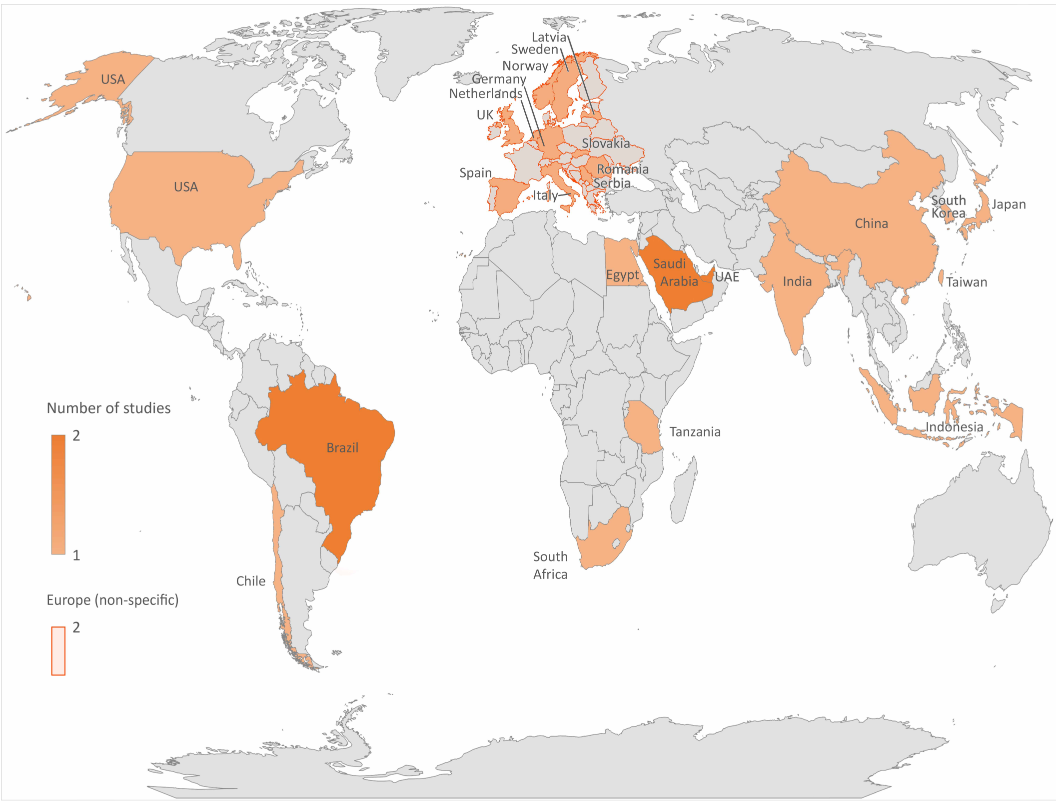


(a) Geographic grouping of the selected studies' research focus.



(b) Geographic map of the selected studies' research focus.

Figure 3.4: Geographic focus of the research e.g., case studies, data analysis, etc.

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China, and India), eight per cent to Arab States (Egypt, UAE and Saudi Arabia) and five per cent to both Africa (South Africa and Tanzania) and South America (Brazil). Only three per cent of the research focussed on North America.

3.2.2 Publication timeline

Literature of both primary relevance (38 papers) and secondary relevance (112 papers), as well as the summed total are plotted on the research publication timeline in Figure 3.5. The timeline stretches until the end of 2019 and was updated in 2020. Secondary literature is regarded as literature that in some ways digress from the research direction but can contribute towards building the transition framework or understanding parts of the project. An exponential like growth rate can be observed in all three trend lines in Figure 3.5, but a decline in secondary literature was observed for 2019. Knowledge useful to smart sustainable city transitions is very fragmented. In 2019 a slight shift in fragmented knowledge towards smart sustainable specific literature can be observed. This growth, especially in the primary literature, indicates an increasing interest in and around the field of smart sustainable cities.

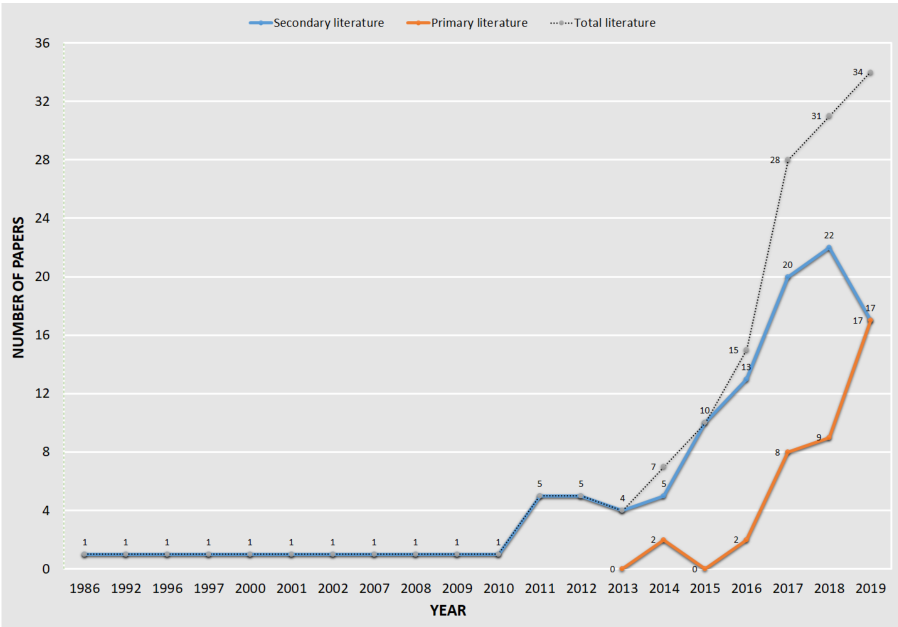

Figure 3.5: Number of papers published per year for primary, secondary, and total relevant research.

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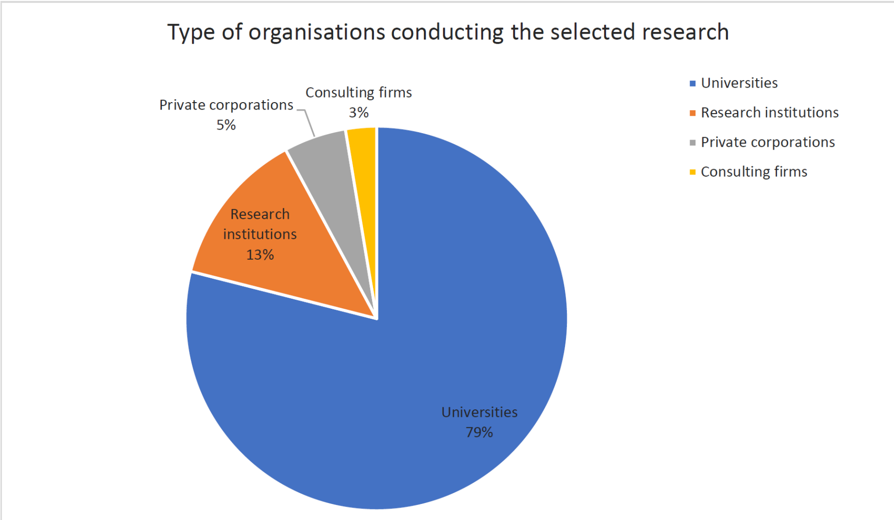

Figure 3.6: Organisations involved in conducting the selected research.

3.2.3 Organisations conducting research

Figure 3.6 presents the organisations involved in conducting research on the final literature selection. More than three quarters of the identified research was conducted through universities, thirteen per cent by public research institutions, five per cent by private companies (specialising in ICT) and three per cent by consulting firms.

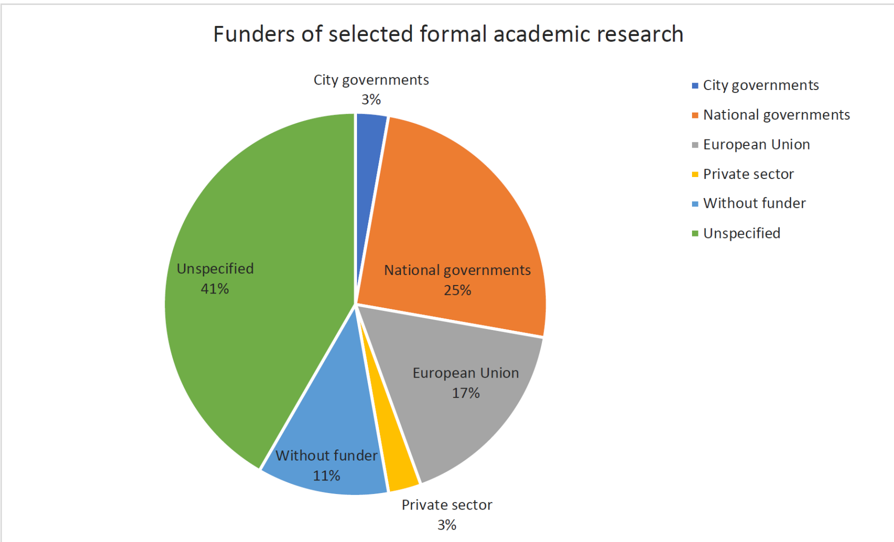

Figure 3.7: The funding sources for the research selected.

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3.2.4 Research funding

In Figure 3.7 the sources of the research funding for the selected papers are summarised in a pie chart, with close to half of the studies neglecting to specify the source of their funding. From this the most financial support, to almost a quarter of the studies, was provided by governments at a national level (specifically the Swedish, Italian, Spanish, South African, Taiwan and Japanese). Sixteen per cent of studies were funded by the European Union and were orientated towards informing current projects, policy and the Horison 2020 Smart Cities and Communities (H2020 SCC) initiative. Four per cent of the studies were without funding, another four per cent funded by the Toyota Foundation from the private sector, and four per cent by government at city-level in Indonesia with future plans to transform the Yogyakarta city to a smart sustainable city.

3.2.5 Research drivers and aims

Indonesia, Sweden, Serbia, and Saudi Arabia form eighteen per cent of the total research that have future urban transformation projects as a driver behind their research, indicated in Figure 3.8. Eight per cent of the identified research is concerned with current projects underway, the main intent being evaluation of progress and status with regards to smart sustainable city dimensions. These studies focus on developing and refining indicator-based approaches for this purpose. Work done on existing cities also make up another ten per cent of the total and is focussed on observing and learning from existing cities as examples and sources of information useful for conceptualisation and evaluation research. Sixteen per cent of the research have an analytic intent and are predominantly big data and ICT orientated. Another study specifically concerned with energy planning in smart sustainable cities is also of an analytical nature. The largest driver behind almost half of the research is to inform policy and agenda at local and international level. This mainly entails developing indicators to promote measurability, standardisation, and target setting, as well as identifying challenges, barriers and possible interventions requiring future research.

3.2.6 Subject fields

In Figure 3.9 a grouping of the main subject fields involved in the research papers selected for the study is summarised. A ratio of thirty-seven per cent and thirty-four per cent respectively for an urban studies perspective and information and communication technologies (ICT) can be observed. Urban studies are not a development focused on a single science, but focusses on the cross-cutting involvement covering multiple disciplines (Acuto *et al.*, 2018).

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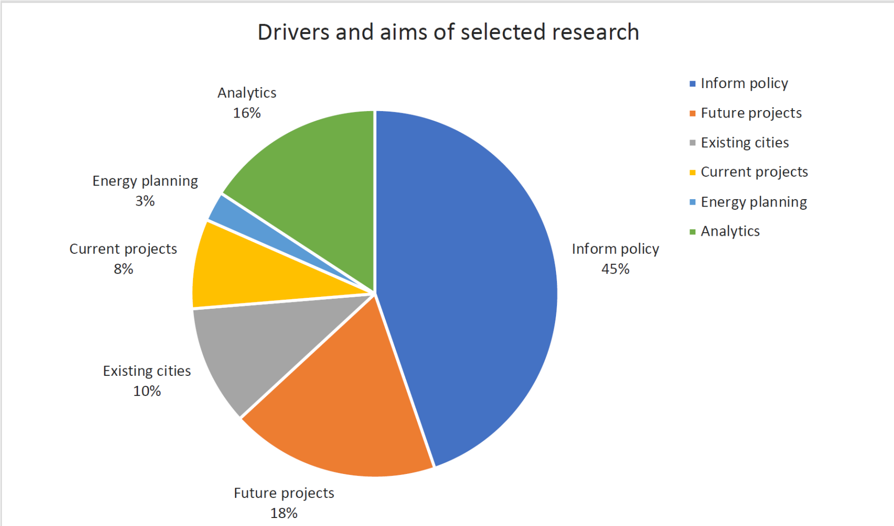

Figure 3.8: The grouped drivers and aims behind the selected research papers.

The literature grouped under ICT include big data analysis, information management, communication networks within smart cities, IOT (internet of things) and sensor-based applications. These ICT studies are generally conducted by researchers with a computer science background and focus on smart cities, and recently a slight shift in research has emerged towards smart sustainable cities.

Ten per cent of the literature have a sustainability focus, which entails establishing a balance between the three dimensions of sustainability, (namely economic, environmental, and social impact) and shares a close relation to urban studies. The sustainability literature addresses the evaluation and transitioning of cities to become more sustainable and inform policy to mitigate

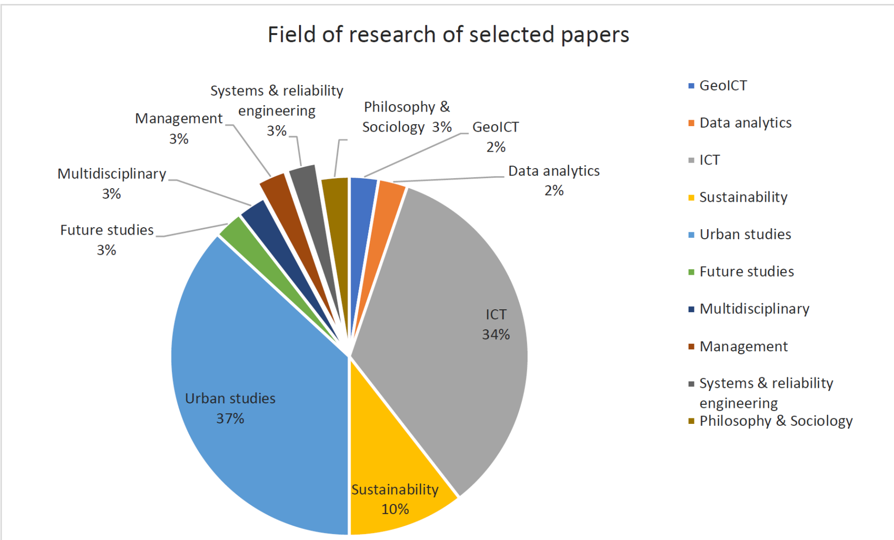

Figure 3.9: Subject fields represented in the selection of research papers.

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climate change.

Data analytics and geographic information communication technologies (GeoICT) each make up equal portions of two per cent of the total research. Philosophy and sociology, systems and reliability engineering, management, multidisciplinary and future studies each make up three per cent of the total research. Literature on data analytics focused on rigorous mathematical relationships and optimisation approaches for smart cities. GeoICT literature focused on the purposeful implementation and exploitation of ICT systems and sensors that unite the spatial dimension (geographical layer) and informational dimension. GeoICT and data analytics are fields that closely relate to ICT. Philosophy and sociology research investigated the ethics and consequences of digitisation and smart city changes on society. The multidisciplinary research entails decision making and important considerations for smart sustainable city development. The future studies research entails anticipating and understanding the future of smart sustainable cities.

Management research has thus far investigated smart city and sustainable city projects from a strategic perspective to determine significant success and failure factors that could inform policy design. Systems and reliability engineering focused on understanding the city as a system-of-systems (SoS) and decomposing its sub-systems thereby reducing problem complexity to provide effective engineering solutions. It is noted that there is a scarcity of research that informs smart sustainable city development from a management and systems perspective, which plays an important role in the development and transformation of a city (Höjer and Wangel, 2015).

3.2.7 Areas of contribution

Figure 3.10 shows the focus and contributions present in the literature selection. The type and composition of content available in the literature selection surrounding the research question is as follows:

a) Conceptualisation (38%): There is still ongoing exploration and debate regarding, for example, smart sustainable city (SSC) conceptualisation. General topics include definitions, characteristics, components, challenges, and lessons drawn from existing city examples. It is observed that theoretical perspectives such as complex systems thinking and the multi-level perspective (MLP) are somewhat intertwined within the research material, but not formally explored.

b) Evaluation (29%): Attempts to develop performance metrics and assessment tools to measure city status, performance, and progress with regards to smart, sustainable and smart sustainable city dimensions or comparisons with other cities. These topics mostly entail creating and comparing indicators, benchmarking, indexing and ranking systems.

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c) Actualisation (22%): This research is concerned with determining best practice methodology and the planning, design, implementation, coordination, management and governance of real-world systems and projects such as cities, infrastructure, and transitions from a practical perspective. There are very few actualisation papers written for smart sustainable cities. Those included address computer science related aspects such as big data, ICT networks and information management (Bibri and Krogstie, 2018), smart transport management (Dinh Dung and Rohacs, 2019), a stakeholder engagement model (Ibrahim *et al.*, 2017), citisen engagement insights (Teremranova and Mutule, 2019), a visions development model (Bibri and Krogstie, 2019*a*,*b*,*c*), and an urban transformation readiness roadmap (Ibrahim *et al.*, 2018). A climate change framework for urban transitioning (Göpfert *et al.*, 2019) is included to enrich the knowledge pool regarding the possible means for implementation and actualisation of the new smart sustainable urban concept.

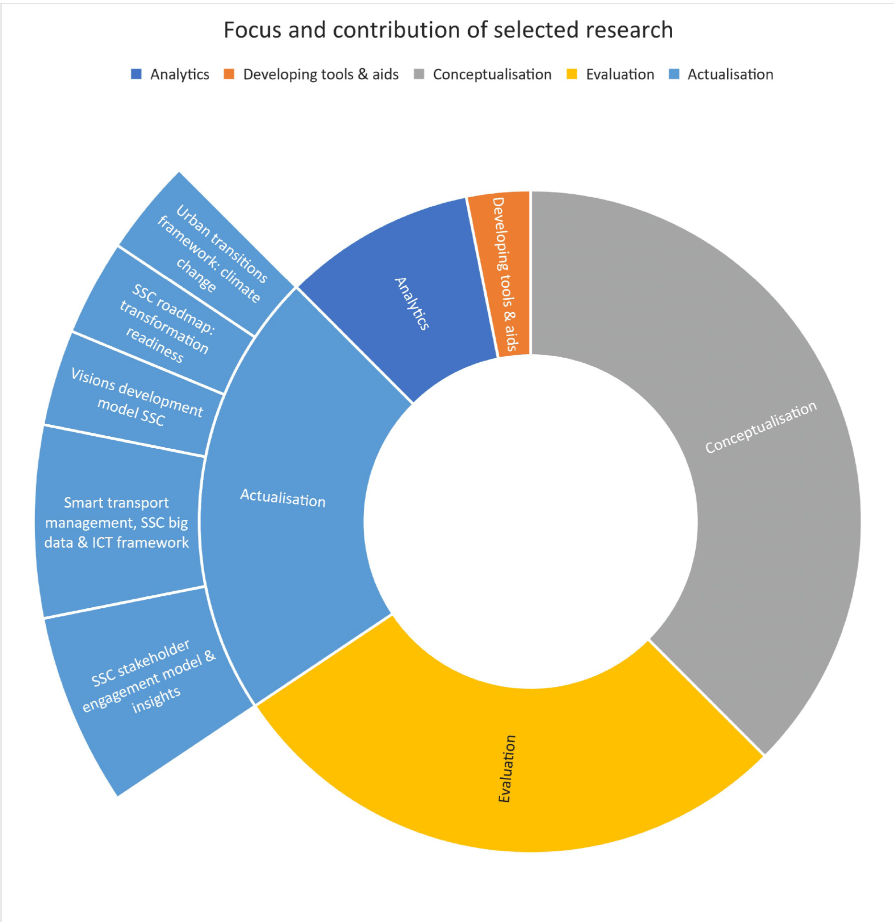

Figure 3.10: The focus and contribution of the selected research papers.

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d) Analytics (9%): Papers focussed on data processing and analysis for smart sustainable cities. Examples include big data and ICT information management frameworks, qualitative methods and optimisation models, risk and resilience analysis for infrastructure and energy planning.

e) Development of tools and aids (3%): This category refers to specialised and practically implementable tools and technology solutions for smart sustainable city applications. Current tools related to smart and sustainable city solutions and applications are continually evolving as technological capabilities advance and diverse solutions emerge from bottom-up development.

A broad sense regarding the structure and progression of knowledge available surrounding smart sustainable city development is conveyed in Figure 3.10. The first observation is the prominence of the conceptualisation portion indicating that most literature available are focused on defining and understanding the main concepts, foundational aspects and supporting knowledge for smart sustainable cities and its relation to its respective smart and sustainable predecessors. The second largest portion represent the studies that strive to determine how cities should be evaluated and monitored with regards to the recently established smart sustainable cities ideal. This is followed by studies concerned with practices and guides for the real-world actualisation and implementation of urban agenda. Thus far there is an absence of a detailed and holistic framework for smart sustainable city transitioning. Analytics will determine how the data will be processed and utilised to provide structured information. The development of sophisticated tools and aids will ultimately depend on availability and usability of city information.

This progression of knowledge presented in Figure 3.10 corresponds to the main avenues of research for smart sustainable cities discussed by Bibri and Krogstie (2017) namely theoretical grounding, urban evaluation, translation into built environment and infrastructure, hereby enabling advanced analytical capabilities of the city and subsequently the development of innovative solutions and approaches.

3.2.8 Deliverables

The main deliverable presented by each item of literature is grouped under specific types as illustrated in Figure 3.11. They are as follows:

a) Dimensions and characteristics (3%): This entail recognition of the main dimensions of a smart sustainable city and its sub-systems in order to understand the various domains at stake. The literature in this grouping had this as their main output or contribution.

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b) Indicators (12%): These studies investigate and compare various existing indicator standards for smart cities and sustainable cities to develop an appropriate and holistic indicator standard for smart sustainable cities.

c) Index (3%): Bhattacharya *et al.* (2018) combined multiple indicators, which capture various characteristics in the environmental, economic, social, cultural and lifestyle dimensions of the city, to determine a single performance value or *index*. The Smart Sustainable Cities Development Index (SSCDI) is aimed to assess, guide, and compare the performance and progression of development between smart cities in India as part of their national milestones.

d) Ranking (3%): The ability to benchmark and rank cities can enable policy makers to identify areas of improvement and strengths that can be leveraged to become smarter and more sustainable. The research by Akande *et al.* (2019) developed a system for ranking twenty-eight European capital cities according to how smart and sustainable they are. The results revealed various anomalies and trends that are insightful.

e) Review (9%): These studies presented literature reviews regarding the origins, foundational concepts, and components of smart sustainable cities as an urban practice. One study also presented five tensions between the visions and policies of smart cities and sustainable urban development goals.

f) Insight (24%): These papers mainly focus on gaining understanding and building new knowledge. One example is the study by Aina (2017) which compared frameworks and case studies in literature to gain lessons and determine policy implications of using GeoICT for smart city development in Saudi Arabia. Elgazzar and El-Gazzar (2017) identified success and failure factors of smart and sustainable city projects by analysing five existing smart and/or sustainable city examples.

g) Model (15%): Models are representations to provide an understanding regarding the structure, functioning and dynamics of certain concepts, but do not provide instructions or guidance. They are conceptual in nature and can play a supportive role to a framework or roadmap.

h) Methodology (6%): Methodology entails detailed approaches for specific applications. Timashev (2017) proposed a methodology for urban risk management of critical infrastructures based upon the concept of a quantitative resilience factor. This approach can be useful to decision making at a municipal level.

i) Roadmap (3%): Ibrahim *et al.* (2018) presents a smart sustainable city transformation roadmap focused on the transformation readiness of a

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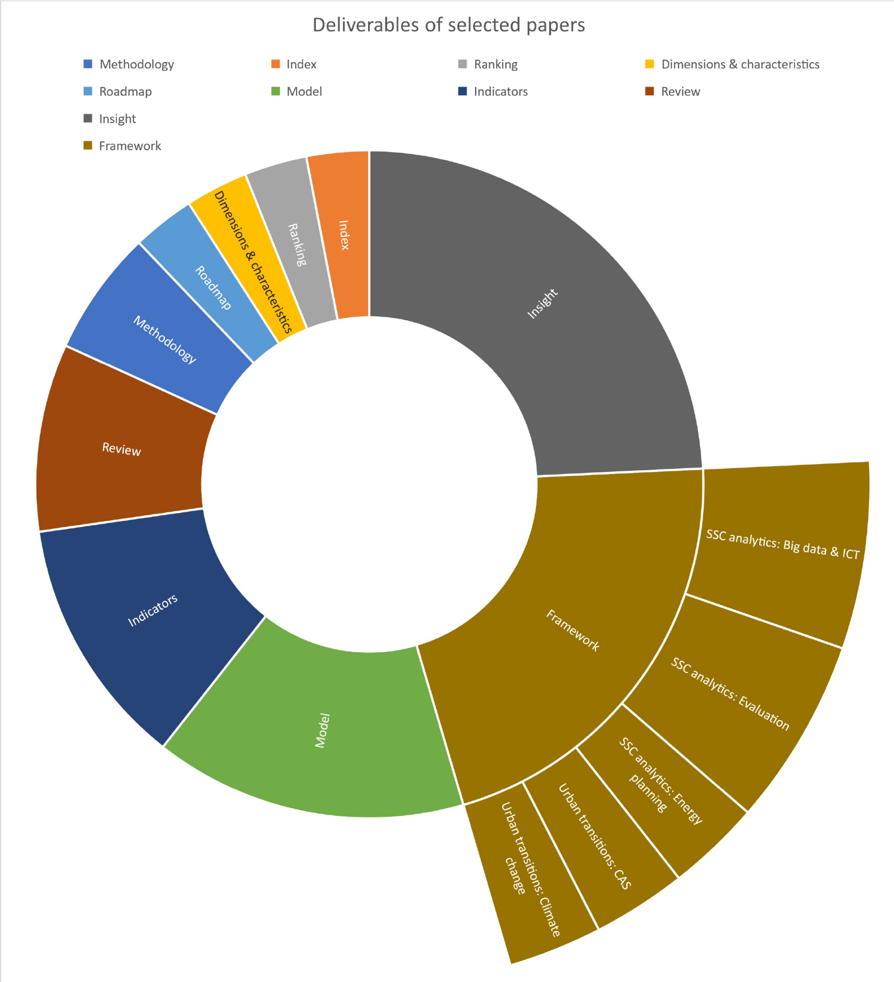

Figure 3.11: The deliverables developed in conjunction to the selected research papers.

city. A roadmap provides the general vision, direction and high-level goals and priorities of the transformation process towards becoming a smart sustainable city in the form of phases (Ibrahim *et al.*, 2016; Withers *et al.*, 2012). Frameworks, in turn, aim to provide tools and detailed guidance on how to achieve the objectives related to the stages of a roadmap. The developed roadmap serves as a foundation for the future development of a framework for smart sustainable city transformation (Ibrahim *et al.*, 2018).

j) Frameworks (21%): Frameworks are needed to provide the required guidance to planners and stakeholders to turn the phases of a roadmap into actionable steps and solutions (Di Biase, 2015; Borowik *et al.*, 2015). According to (Ibrahim *et al.*, 2018) a framework can also serve an additional function as a generic list of the areas of importance related to the priority dimensions that need to be observed when initiating a

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transformation, process, or project. The smart sustainable city (SSC) frameworks that fall within the primary literature selection of this review relate to big data ICT and analytics (Bibri and Krogstie, 2018; Bibri, 2018), SSC evaluation analytics (Wey and Ching, 2018; Ahvenniemi *et al.*, 2017), analytics for SSC energy (Kramers *et al.*, 2014), urban transitioning for climate change (Göpfert *et al.*, 2019) and complex adaptive systems (Nel *et al.*, 2018). Ibrahim *et al.* (2016) conclude their research by encouraging the development of a potential smart sustainable city transformation framework that builds upon the developed roadmap. Ibrahim *et al.* (2016) perceive such a framework as a layered structure to lead city planners and stakeholders through the process of transformation and developing innovative solutions for city sustainability and quality of life.

3.2.9 Continuing research

The same literature search, as depicted in Figure 3.2, was performed again in September 2022 to see what literature had been published after the January 2020 search had been performed. A small selection of relevant articles was retrieved. Most new articles have a stronger focus on smart sustainable cities than the earlier literature, which had a stronger focus on either smart or sustainable cities as distinct concepts. This can be considered an indication that the anticipated trend towards smart sustainable cities in urban development is already starting to show more clearly as time progresses. The work by Al-Gindy *et al.* (2021) entails a cost benefit analysis for smart city implementations, smart sustainable city challenges and a list of smart solutions for sustainability problems. In Darmawan *et al.* (2020) an e-governance assessment framework for smart sustainable cities was developed and research in Pereira and De Azambuja (2022) focuses on the roadmap requirements for building governance capacity for a smart sustainable city. Al-Nasrawi (2021) presents a citizen engagement model for smart sustainable city planning, exploring the pathways that citizens can utilise to influence smart sustainable city planning processes and outcomes. A descriptive model of the future city, or smart sustainable city, presented in Bibri and Krogstie (2020), was compiled by devising the components, characteristics and aims applicable to be considered a smart sustainable city. It provides a list of all potential outcomes related to each dimension of a smart sustainable city. This is a useful index to inform urban planning of possible aims and initiatives that can be pursued. Among all the research including the newly published articles, there still is no similar framework published such as the one developed by this study. The work done in Ibrahim *et al.* (2018), Bibri and Krogstie (2020), Darmawan *et al.* (2020), Pereira and De Azambuja (2022), Al-Gindy *et al.* (2021) and Al-Nasrawi (2021) are of complementary nature.

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3.3 Knowledge landscape for smart sustainable cities

Only a small number of articles are directly aimed at smart sustainable cities as an urban concept, with most other research written about sustainable cities, smart cities or climate change. This balance has started to shift in research after 2020 with more articles starting to directly address the concept of smart sustainable cities. Most research was published in urban studies and information and communication technology (ICT) fields, each making up a third of the total. Only three per cent of the literature was published in the management sciences, and the same amount in systems and reliability engineering. The work in the management research focusses on strategic aspects such as determining success and failure factors related to sustainable cities and smart cities specifically. The systems engineering research provides guidance on understanding cities as systems-of-systems, identifying the system properties and using the systems perspective as an analytical lens when investigating complex problems and developing solutions. The types of contributions present in the literature was: the conceptualisation of certain urban concepts (types of cities, dimensions and definitions); urban evaluation methodology; actualisation (practical aspects like planning); advanced analytics; and the development of tools and aids.

3.4 Rationale of the proposed study

There is a scarcity of literature and absence of frameworks to guide city-level planning, implementation, and management of smart sustainable city transitions from a holistic perspective. The research by Ibrahim *et al.* (2018) developed a transformation readiness roadmap indicating the main phases of the overall transformation process towards a smart sustainable city. The roadmap does not provide detailed steps to accomplish the goals outlined in the phases due to lacking availability of relevant and detailed literature on smart sustainable city development at the time. For this reason, Ibrahim *et al.* (2018) encouraged future research that extends on their work through the development of a transition framework for smart sustainable cities. This also correlates with work in Pereira and De Azambuja (2022) where future research was suggested to build on existing roadmaps to develop a more detailed and comprehensive guide or framework for transitioning towards smart sustainable cities.

3.4.1 A systems perspective

Cities comprise of various complex systems that are interconnected to form larger systems-of-systems (Tiwari, 2016; Larasati *et al.*, 2018). The

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components within these systems are diverse (Tiwari, 2016) and their interactions with one another lead to emergent behaviour in the system and cascading effects across other systems (Francis and Thomas, 2022). Many urban systems possess the ability to adapt and self-organise (Nel *et al.*, 2018), and function at multiple nested levels (Kivimaa *et al.*, 2019). Complex adaptive systems are known by these characteristics and cities are a typical example of this (Roggema, 2012).

Although Ibrahim *et al.* (2018) selected the theory of change (ToC) as a theoretical foundation during the development of the smart sustainable city's transformation readiness roadmap, Ibrahim *et al.* (2018) believe this provides other researchers with the opportunity to explore other theories for transformation towards smart sustainable cities. The proposed research will investigate urban transitioning approaches from a systems perspective, which has emerged as the dominant school of thought relevant from the sustainable city, smart city, and urban transitioning domains (Olazabal, 2017; Abbas *et al.*, 2019; Nel *et al.*, 2018). It is also inter-weaved in the recent research that has emerged regarding smart sustainable cities due to its appropriateness.

3.4.2 Infrastructure as an intervention point

Sustainable urban development requires interventions in the built environment and infrastructural systems (Ferrer *et al.*, 2023). The self-organising behaviour within cities as complex adaptive systems can be leveraged to adapt within well-structured infrastructure networks that function as a new skeleton for the co-evolution of social and environmental systems (Cole, 2012; Nel *et al.*, 2018).

Infrastructure is not only for aesthetic appeal or efficiency, but most important to guide and predetermine how a city is used and how it functions (Neal, 2012). Infrastructure networks, which also includes information and communication technologies (ICT), serve as a crucial support system to society (Francis and Thomas, 2022).

Proper planning and strategic management or the absence thereof, determines whether infrastructure contributes as an enabler of societal and economic growth and environmental management, or a contributing agent of growing inequality and accelerated resource exploitation and depletion (Höjer and Wangel, 2015). Failure of infrastructure systems can have a high impact reaching as far as a global level, potentially affecting global economy, climate, and national securities. Infrastructure networks of high concern include energy, mobility, food, water, finance, and ICT (USA Patriot Act of October 26, 2001). These networks are interdependent, thus a collapse of one system will have a ripple effect on the interconnected system-of-systems it is embedded in. The additional pressures that result on the rest of the interconnected infrastructures cause cascading effects that amplify the disruptive impacts (Ryan, 2017).

Infrastructure is selected as the primary focus of the study as a purposeful intervention pathway for a smart sustainable city transition. Hereby the

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proposed framework will focus on various aspects needed for successful planning and execution of the multi-project transitioning of the city.

3.5 Insights and concepts from literature

Whilst reviewing the literature, important concepts were highlighted in the articles. These highlighted pieces of information were then used to write and discuss the themes that came to the forefront among the selected excerpts. The guiding questions for the literature study, provided in Chapter2, were used to identify and prioritise the most important themes and insights:

- Smart cities definition, components, capabilities and functioning.
- Sustainable cities, urban metabolisms, cities as complex adaptive systems and the multi-level perspective.
- Smart sustainable cities drivers, dimensions, evaluation and implementation challenges.
- Urban infrastructure's role, transitioning and context in the fourth industrial revolution.
- Key aspects such as financing, benchmarking, policy-making and stakeholder management.

These topics will be discussed in more detail in the sections that follow.

3.6 Smart cities

Smart cities came about because of modern technological developments, with the goal of increasing city performance and quality of life (Keshavarzi *et al.*, 2021), and is still today a relatively new concept (Nasreen Banu and Metilda Florence, 2022). Throughout literature the definitions of smart cities, as well as their smart characteristics and initiatives also indicate that these cities are not only about technology (Neirotti *et al.*, 2014; Nam and Pardo, 2011; Dameri, 2013; Caragliu *et al.*, 2011; Giffinger *et al.*, 2007; Keshavarzi *et al.*, 2021). In Monzon (2015) a smart city is described as an integrated system of collaborative human and social capital that uses technology developments for improved quality of life and to assist the strive towards resilience. A smart city according to Monzon (2015) entails the inclusion of smart strategies, stakeholder, and government collaboration, as well as bottom-up approaches that are balanced simultaneously with top-down approaches. According to Giffinger *et al.* (2007) the occupants of a smart city should also form part of the city design and be informed or educated on the functioning of the city and be made aware of city matters and events.

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3.7 Smart city aspects and technology

To become smarter and function more effectively, it is necessary that stakeholders in cities devote attention to technical aspects such as embracing new technology and modernising their infrastructure (Keshavarzi *et al.*, 2021). These aspects not only affect the function of the city, but also people's lives in terms of culture, social services, energy, environment, infrastructure and more (Čorejová *et al.*, 2021). A smart city development should have a holistic approach towards the functioning of a city region (Čorejová *et al.*, 2021) and understanding the components of such a city will help with integrated planning.

To provide better context on the matter, ICT is the backbone of smart cities and utilized to improve the quality, performance, and interactivity of municipal services, to minimize costs and resource consumption, and to facilitate communication between city stakeholders and citizens (IEEE, 2022). The three components of ICT is IoT, big data and cloud computing (Park *et al.*, 2021). IoT systems entail sensors, connected through a gateway to the cloud, where data is being processed, and is then fed back to a user interface (Pianalytix, 2022; Banafa, 2021). Artificial intelligence (AI) in smart cities assists the processing of data for making environmentally conscious decisions and solving problems such as traffic congestion, pollution rates, water and energy efficiency, waste management and noise reduction (Diran *et al.*, 2021). But smart cities face another challenge which is that smart grids are susceptible to protocol weaknesses, eavesdropping, privacy breaches and internet-connected device assaults (Ismagilova *et al.*, 2020). It is therefore that research in Paul *et al.* (2021); Salimitari and Chatterjee (2018); Fernández-Caramés and Fraga-Lamas (2018) suggest blockchain as a possible means to help secure smart cities. In the following sub-sections ICT (Information and Communications Technology), IoT (Internet of Things), sensors and wireless technology, cloud computing, big data, AI (Artificial Intelligence) and blockchain will be discussed.

3.7.1 Information and communications technology (ICT)

The adoption and applications of information communication technology (ICT) has accelerated globally in recent years (Ebin *et al.*, 2022), with internet technologies keeping society functioning throughout the COVID-19 pandemic. It is believed that without ICT, many companies would not have been able to keep their workforces going beyond interruption (Ebin *et al.*, 2022). According to Ebin *et al.* (2022), effective ICT management, especially now, has become a critical part of a country's economic growth (Ebin *et al.*, 2022).

ICT for smart city is described in Visser (2019) as a utility, providing that it is similar to supplying electricity or water in a city, but distinct when acknowledging that machine intelligence provides the ability to make decisions,

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solve problems, and learn. The advances in ICT according to Bibri and Krogstie (2017), originated from the data and complexity sciences to address complex urban challenges, mostly orientated towards the infrastructure, operation and functionality of a city. And the overall process of reshaping and transitioning a city towards becoming a smart city and staying innovative, relies on the methods for increasing people's efficiency and quality of life (Ebin *et al.*, 2022). This procedure involves the gathering of data, the evaluation of information, and the proper use of that information.

Opportunities that can bridge smart cities and ICT in their application are discerned in Bibri and Krogstie (2017) as: applying advances in sensor technology and real-time city applications to inform future urban design through forecasting and predictive insight regarding medium and long-term change; and applying context-aware computing and big data analysis to for instance optimise physical and virtual mobility in terms of density, diversity, and mixed land-use. Accessibility to employment opportunities, facilities, public and social services can also be enhanced in spatial and non-spatial dimensions in a sustainable manner (Bibri and Krogstie, 2017).

3.7.2 Internet of things (IoT)

Information communication technology (ICT) generally refers to a wide range of applications and devices, while internet of things (IoT) entails linking devices to make them self-controllable and function intelligently (ur Rahman *et al.*, 2016). The term IoT was only established a decade ago, but now its fast-growing ecosystem progressively becomes a part of our everyday lives (Dharshini *et al.*, 2022). Consumer goods, industrial devices, utility items, cars, sensors, and other commonplace components are being coupled with internet connectivity and powerful data processing capabilities, with the potential to transform people's livelihoods. As people, things, and machines become more connected to the internet, smart cities arise, bridging the physical and virtual worlds. IoT applications in smart cities provide substantial value to our daily lives in applications such as transportation, energy management, industrialisation, agriculture, environment, safety, commerce, communities, health, entertainment, tourism, and utilities. The fast expansion of IoT has provided users with a plethora of new options to explore beyond their traditional industrial boundaries (Dharshini *et al.*, 2022).

With significant global social and environmental shifts occurring, a growing number of cities are focusing their infrastructure plans on sustainable transportation policies, updating energy requirements in building stock, boosting renewable energy generation, improving waste management, and adopting ICT infrastructures (Zhang *et al.*, 2021*a*). In Dharshini *et al.* (2022) a literature survey was completed on all available papers published up until 2019 on the applications of IoT in smart cities. The main themes of these papers were summarised in Figure 3.12 and categorised according to nine use cases of

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IoT. These are listed in Vijayalakshmi *et al.* (2022) as smart transport; smart energy; smart city; smart health; smart living; smart living; smart industry; animal tracking; smart agriculture; and smart homes.

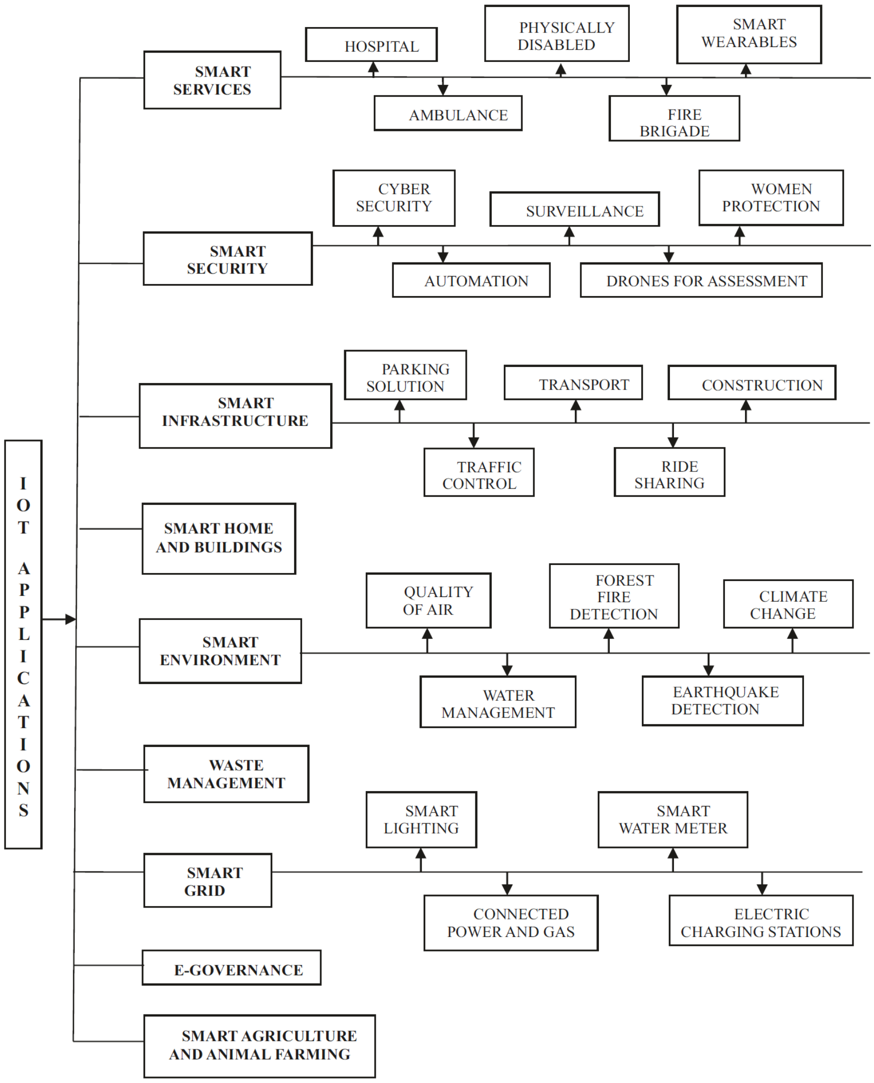

Figure 3.12: Various applications of IoT in smart cities (Dharshini *et al.*, 2022).

The different components of IoT and the flow of information from the IoT devices to the end user is simplified and illustrated in Figure 3.13. In the context of the Internet of Things, the word *thing* implies a physical item that has a unique identity (such as a MAC address) and is capable of exchanging data via a network (Vijayalakshmi *et al.*, 2022), for instance sensors in smart cities. A gateway controls the flow of this data between protocols and networks and serves as a connection point between the IoT sensors or devices and the cloud. Through the gateway, devices are linked to cloud services and analytics (Vijayalakshmi *et al.*, 2022).

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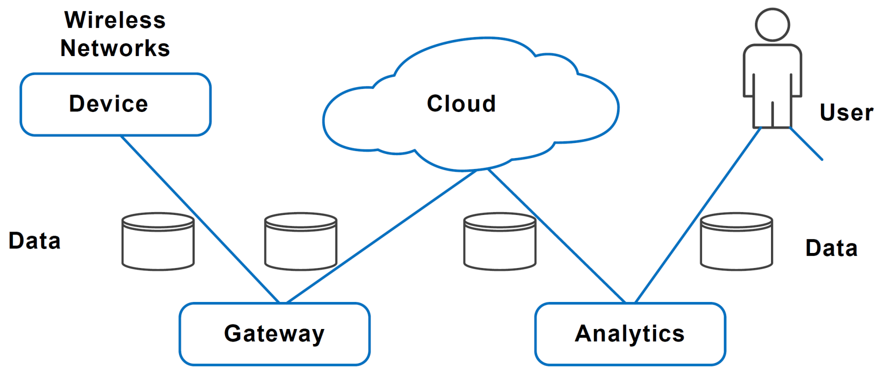

Figure 3.13: Ecosystem of the internet of things (IoT). Reproduced from Vijayalakshmi *et al.* (2022).

The layered architecture pertaining to the internet of things is presented in Figure 3.14. In Figure 3.14 the service layer (SL), composite virtual object layer (CVOL) and virtual object layer (VOL) form the core layers for IoT architecture, collectively known as the IoT Daemon (Vijayalakshmi *et al.*, 2022). The IoT Daemon layer sits above the communication and physical layer, which consists of heterogeneous devices, sensors, networks or systems. The three layers within the IoT Daemon (VOL, CVOL and SL) are respectively responsible for virtualising objects, composing, and executing services, and creating and managing services. These services and objects in the Daemon layer are merged, with minimum human input, to enable and create IoT applications or service-oriented architecture (SOA) (Vijayalakshmi *et al.*, 2022). The virtual object layer (VOL) is primarily accountable for the representations of virtual objects and functions as a translator that links the cyber and physical dimensions. The service layer (SL) and the composite virtual object layer (CVOL) include features for example automation, coordination, and management (Vijayalakshmi *et al.*, 2022). The

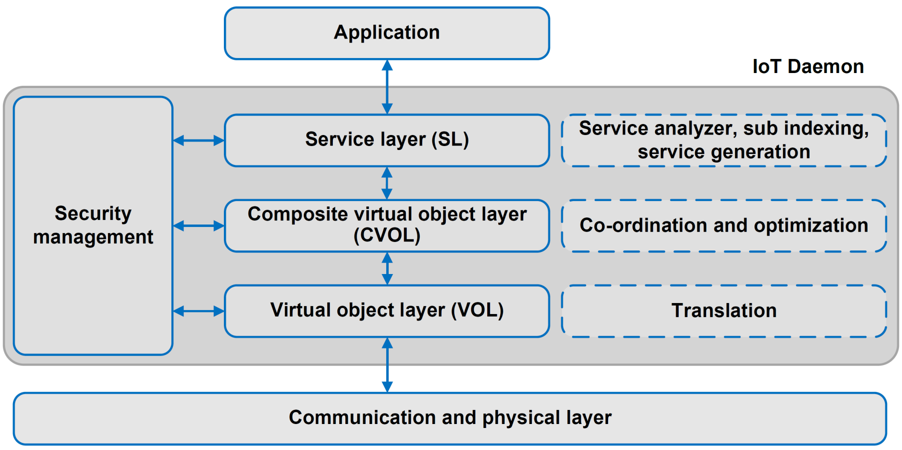

Figure 3.14: An Internet of things (IoT) layered architecture. Reproduced from Vijayalakshmi *et al.* (2022).

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resources required (e.g., memory and processing power) will increase when moving from a lower level (VOL) to a higher level (CVOL or SL), but so will the cognitive capabilities. The security management (SM) module in the IoT Daemon manages all privacy and security policies for the VOL, CVOL and SL layers (Vijayalakshmi *et al.*, 2022).

Compatibility across different IoT implementations and devices was a significant issue a decade ago during the rollout of IoT applications. As a result, the necessity for a new architecture that incorporates intelligent control and actuation became inevitable (Vijayalakshmi *et al.*, 2022). From the remarks in Dharshini *et al.* (2022), Zhang *et al.* (2021*a*), Liu *et al.* (2019) and as pointed out in Pimpinella *et al.* (2019), it is clear that the ability of current IoT to support an interoperable platform, ubiquitous access, and heterogeneous device communication is important and makes it a notable and growing part of smart cities.

3.7.2.1 Sensors and wireless technology

Many of the large cities have already begun the process of becoming smarter cities (Lisangan and Sumarta, 2018). With increased popularity in the expansion of the internet of things (IoT), technology in wireless sensor networks (WSNs) have gained prominence in the progress and development of ICT technologies (Sheng *et al.*, 2015). Today, wireless sensor network (WSN) has become a key consideration for the development of smart city applications (Khan *et al.*, 2021). WSNs have been incorporated and linked to a wide variety of industrial applications on the internet. Not in all cases, but in many, wireless sensors in cities may have to run on batteries for an extended amount of time and in such cases the device can be very resource constrained (Sheng *et al.*, 2015). Efficient power consumption and communication overhead of a battery powered sensor will be paramount (Sheng *et al.*, 2015). To handle these wireless sensor devices collectively and effectively, industrial authorities must be ready to offer a network infrastructure capable of supporting a variety of WSN services and applications that enable the administration of sensor-equipped real-time operations (Sheng *et al.*, 2015).

To provide an improved outlook on IoT applications, Table 3.1 was compiled in Sheng *et al.* (2015) to highlight some of the major IoT development areas, including their requirements and respective challenges. The Internet of Things makes use of a variety of wireless and wired sensor devices to record events and monitor the condition of various objects, such as inventory or temperature levels (Sheng *et al.*, 2015). The data of the IoT device is transmitted using wired, wireless or hybrid networks to a gateway which then connects device data with higher network layers and additional functions. In Table 3.2 examples of the wireless technologies; typical radio frequency used; and the possible range for placement from an access point; expected data rates; and the applications that use them are listed (Sheng *et al.*, 2015).

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Table 3.1: Key IoT domains, as well as application requirements and difficulties (Sheng *et al.*, 2015).

Key development areas	Application requirement	Challenges
Smart grid	– Sensor monitoring of power generation, – Warning of power transmission, – Management of power supply automation, – Metering of power usage.	Lack of core technologies, including reliable communications, MANET, gateway, middleware, electromagnetic compatibility and security.
Smart transportation	Development of RFID technology on intelligent transport system (ITS).	Information island on transportation managements from different administration departments; Low level of system integration.
Intelligent logistics	Development of RFID, GPS, GIS, smart container and smart tracking etc.	Less developed value chain and standards create a bottleneck; Information based application needs to be further promoted in greater scope and depth.
Smart home	– Industry consolidation, – Development in multi-access, energy saving and cross application integration, etc.	Lack of standard, core component, industry collaboration, security, privacy protection, support of policy and funding.
Environment protection	– Environment monitoring includes population, atmospheric sciences, geographic research, – Monitoring of flood and fire.	Limited number of monitoring stations and lack of well developed management platforms; Less developed on manufacturing of high precision sensor chips; No unified industry standard.
Industrial automation	– Intelligent of industry raw material and product supply chain, – Manufacture management and safety, – Energy saving and low carbon economy.	Limited scope and depth of industry application; Lack of technology breakthroughs and industry standards.
Intelligent health care	– Telemedicine, visualization of remote treatment, – Information sharing and management of patient treatment, drug and medical stuff, – Computerized physician order entry (CPOE).	No clear industry planning; High cost and lack of security and privacy; Limited manufacture ability of medical and biomedical sensors, large scale data mining.
Agriculture	– Real-time access and information sharing of agricultural resources, – Intelligent management of products circulation and safety.	Lack of low cost sensing technology and devices; Lack of communication infrastructures in countryside.
Financial services	Development of mature technology and safer security.	Lack of technology standard, secured and effective identification mechanism; Problem of user privacy loss.
Public security	The need for full support and financial investment from government.	Lack of public security standard; Uncoordinated development of value chain and lack of intellectual property rights.

Lastly, employing wireless sensor networks (WSN) for various applications

Table 3.2: Industrial wireless sensor networks (WSN) applications mapping and short-range radio technologies (Sheng *et al.*, 2015).

	Technical Summary	Typical Radio Band	Transmission Range	Data Rate	Applications
Wi-Fi	It is probably the most widely used wireless local area network (WLAN) technology based on the IEEE 802.11 series of standards.	2.4 GHz, 5GHz	150m	54Mbps	Video and monitoring based applications, smart home
Bluetooth	Bluetooth low energy technology is a global standard, which enables devices with coin cell batteries to be wirelessly connected to standard Bluetooth enabled devices and services.	2.4GHz (v1.x,v4), 5GHz (v3.0)	10-150m	1Mbps, 24Mbps	Remote access, Sports & Fitness, Indoor positioning (HAIP), smart phone based applications
ZigBee (IEEE 802.15.4)	A well-defined protocol stack for WSN with features of self-deployment, low complexity, low data rate and low cost, etc, based on IEEE 802.15.4 standards.	780MHz (China), 868MHz, 915MHz, 2.4GHz	100-300m	20Kbps, 40Kbps, 250Kbps,	Smart Energy, Home Automation, Building Automation, Health care, Remote Control, Retail Services, etc.
RFID	A fast developing radio technology used to transfer data from an electronic tag, which includes identification, information collection, etc.	125KHz (LF), 13.56MHz (HF), 433MHz (UHF) 2.4GHz (MW),	<10cm, <1m, 4-20m, 60-100m	1-5Kbps 6.62-26.48Kbps 40-640Kbps 200-400Kbps	Logistic, E-car license, one pass card
433MHz enabled proprietary solutions	Proprietary solutions by using one of the most commonly used ISM (industrial, scientific and medical) radio band in China.	433MHz	300-1500m	<10Kbps	Home security, environment monitoring, etc.

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help save costs (Khan *et al.*, 2021), but good consideration should always be given to wireless network congestion and balancing traffic (Lisangan and Sumarta, 2018), especially when executing such networks on a large scale.

3.7.3 Cloud computing

Smart cities encourage cloud- and Internet of Things (IoT)-based services that are interconnected (Alam *et al.*, 2022) in which sensors, RFIDs and smart phones facilitate real-time user interfaces (Kaur and Maheshwari, 2016). These sensors and devices can potentially generate massive amounts of data, stored as big data (Saiki *et al.*, 2018). Fortunately, cloud systems have the potential to store the data detected by these sensors and facilitate the data interchange between diverse platforms (Dener, 2019). This is done through infrastructure made up of huge pools of virtualised computers and storage that are networked together and provide computing and analytical capabilities (Banafa, 2021).

3.7.4 Big data

At the heart of smart infrastructure's functioning is the way information flows through it (Kumar and Mishra, 2021). In Figure 3.15 the amount of global data produced, utilised, and retained is shown up until 2019 and forecasted till the year 2025 (Holst, 2021). An exponential growth trend from 2010 can be observed in Figure 3.15. It was forecasted that the quantity of data produced and duplicated will have increased to an all-time high in 2020, however in reality due to the COVID-19 pandemic, these predicted numbers were exceeded. This was because more individuals worked and studied from home and used home entertainment options (Holst, 2021). To gain a sense of the quantity of data that is produced daily, Google receives more than 500,000 searches per second, which equates to approximately 3.5 billion searches per day (Berisha and Mëziu, 2021). Imagine for a moment that these simple searches in a city can be utilized to predict and prevent a potential crime.

Sensing technologies and location-based services (LBS) in smart cities account for large volumes of smart city data generated and is referred to as location-based big data (LocBigData). This type of big data can be used to combine location tracking with data such as social media, camera imagery, wifi services, installed city sensors, crowdsourced geographic information and more (Huang *et al.*, 2021). Analysing LocBigData, particularly in and about the urban system, would enable new insights into social interaction, human movement, and the city dynamics and structure. Empirical support and insights for addressing major urban issues such as traffic congestion, uneven development, and overcrowding can be gained.

The real-time insights from data have the potential to assist in transforming modern cities into smart and sustainable cities and to improve the well-being and quality of life of city occupants (Huang *et al.*, 2021). When planned

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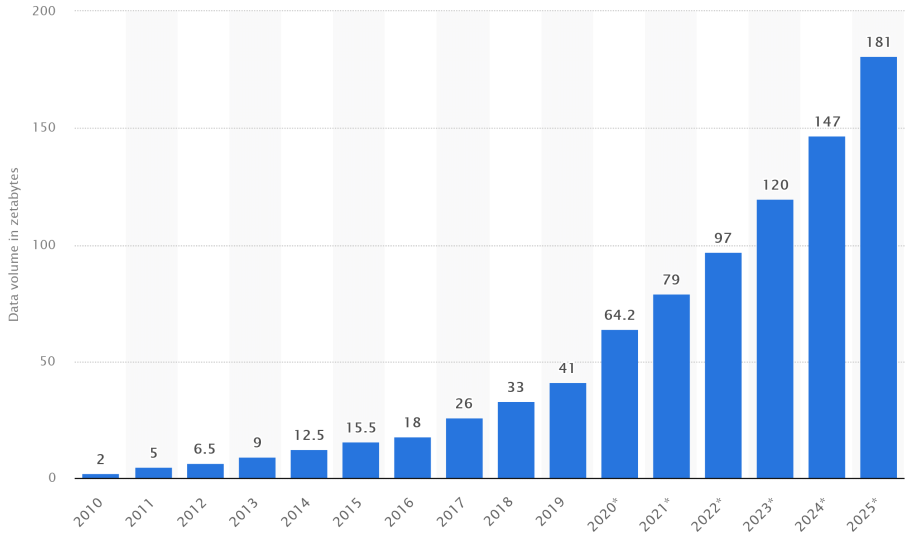

Figure 3.15: Amount of data produced, utilised, and retained 2010-2025 (Holst, 2021).

properly, LocBigData can potentially help with planning and design of an efficient and effective sustainable society. But care should be given to social and ethical problems, as well as implementing data analytics that preserve privacy and are executed in a morally conscientious way (Huang *et al.*, 2021).

In some instances, it can be difficult to preserve such privacy. It was demonstrated in Boulos and Koh (2021) that location-based big data used for public health problems such as type-2 diabetes and obesity in a city is hard to accurately interpret when the data sampled is too universal. Previous research discussed in Boulos and Koh (2021) compare factors such as neighbourhood walkability to the nearest public gym, green space, fresh vegetable and fruit store, as well as fast food restaurants, with the average body mass index (BMI) and physical activity level of the neighbourhood. Addressing problems such as type-2 diabetes and obesity in a city, requires a dashboard or application that targets at an individual level, as suggested in Boulos and Koh (2021). Such a dashboard will collect and use information specific to the individual's profile such as gut bacteria profiles, metabolic factors, gut hormone profiles, dietary and lifestyle habits, stress levels, screen viewing times, sleep patterns, socio-economic status, environmental air, and noise pollution levels and more (Boulos and Koh, 2021). This might be a daunting task on a city level but collecting such data and gaining the permission required will be difficult as there is also some privacy concerns. However, for instance, applications such as MyFitnessPal is a voluntary application and has shown success in helping individuals with losing weight and managing a healthy lifestyle. MyFitnessPal uses data such as an individual's current weight; age; gender; exercise (either by linking the fitness data from a smart watch or entering the exercise manually); and calorie intake by entering exactly what was consumed throughout the

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day (MyFitnessPal, 2021). MyFitnessPal has an existing food database of 11 million foods entries according to nutritional values. The data collected is used to help an individual to achieve a set goal weight by calculating the calories left after each meal, encouraging exercise, and suggesting slight dietary changes to help balance nutritional intakes (MyFitnessPal, 2021).

In El Azzaoui *et al.* (2021) it is said that social network service (SNS) platforms can also be a valid means of collecting data to better predict COVID-19 outbreaks. This follows a trend which was noted in El Azzaoui *et al.* (2021) that individuals are increasingly depending on social network services (SNS) to stay informed about the epidemic, exchange their perspectives, and express their emotions and symptoms.

A framework was developed in El Azzaoui *et al.* (2021) for the data analysis in predicting COVID-19 outbreaks. To test the framework, a geographical area in the USA was selected, and over 10,000 Tweets were gathered over two months. From the data gathered, 38% of users were between the ages of 18 and 29, while 26% were between the ages of 30 and 49 with males accounting for 56% of the data, while females accounted 44% (El Azzaoui *et al.*, 2021). Using the developed framework, an COVID-19 outbreak could be detected seven days earlier with a 0.989 indicator score, thereby assisting in the control of a pandemic situation in a city (El Azzaoui *et al.*, 2021). This prediction can help to assist in reducing infection cases by predicting potential virus carriers in advance, and assisting in understanding users' fear and sentiment, as well as their proclivity towards following authorities' regulations. SNS big data showed the potential in El Azzaoui *et al.* (2021) to be a valuable instrument for future study since it enables us to monitor a pandemic situation in the city and aid in the containment of it, such as COVID-19. This could potentially help smart sustainable cities to preserve a key performance indicator (KPI) for 'healthy cities', by indirectly enhancing the healthcare services given to its city occupants (El Azzaoui *et al.*, 2021).

Another example of how big data can aid cities is found in Zhang *et al.* (2021*b*), who suggests that data from IoT city sensors can be further expanded using artificial intelligence (AI) to determine early signs of fire outbreaks. According to Zhang *et al.* (2021*b*) the suggested approach accurately identifies fire outbreaks at a rate of 98.4 percent.

Big data, fuelled by information communication technology (ICT), opens new growth possibilities for urban development according to Zhang *et al.* (2021*b*). Many technological advances, such as the internet of things (IoT) facilitating data collection and Artificial Intelligence (AI) for big data analytics, are being used to improve the exchange and integration of data, as well as to optimise some of the fundamental principles of smart cities and smart sustainable cities (Zhang *et al.*, 2021*b*). It is believed in Zhang *et al.* (2021*b*) that big data and the interpretation within cities can play an important role in creating a sustainable urban environment.

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3.7.4.1 Value chains in big data

When designing a smart infrastructure and initiatives, it is important to find creative ways to create value in order for a city to be more financially sustainable (Dana *et al.*, 2022). According to Löfgren and Webster (2020), big data has brought a new dimension to the way technology is employed in public services and digital governance for creating value. A value chain model, which emerged from the commercial sector, is explored in Löfgren and Webster (2020) to help find value-adding activities that can be utilised in cities using big data and sensors.

In Figure 3.16, the generic value chain model is a hierarchical representation of an organisation's general value-adding operations. The method is a straightforward linear model that denotes the sequence of critical sequential actions involved in the production and delivery of an item or service (Löfgren and Webster, 2020). By deconstructing the production chain in for instance in a company into a number of interconnected activities, it becomes simpler for a company to recognise whether one of the chain's links is underperforming, causing issues, or impeding value generation. This should in theory also be possible when applying value chains to big data in cities, to detect areas of underperformance, neglect, other issues or under-utilized opportunities (Löfgren and Webster, 2020).

While the generic value chain was not primarily intended to include new digital technologies, it has over time been employed to services and products that incorporate new technology (Löfgren and Webster, 2020). A value chain for public policy and service environments as in Figure 3.16 also suggests another method in which value chain analysis might aid in value generation. Many public service organisations are tasked with resolving difficult 'wicked problems' that span many service domains. Crime, drugs, deprivation, and

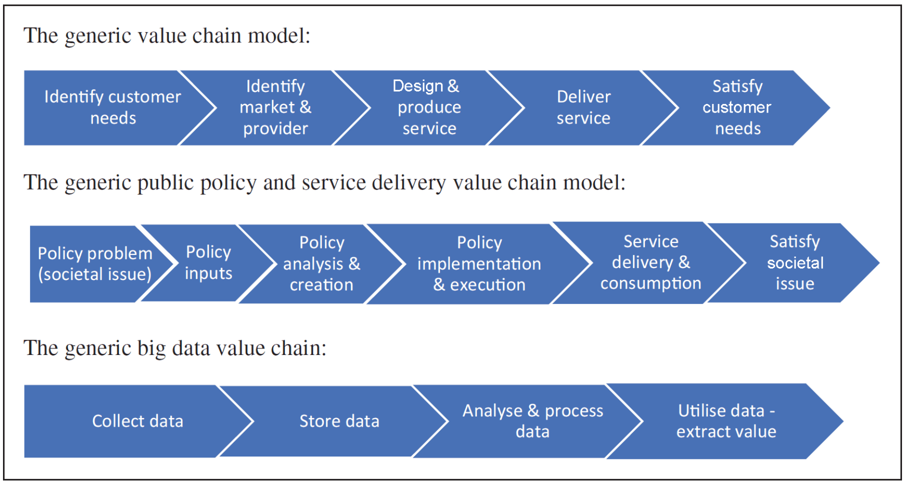

Figure 3.16: Examples of different value chains present in a smart city (Löfgren and Webster, 2020).

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employment are all instances of issues that necessitate multi-agency solutions (Löfgren and Webster, 2020).

A big data value chain as illustrated in Figure 3.16 includes four sequentially connected operations, from data collection/mining through storage, analysis, and finally utilisation of the data (Löfgren and Webster, 2020). Another thing to keep in mind is that some of the classic technology difficulties experienced by public service providers, such as a lack of technical competency, personnel skills, and resources, are already present in the smart city environment (Abellá-García *et al.*, 2015). The specific challenges of Big Data practices in smart city contexts differ depending on the stage of the value chain (Löfgren and Webster, 2020). The stages of the big data value chain developed in Löfgren and Webster (2020) are:

1. Data Collection: In a smart city, multiple data sets are likely to be collected by various stakeholders. Data can be provided voluntarily by users, customers, and citizens, as well as acquired automatically during digital transactions.

2. Data storage: The ultimate responsibility for data collection and storage in smart cities is likely to be shared between public sector actors (utility providers, local government, law enforcement officers, public transportation agencies and more) and a number of private sector actors (retail and hospitality industry companies, social media companies, data brokers, cloud providers, internet providers, telecoms companies and more). To fulfil the ostensible advantages of the smart city, strong connections between these players are required, as well as effective technical data flow across the organizations, technology platforms, and data sources involved.

3. Data analysis: There are three main points that are to be made when analysing data. One, at this stage, issues pertaining to different standards used in a variety of companies and technology for storing data can cause complications. Policies (and/or insufficient or absent policies) influence the potential of reaching common standards in information architecture, the use of algorithms, and the planning of consequences and effects in the context of smart city services. Two, when analysing data, be cautious of correlations as 'data cannot speak for itself' and not all correlations is necessarily correct. Three, algorithms in big data are capable of clarifying and extracting in 'real-time' key patterns to predict human behaviour. Finding a reliable algorithm is regarded as the key for the success of big data analysis. Remember that the process of developing algorithms is likely to promote modest institutional biases that reflect the actors' environment of operation when it was designed by a previous scientist for a specific purpose.

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4. Data utilisation: Thought should be given to the privacy of an individual during surveillance operations. When data is aggregated in large volumes, privacy is generally not an issue. But when data is restructured on an individual, this can be seen as a threat to that individual's privacy. Know that the better the quality and the larger the volume of the dataset, the more valuable the set becomes to the city. Note, at this stage, issues regarding intellectual property on algorithms used, source code, databases and software is not a new concern and will subsequently have to be dealt with.

3.7.5 Artificial intelligence

When large volumes of data is collected in a city, AI can serve as an effective means to quickly processes information for real-time decisions-making, and to make recommendations based on future predictions (Voda and Radu, 2019).

According to Yigitcanlar *et al.* (2020) in Figure 3.17, there are three levels of AI intelligence which can be classified as narrow, general and super intelligence. It is believed in Chavanel (2021) that all applications of AI to date are still instances of 'narrow AI'. In comparison, 'general-' or 'self-aware' AI, which refers to machines and computer systems with common sense and the ability to solve a wide variety of issues autonomously, like a human, have not yet been developed (Chavanel, 2021). The same applies to 'strong AI', or 'super AI' which would outperform a human in many jobs and is superior to 'general AI' which has also not to date been developed (Chavanel, 2021).

Although AI is still in the early stages, there are already many uses for AI in smart cities today according to Voda and Radu (2019). These uses were categorised in Figure 3.18 according to energy efficiency, security and privacy, government, healthcare, education, intelligent transportation and smart homes

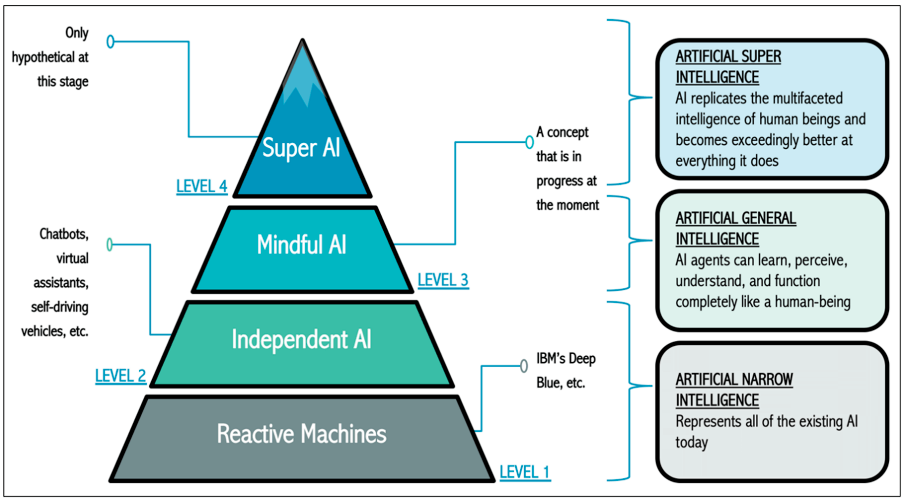

Figure 3.17: Artificial intelligence levels (Yigitcanlar *et al.*, 2020).

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(Voda and Radu, 2019).

In most infrastructures, including railway, the operation effectivity and capacity depends on this flow of information, as it helps appropriate planning and control to guarantee success in an established plan (Kumar and Mishra, 2021). For passenger and freight transportation there are two approaches to meet growing demands. One option is to expand or develop dependable infrastructure, which is an expensive operation. Another option is to optimise the existing infrastructure with developing intelligent algorithm-based software (Kumar and Mishra, 2021). This incorporates machine learning and artificial intelligence which can entail major cost saving (Kumar and Mishra, 2021). In Figure 3.19 the many facets of railway transportation in which artificial intelligence is currently playing an increasing role is shown. These include real-time operations management, customer analytics, predictive maintenance, and network planning and route design.

According to Rehman *et al.* (2020), the increasing use of AI in numerous fields, including infrastructure, healthcare, smart homes, social services, marketing, insurance, investing and banking has significantly altered the ergonomics of modern-day activities. Financial institutions are incorporating AI into their operations in a variety of ways, including in-house, outsourced, and ecosystem based (Ashta and Herrmann, 2021). As wealth managers and financial service provider's struggle with volatility, complexity, ambiguity and uncertainty, the rise of AI-based fintech companies has prompted numerous mergers and acquisitions, but companies need to be mindful of the risks associated with AI (Ashta and Herrmann, 2021). The potential of cost savings and greater uniqueness appeals to people or organisations from all walks of life. However, apart from fraud detection, these advantages may be dependent on an organization's size. It is maintained in Ashta and Herrmann (2021) that for the foreseeable future, risk minimization necessitates a careful division of labor between AI and humans.

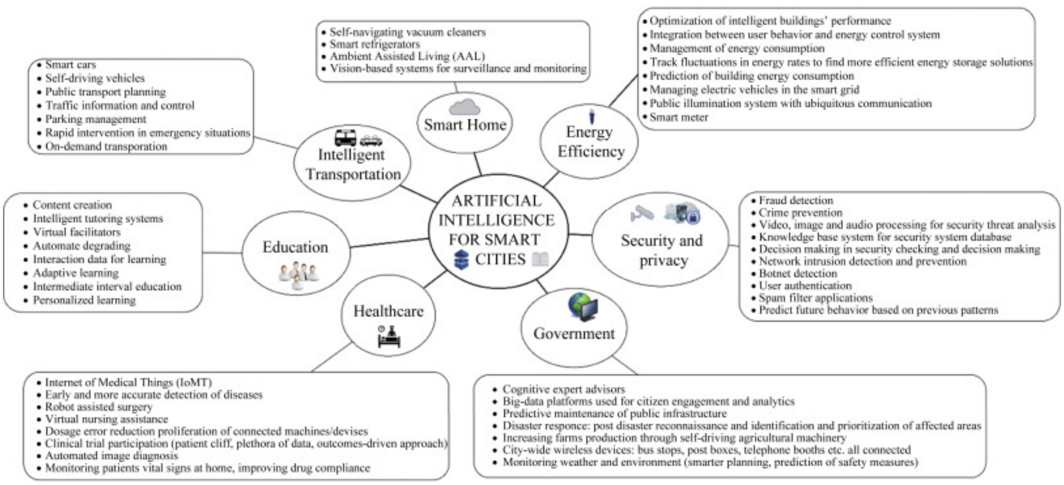

Figure 3.18: AI in smart cities (Voda and Radu, 2019).

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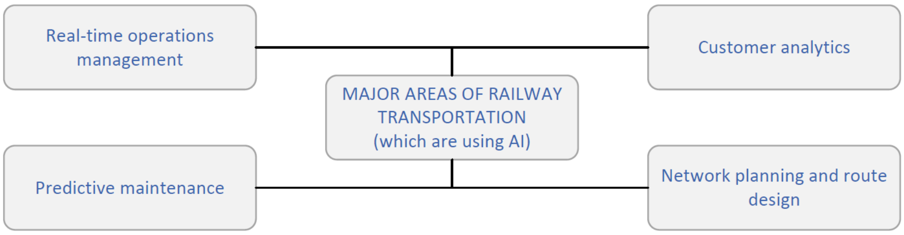

Figure 3.19: Areas of railway transportation in which artificial intelligence (AI) plays an active role. Reproduced from Kumar and Mishra (2021).

3.7.5.1 Seven principles for trustworthy AI

In Hleg (2019) seven principles were outlined for creating trustworthy AI systems. These principles can be applied when designing AI systems for cities. These standards apply to all stakeholders involved in the life cycle of AI systems, including developers, deployers, and end users, as well as the larger society. While all criteria are equally important, context and any conflicts between them must be considered when applying them across various areas and sectors. These principles are:

1. Human oversight and agency: Human autonomy and decision-making should be assisted by AI systems. AI systems must work as facilitators of a democratic, prosperous, and egalitarian society by promoting user agency and fostering basic rights, while also allowing for human monitoring.

2. Technical safety and robustness: This is strongly related to the notion of damage prevention. AI systems should be designed with a risk-averse mindset in order to reliably perform as expected while reducing unintended and unanticipated damage and avoiding intolerable harm. Possible changes in their working environment or the existence of other agents (human and artificial) that may engage antagonistically with the system.

3. Data and privacy governance: AI technologies influence privacy, a core right. Effective data governance is necessary and includes data quality and integrity, applicability to the area in which AI systems will be implemented, access processes, and the ability to handle data in a manner that respects privacy.

4. Transparency: To enable for traceability and increased transparency, traceability should be recorded to the highest feasible degree. Explainability refers to an AI system's ability to articulate both its technology operations and its human judgements. Users should not be misled by AI systems that pose as humans; instead, individuals have the right to be informed that they are dealing with an AI system.

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5. Diversity, fairness and non-discrimination: Keep an open mind about the AI system's lifespan. using inclusive design to provide equal access and treatment This condition is intertwined with the idea of fairness.

6. Environmental and societal well-being: The development of AI solutions that solve global issues, such as the Sustainable Development Goals, should be supported together with ecological responsibility and sustainability. All humans, including future generations, should profit from AI.

7. Accountability: Related to fairness in a similar manner, this principle requires procedures be put in place to assure responsibility and accountability for AI systems and their effects.

3.7.5.2 AI in cities

Smart cities are generally regarded as places where data and digital technology are extensively used to improve quality of life, economic development, and efficient resource management (Mora *et al.*, 2019). AI has been a topic of discussion in a variety of urban policy circles and discussions about smart city transformation, especially among urban planners and policymakers seeking technocentric answers to worrisome urbanisation issues (Kassens-Noor and Hintze, 2020). This popularity stems from the growing awareness of technocentric solutions as a possible cure for complex and intricate urbanisation problems spanning from climate change to quality of life, and from mobility and accessibility to safety and security (Yigitcanlar *et al.*, 2020).

According to Yigitcanlar *et al.* (2021), most attempts to use AI in cities to enhance city efficiency to date have either failed or struggled. The technology is still in an infancy stage for many of the current city challenges, but according to Yigitcanlar *et al.* (2020) due to significant study and advancements in artificial intelligence, it is anticipated that by 2035, our cities and society will shift from sophisticated machine language-based AI to AI that is likely completely functional and understandable by humans.

3.7.6 Blockchain as added security solution

The internet of things (IoT) has the potential to change how we think about information and communication technology (ICT) (Tseng *et al.*, 2020). IoT has been widely researched across several fields, including networking, security, business, communication, and management. However, there are still uncertainties, particularly in managing heterogeneous IoTs (Tseng *et al.*, 2020). Even though standard and conventional security solutions have been offered for IoT, there still remains privacy and security issues (Paul *et al.*, 2021). Many frameworks embrace IoT in smart cities, but from the cities' management perspective, they are exposed to some challenges, including security, diverse

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devices and data, support for various applications, resource management, and platform independence (Paul *et al.*, 2021). Providing security for IoT devices in a smart sustainable city can be a difficult task according to work in Xihua and Goyal. This is mainly due to the fragmented topology and resource limitations of IoT devices (Paul *et al.*, 2021).

To better understand, fragmented topology refers to the degree in which thousands of individual IoT devices are distributed over a city. Each of these devices has its own function to perform, is connected to a network, and forms part of a system. IoT devices generally have very limited resources or processing power. It only requires limited processing as its intended to do basic functions, for instance to measure carbon dioxide levels at specific locations in a city. Designing these devices with limited resources benefits lower production cost, lower power consumption and contributes towards a smaller form factor. The problem arises that these devices are individually connected to the internet and potentially lack the necessary resources to protect against cyber-attacks. Even, when properly installed and individually 'isolated' on a network, these devices can still be a vulnerability to the network.

During the course of time security deficiencies regarding IoT devices are continually discovered and must gradually be met with adaptation and remediation actions (Zhang *et al.*, 2021*c*; Cao *et al.*, 2019; Gross *et al.*, 2015; Amoozadeh *et al.*, 2015; Skarmeta *et al.*, 2014). In Tseng *et al.* (2020) and Ho *et al.* (2016) it is believed that weak and unprotected locations on a IoT network will possibly be discovered and exploited in a highly scalable and large-scale IoT system. As a result, effective, scalable, and secure administration of IoT systems with heterogeneous devices is critical (Tseng *et al.*, 2020). It is necessary to understand how IOT devices transfer data and where possible design factors could help in protecting them.

In IoT systems, data is constantly transferred from a device to the cloud, where it is analysed using analytics processes before being returned (Tseng *et al.*, 2020). The potential of utilizing blockchain as means to help solve many of the different IoT problems, and more, have surfaced several times in research (Paul *et al.*, 2021; Salimitari and Chatterjee, 2018; Fernández-Caramés and Fraga-Lamas, 2018). Blockchain could potentially be used to better encrypt the communication and the transfer of data from and to IoT devices.

The basic structure of a blockchain is represented in Figure 3.20. Each block of the chain in Figure 3.20 has a header and a body, with the header containing the identifier of the previous block, and the content containing recorded transactions in a Merkle tree (Tseng *et al.*, 2020). Merkle trees are a popular data structure for storing and validating data on a blockchain (Zhou *et al.*, 2021). A Merkle tree is an important part of blockchain technology because it eliminates the requirement to download all transaction data to verify if a transaction was authorised by the entire network (Zhu *et al.*, 2021). A timestamp is also stored in each block header in the blockchain, which helps to guarantee the traceability of the data recorded in the blockchain.

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One advantage of blockchain is that when the content of a block in a blockchain block has been modified, it causes equivalent modifications in all future blocks linked to it. This would mean that if an attacker wishes to alter the contents in the header of a block, a completely new blockchain would be obtained and will cause equivalent modifications in all future blocks linked to it, making the change detectable and traceable (Zhu *et al.*, 2021). It is this property of a blockchain that was first used with Bitcoin to address the issue of double spending (Christidis and Devetsikiotis, 2016; Nakamoto, 2009). Double spending occurs when money is effectively spent more than once (Karame *et al.*, 2012). Similarly, smart contracts utilize blockchain's decentralized consensus process, which enable mutually distrusted parties to execute data exchange or transactions without the requirement for a third-party trusted authority (Li *et al.*, 2020).

An example of how blockchain can be applied in conjunction with IoT and sustainability projects is the TransActive Grid case, which tested the peer-to-peer market for renewable energy in a Brooklyn neighbourhood (Cali and Fifield, 2019). Blockchain enabled IoT based energy meters to automatically sell, and purchase energy on criteria set by users. It enabled the surplus energy produced by a home's solar panels to be logged on the blockchain and sold to a neighbour through smart contracts (Cali and Fifield, 2019).

In closing, blockchain has the potential to enable the creation of robust, distributed peer-to-peer interactions and networks in an auditable manner, even in low-trust environments (Christidis and Devetsikiotis, 2016). Blockchain can preserve the five fundamental cryptographic primitives in IoT. These cryptographic primitives are authenticity, confidentiality, integrity, non-repudiation, and availability (Paul *et al.*, 2021). It is believed in Tseng *et al.* (2020) that integrating blockchain and IoT would provide more resilient, distributed peer-to-peer networks for smart city sensors, devices and networks with sensitive data, with auditable interactions.

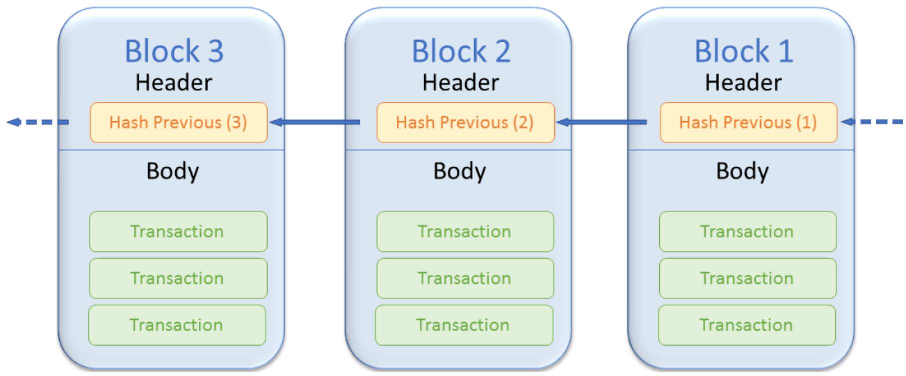

Figure 3.20: Representation of a blockchain structure (Tseng *et al.*, 2020)

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3.8 Greening

According to Jabareen (2006), green urbanism, is an essential design principle for the development of a sustainable urban form and contributes to the sustainability agenda. Greening aims to integrate nature into city life via a variety of open landscapes, while simultaneously making settings more attractive (Jabareen, 2006). Several additional advantages exist from urban greening:

1. Protecting the sustainability of biodiversity amid urban development activities (Esmail *et al.*, 2022).
2. Protecting and improving the well-being of human health and livelihoods (Kelly *et al.*, 2022; Esmail *et al.*, 2022).
3. Beneficial for schools as an outdoor education unit shown to improve child behavior and learning (Baro *et al.*, 2021).
4. Educative as a representation of nature (Baro *et al.*, 2021).
5. Improving on problems such as urban flooding, heat-islands and pollution while providing a potential cost effective solution (Cuthbert *et al.*, 2022).

Reports have surfaced in the past of cases where certain areas in a city that has undergone greening, for instance in Chicago, caused gentrification. Although this is not always the case, consideration should also be given to the social effects when planning greening areas in a city (Rigolon *et al.*, 2020).

3.9 Biodiversity in cities

Urban diversity entails the amount and variety of living species in a city (Puppim de Oliveira *et al.*, 2014). Human activities, such as urbanisation and agriculture, have caused considerable harm to the natural environment. Habitat restoration and development have been employed to combat the consequent biodiversity loss (Bretzel *et al.*, 2016).

According to Prominski (2019) the success of designing for urban biodiversity relies on the pursuit of a delicate equilibrium between the human benefits deriving from the experience of biodiversity in the city and the requirements of the natural environment. It is believed in Gottlieb and Girguis (2022) that there are an abundance of ways in which biodiversity can be fostered.

3.10 Ecosystems

Conserving ecosystems in urban regions is a challenging task (Tobias, 2013). Urban landscape planning is necessary for sustaining vital ecosystem

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services (ESs) in fast developing urban regions and is one of the key areas to address in landscape ecology and urban ecology (Zhang *et al.*, 2019).

Many European urban areas have a high building concentration in the city center and neighbouring municipalities, as well as increasingly dispersed settlements on the urban outskirts (Tobias, 2013). As demonstrated by the work in Tobias (2013), this settlement pattern can provide a wide range of ecosystem services as long as individual settlement units possess clear external boundaries and attractive and functional public green spaces. Spatial planning can help to preserve ecosystem services in three ways (Tobias, 2013):

- fostering cooperation between municipalities for holistic planning and specific development target points,
- establishing settlement boundaries, and
- compensation for the sealing of new soil.

3.11 Sustainable cities

It is known that more than half the global population resides in cities, where resource use is *increasingly originating*. Increasing urban densification has intensified urbanisation issues and the need for sustainable development practices, which led to the emergence of the sustainable cities concept, portrayed in Figure 3.21 (Perlman and Sheehan, 2007). Sustainable city practises are centred around a combination of the following priorities (Tabibian and Movahed, 2016):

- Minimising the urban ecological footprint by having an awareness that a limit (carrying capacity) exists to the land and resources (water, energy, food, minerals, and materials) available to carry the consumption and waste production of the city, protecting biological life; and
- Valuing social and economic innovation and balance without neglecting its responsibility to decrease its carbon footprint (in essence, improving the quality of life while using less resources); and
- Governance in a manner that recognises and promotes sustainability innovations by involving the community, businesses, and government. Pride is shown in the creativity and expressions present in sustainability applications that embrace the city's uniqueness. Communicating with other cities regarding insights and findings from these implementations that could serve as examples or models.

It is widely accepted by industry professionals, scholars, and government representatives that a key driver for sustainability is innovation (Silvestre and Ţîrcă, 2019). Making cities more sustainable requires the modernisation or

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Figure 3.21: A typical image used to convey the perceived difference and implications between a conventional city (left) and a sustainable city (right) (Word Bank, 2017).

replacement of infrastructure with new, more sustainable systems, designs and practises.

3.12 Aspects and examples in sustainable cities

3.12.1 Sustainable transportation

Cycling is gaining more traction in the sustainable city movement as it can be considered as an alternative for automobility that is non-polluting and affordable (Soliz, 2021). Research in Soliz (2021) emphasized the importance of, and drew conclusions on creating temporary or makeshift cycling lanes in cities to help re-envision sustainable transportation systems and monitoring social movements, before implementing permanent infrastructure (Soliz, 2021). By doing so a city planner can much better predict user behaviour before investing in a permanent solution.

In Göddeke *et al.* (2021) data from eighty large German cities were analysed to better understand German transport dynamics and car-sharing's potential as a catalyst for sustainable transport in cities. From the data analysed in Göddeke *et al.* (2021) it was found that car-sharing numbers, as a mode of transportation in Germany, has increased on both the user and demand side. It is shown that station-based car-sharing is offered in most German cities with free-floating services as an extension mostly in metropolises.

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By using multinomial logistic regressions, the influencing factors on sustainable mobility practices were investigated (Göddeke *et al.*, 2021). Factors such as an individual membership to a car-sharing group or the density of car-sharing vehicles in an individual's city prove to be less influential. Rather many influential factors were found to be individual mobility tools such as bicycle ownership, public transport pass membership, corresponding infrastructure, or the total cars in the family home (Göddeke *et al.*, 2021). Thus, as argued in Göddeke *et al.* (2021), by merely increasing the concentration of car-sharing availability or seeing an increase in the membership of car-sharing services, is not a reliable indicator to show progress has been made towards changing patterns leading towards sustainable transportation. Instead, it was found in Göddeke *et al.* (2021) that the number of privately owned cars is a better means to predict sustainable transportation behaviour in German cities. It is recommended on a policy level in Göddeke *et al.* (2021) to reduce the attractiveness of private car ownership and increase demand for car-sharing to reduce carbon emissions.

In Rampalli *et al.* (2020) it is believed that current road transport infrastructure not sufficiently designed to fully accommodate modern advancements made in vehicle technologies and intelligent transportation systems (ITS). Accordingly, research done in Rampalli *et al.* (2020) investigates the potential of better accommodating autonomous vehicles (AV) in current transportation infrastructure with simulations done on Singapore city. From the research it was found that urban planners can not only increase transportation safety, but also decrease overall congestion and travel time (Rampalli *et al.*, 2020). In keeping with the findings, by including physically separate AV bays throughout a city, the mean AV travel time can be reduced by 5%. Overall traffic congestion lengths at a signal or near a bus stop can be reduced by 27% because of this arrangement (Rampalli *et al.*, 2020). In effect, being more efficient can reduce the carbon footprint of urban traffic and by allowing AVs to move more effectively, they can become more attractive for car-sharing.

3.12.2 Renewable energy management

Energy systems are essential for the modernisation of a city, since practically all activities in a city require energy (electricity and/or gas) (Mahmud *et al.*, 2021). Focusing on renewable energy sources to produce only electrical energy is not a sufficient way to establish a holistic energy supply at a large scale (Drozd, 2020). As illustrated in Figure 3.22 and expressed in Drozd and Kowalik (2021), it is important to investigate various types of energy technologies to efficiently convert and manage renewable energy sources into more sensible forms of energy outputs that can be utilised, such as heat, chemical and electrical energy.

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It is known that power consumption levels in cities are much higher than in suburban and rural areas (Mahmud *et al.*, 2021). Even though the energy system is an essential element of any city (smart or sustainable), there is not enough focus on managing the resource according to Mahmud *et al.* (2021). As such, smart grids can help to facilitate the management of energy efficiently from renewable and sustainable sources such as solar, wind, and battery energy storage systems (Mahmud *et al.*, 2021).

Smart grid covers the economic advantages of a sophisticated and modern power grid to meet increasing sustainability and energy efficiency obligations (Saidani Neffati *et al.*, 2021). Infrastructures such as a smart grid can rapidly and efficiently coordinate power-sharing across multiple renewable energy sources (residential or regional) to offer dependable, secure, and cost-effective power grid services (Mahmud *et al.*, 2021; Saidani Neffati *et al.*, 2021). Power control is a difficult task that involves scheduling linked devices to maximize energy use (Saidani Neffati *et al.*, 2021). The main advantage of smart grids in energy systems is the creation of new electric grids for computers and technology. Smart grid technology includes hardware and software. To

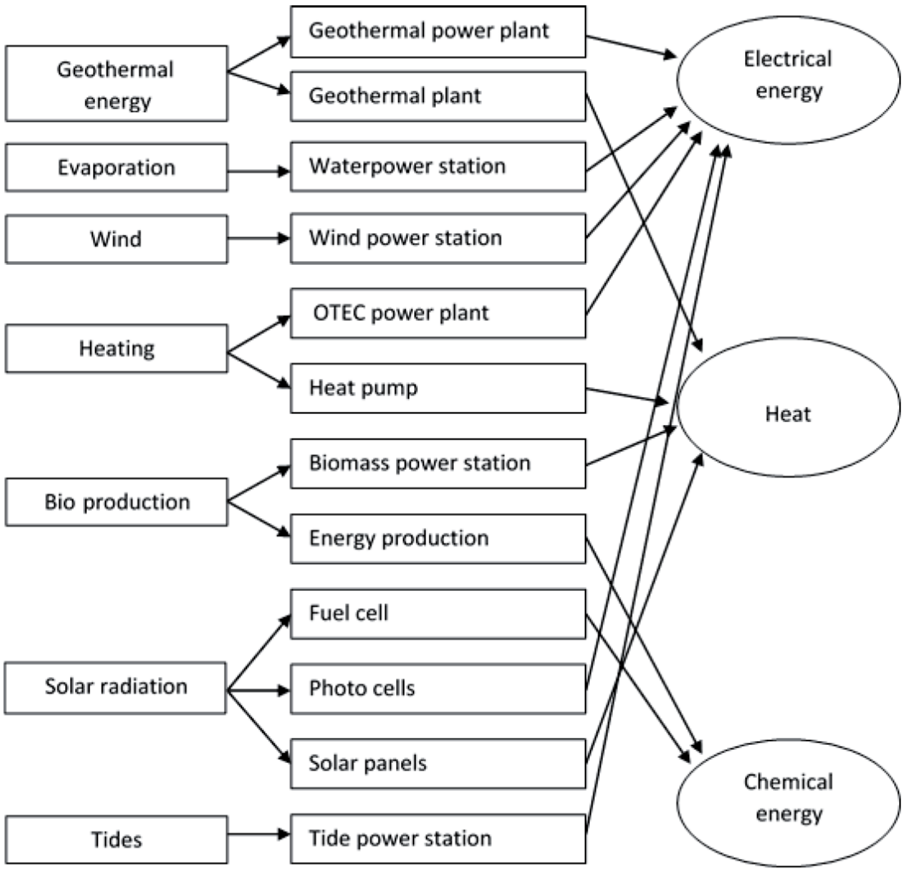

Figure 3.22: Renewable energy sources, technologies, and possible energy outputs (Drozd and Kowalik, 2021).

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make energy consumption precise and helpful, the phrase "smart grid" involves digital advances, sensor systems, and ICTs (Saidani Neffati *et al.*, 2021).

There are many techniques for optimizing energy in cities, but real time energy optimisation is still under development, for example research in Khalil *et al.* (2021). A hybrid smart grid obtains energy from a variety of sources, including photovoltaic, hydro, and thermal electricity. The research in Khalil *et al.* (2021) entails developing resources in a smart grid for efficient real-time power operations management, as well as to model sustainable energy from all-natural sources and the effective distribution of energy in a city.

Energy conversion from the generating station to the distribution system or the consumer end is quite expensive in modern power grids (Khalil *et al.*, 2021). It is essential to also leverage energy from local renewable sources, which may be done through a smart grid using a variety of techniques which include monitoring, controlling, and projecting (Khalil *et al.*, 2021).

Wind and solar energy may potentially completely replace high-emission energy sources (Khalil *et al.*, 2021). It is believed that smart cities can meet their power requirements using the proper management of renewable energy sources. Globally, the needs for energy in cities will only rise in time (Khalil *et al.*, 2021). Unsustainable energy sources will not be available forever and will therefore not be able to keep up with future energy requirements. The management of different sustainable energy sources will be of essence in future cities to meet their energy requirements (Khalil *et al.*, 2021).

3.12.3 Biogas recovery in sustainable cities

In most modern cities, wastewater treatment plants (WWTP) are one of the major energy-intensive activities (Daneshgar *et al.*, 2018; Gandiglio *et al.*, 2017). According to estimates, these facilities alone may consume between one and three per cent of a country's entire electric energy production, accounting for a considerable portion of municipal energy costs (Capodaglio and Olsson, 2020). Even if older plants may have greater needs, the specific energy consumption of state-of-the-art facilities should vary between 20-45 kWh per population-equivalent serviced each year (Capodaglio and Olsson, 2020).

In a conventional wastewater treatment plant, the physical-chemical properties of the wastewater to be treated, as well as the final application of the treated effluent, are factors that influence the amount of treatment required in the plant (Stamatelatou and Tsagarakis, 2015). Energy usage in the conventional activated sludge (CAS) process currently ranges from $0.26 - 0.68 kWh/m^3$ of treated wastewater, with an average of $0.47 kWh/m^3$ (Liu *et al.*, 2020). According to Tchobanoglous *et al.* (2015), on average, the activated sludge aeration process consumes 55 per cent of the energy required in a WWTP; primary settling, and sludge pumping are the stages with the second-highest energy requirement (Tchobanoglous *et al.*, 2015).

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As detailed in Capodaglio and Olsson (2020) and Smith *et al.* (2018), anaerobic digestion is considered the most energy-intensive process in sewage sludge treatment (approximately 14 per cent of a WWTP's overall energy consumption) when compared to gravity thickening and dewatering units. But additionally, anaerobic digestion is a process that generates energy. Roughly $0.27kWh/m^3$ of electrical energy may be recovered by anaerobic digestion of sewage sludge, implying that the energy recovered in a WWTP could counterbalance about 50-60 per cent of the plant's total input energy consumption (Liu *et al.*, 2020).

In Chrispim *et al.* (2021) it is hypothesized that municipal WWTP has the potential for improving energy efficiency and lowering greenhouse gas emissions by utilising energy recovery. However, most WWTPs that generate biogas through sludge digestion do not include thermal energy recovery or power production, and the biogas is flared and squandered, especially in developing countries (Chrispim *et al.*, 2021). Research in Chrispim *et al.* (2021) is focused on examining current technical developments in biogas recovery from wastewater treatment, as well as local circumstances that influence adoption. The recovery of biogas in megacities is maintained in Chrispim *et al.* (2021) as being hampered by a lack of government incentives and a poorly developed and regulated biogas market.

3.12.4 An overview of energy recovery from wastewater and biosolids

Techniques and methods for recovering energy from wastewater include using heat pumps for thermal energy recovery; making biogas from anaerobic digestion; burning biosolids or using pyrolysis; employing bio-electrochemical technologies; producing microalgae; and utilising bio-thermochemical sludge treatment (Musfique *et al.*, 2015). As depicted in Figure 3.23, hydroelectricity can be generated by channelling the treated effluent through turbines when released into the river. This can only be achieved if there exists an ample liquid flow rate and a sufficient head difference between the treated effluent and the river (Mo and Zhang, 2013). Added benefits from using effluent hydroelectricity is that the dissolved oxygen concentration increases in the effluent after passing through the turbines (Gaius-obaseki, 2010). Additionally, other renewable energy options include installing solar energy or wind turbines on available areas of the plant (Kretschmer *et al.*, 2016).

In Figure 3.24 a summary of the available renewable energy sources in a WWTP is presented. The words in brown italics (Figure 3.24) represents technologies that are emerging or recent and still require optimisation and further research before they can be applied in large-scale applications. Words in black (Figure 3.24) represent well-established technologies already used in large scale municipal WWTPs (Chrispim *et al.*, 2021). Biodiesel, biohydrogen

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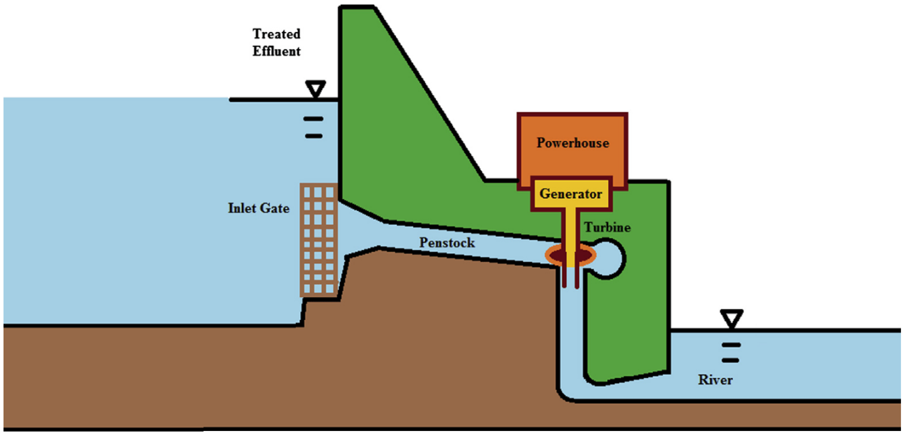

Figure 3.23: Effluent hydropower schematic for a WWTP. Adapted from Mo and Zhang (2013).

and bioethanol are among the other technologies currently in development to recover bioenergy. However, as compared to anaerobic systems, they currently have a lower feasiblity (Chrispim *et al.*, 2021; Puyol *et al.*, 2017).

In Figure 3.25 the flow and distribution of chemical energy is illustrated during the treatment of effluents. In a WWTP, some of the chemical energy in the liquid stream is removed during preliminary and primary treatments as sludge and screening material. Part of the chemical energy is converted into biomass and gaseous by-products in biological treatment processes, or dissipated as heat by the micro-organism's metabolism (Tchobanoglous *et al.*, 2015). When studying the energy flows in a WWTP, it was found in Silvestre *et al.* (2015) that two-thirds of the initial energy content of raw wastewater is converted to sewage sludge, and the anaerobic digestion process through biogas may recover half of the energy stored within the sludge, which equates to a third of the initial energy content in raw wastewater.

As described in Capodaglio and Olsson (2020), the low efficiency of biogas production from anaerobic digestion is the primary shortcoming. According to

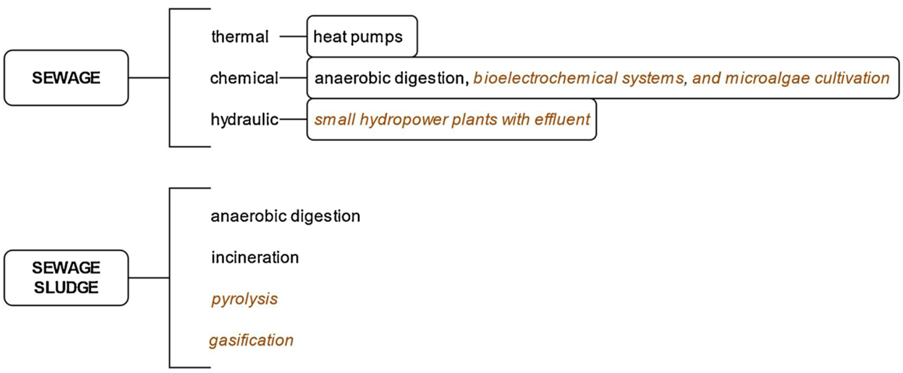

Figure 3.24: Summary of the available renewable energy sources in a wastewater treatment plant (Chrispim *et al.*, 2021).

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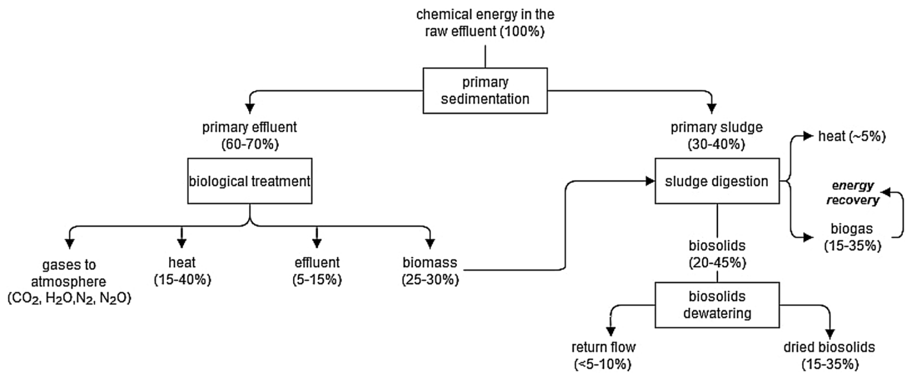

Figure 3.25: Chemical energy distribution throughout the treatment of effluents with activated sludge and anaerobic digestion of sludge. [*A percentage fluctuation range was provided given the variety of treatment methods and effluent properties*] (Tchobanoglous *et al.*, 2015).

Gandiglio *et al.* (2017) only about half of the energy consumed by a WWTP may be provided by biogas from anaerobic digestion. It is believed in Chrispim *et al.* (2021) that there are several ways to improve the yield of biogas at a WWTP, including pre-treatment of sewage sludge or co-digestion. These means for improving biogas yield are further explored in Chrispim *et al.* (2021) towards achieving an energy self-sufficient WWTP.

Self-sufficient in terms of energy usage at WWTPs, describes facilities that generate all or more of the energy they require for operation purely from the energy present in the wastewater and wastes they treat, without the use of external energy sources (Gu *et al.*, 2017) and has globally become a popular topic among scholars (Sarpong *et al.*, 2020).

In conclusion, work done in Chrispim *et al.* (2021) strongly suggests that the potential for higher biogas yields towards achieving an energy self-sufficient WWTP is possible. Funding for research and stronger policies for energy recovery in WWTPs is recommended as part of the climate change agenda. It is believed in Chrispim *et al.* (2021) that the research can support policymakers and planners with decision-making and aid future research.

3.13 Comparison of smart versus sustainable

Research in Ahvenniemi *et al.* (2017) focused on determining the differences between smart cities and sustainable cities through analysis of all available literature. Although this analysis is debatable depending on the scenario or viewpoint, it is still a good example to note that often smart vs. sustainable have different priorities and yet the ability to complement one another. Through the literature studies the following key observations were made in Ahvenniemi *et al.* (2017): As with the general perception, smart city frameworks place a higher premium on contemporary technology

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and "smartness" than urban sustainability frameworks do. Additionally, whereas urban sustainability frameworks include a significant number of indicators assessing environmental sustainability, smart city frameworks exclude environmental indicators in favour of emphasising economic and social elements. These trends among smart cities and sustainably cities were also noted in Strelkova *et al.* (2020).

Smart city approaches in the literature is mostly divided between two components: an ICT and technology-centric approach; or a people-centric approach (Ahvenniemi *et al.*, 2017). While sustainability is generally defined as taking economic, environmental, and social effects into account concurrently, it was observed through work in Ahvenniemi *et al.* (2017) that the evaluation for sustainable cities typically have a strong environmental emphasis. Further tests showed that the variation in indicator distribution across the three aspects of sustainability is substantial for environmental and economic sustainability, but not for social sustainability (Ahvenniemi *et al.*, 2017). These results are also consistent with the findings shown in Figure 3.26a.

Ten sector classifications for social sustainability were used for comparisons in Figure 3.26b. These ten sectors are: natural environment; built environment; water and waste management; transport; energy; economy; education, culture, science and innovation; well-being, health and safety; governance and citizen engagement; and ICT (Ahvenniemi *et al.*, 2017). Although the focuses of both the frameworks in sustainability and in smart cities are substantially different, as illustrated in Figure 3.26b, both sustainability and smart city frameworks have a strong focus on the well-being, health, and safety of a city. This is similar to the finding presented in Figure 3.26a where both sustainable cities and smart cities place a strong and almost equal focusing on the social sustainability dimension.

From the sub-figures in Figure 3.26, both the economic dimension and economic indicator stands out to be the area where the focus of sustainable cities and smart cities vary the most. It is shown that smart cities place much higher value on the economic dimension or economic indicator in the available frameworks. Almost equally different, sustainable cities place a much higher value on the environmental sustainability dimension (Figure 3.26a) or indicators for natural environment, built environment, water and waste management, and transportation (Figure 3.26b).

3.14 City challenges

The relentless growth of cities offers challenges that must be reframed continually for population growth, economic development, and social advancement to progress forwards (Keshvardoost *et al.*, 2018). A smart city project should not utilize the same techniques in every metropolitan region

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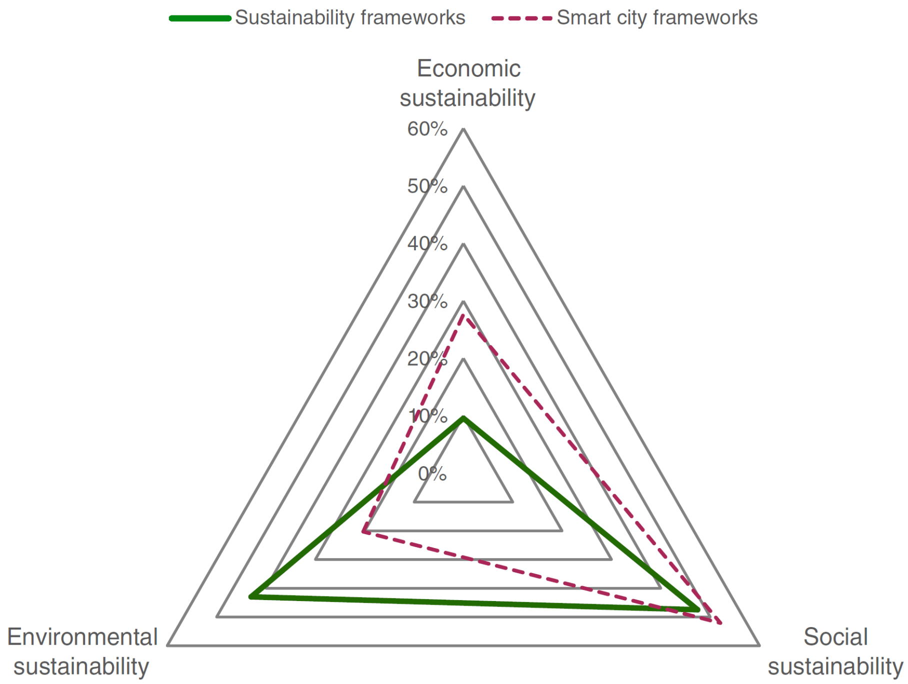
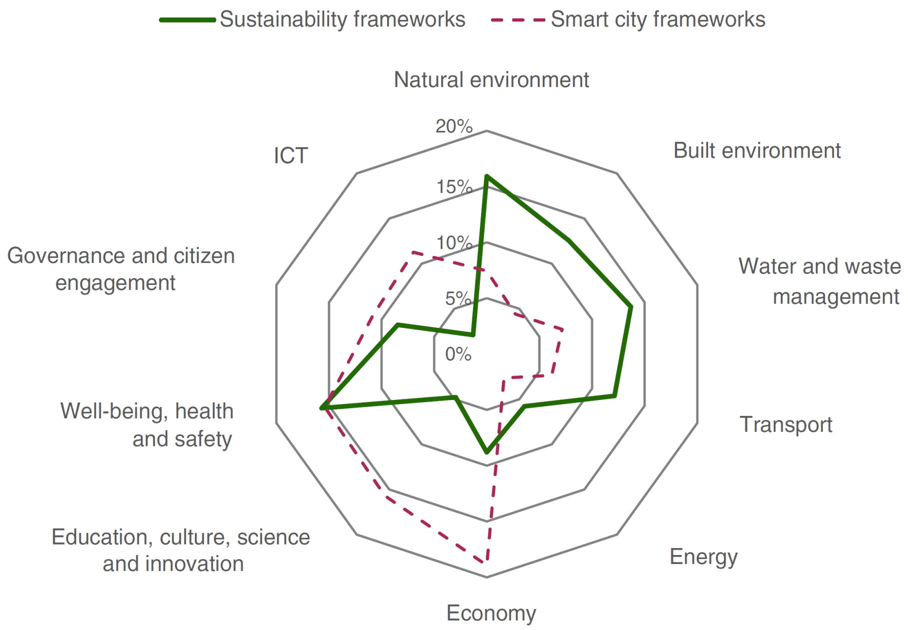


(a) Comparison of the three dimensions of sustainability in frameworks on sustainable cities and smart cities.



(b) Comparison of the different indicators in the social sustainability dimension in frameworks on sustainable cities and smart cities.

Figure 3.26: Comparison of sustainability dimensions and social sustainability dimensions in frameworks on sustainable cities and smart cities (Ahvenniemi *et al.*, 2017).

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given that problems, starting circumstances, available resources, and people's desire might all be quite different (Monzon, 2015).

Work in Monzon (2015) explores the challenges and concept of smart cities in the Mediterranean Region. In many south Mediterranean cities, becoming smart involves offering certain essential services that are lacking, which underscores the importance of considering shortcomings and changes needed in the northern Mediterranean cities system. South Mediterranean towns may have more basic difficulties than northern cities, nonetheless the transferability of projects between cities may be helpful in avoiding repeating mistakes (Monzon, 2015).

In Figure 3.27, a graphical illustration is presented of the relationship between general city challenges, smart city dimensions and challenges in the North, South and East Mediterranean when assessing the possibility of smart cities in the region (Monzon, 2015). An ASCIMER (assessing smart cities in the Mediterranean Region) viewpoint on city concerns was used in

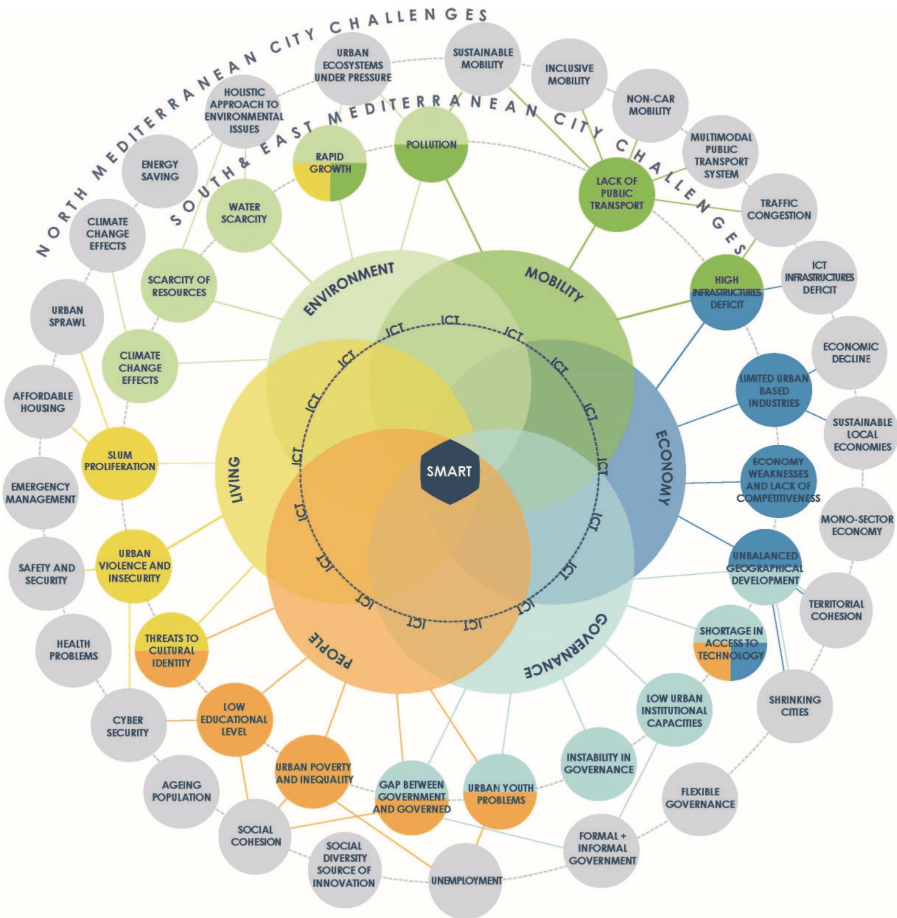

Figure 3.27: A worldwide graph illustration of the relationship between general city challenges, smart city dimensions and challenges in the North, South and East Mediterranean (Monzon, 2015).

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Figure 3.27 in the single worldwide graph. The UPM (Universidad Politecnica de Madrid) created ASCIMER for the EIBURS (European Investment Bank under the EIB University Research Sponsorship Programme) call on "Smart City Development: Applying European and International Experience to the Mediterranean Region" (Monzon, 2015).

As a starting point for ASCIMER's initiative, every smart city evaluation should respond to the genuine difficulties that cities in the twenty-first century face (Monzon, 2015). The many challenges in the North and South interrelate, emerging within the aspects of development and service supply to residents. When discussing smart cities or smart city initiatives in the southern Mediterranean areas, it is important to consider the distinctions between the south and the respective northern counterparts (Monzon, 2015). An example would be the requirement for an effective public transportation system in many south Mediterranean cities, whereas other cities operate at a more basic level and only require a public transportation system. To solve public transportation, the focus shouldn't reside solely on solving the current problem, but additionally factor in future problems, including system sustainability, inclusiveness of the transport system, non-car mobility, and the reality of an effective multi-modal network (Monzon, 2015).

Drawing on Figure 3.27, there are probable connections between the southern Mediterranean city's difficulties and the general city challenges. It is therefore important that future cities will need a comprehensive strategy to satisfy citizens' demands because of the complexity of the issues at hand (Monzon, 2015). It is also clear in Figure 3.27 that a challenge can be multi-faceted. This calls for a holistic approach by collaborative and horizontally integrated effort to better comprehend the complexity of the challenge.

Keshvardoost *et al.* (2018) has identified the possibility of grouping European city challenges within the six smart city dimensions (economy, governance, mobility, environment, people, and living) by Giffinger *et al.* (2007) presented in Section 3.19. These dimensions relate to the aspects that a smart initiative uses in attempting to obtain the goal of a smart city technique, sustainability, efficiency, and high quality of life (Keshvardoost *et al.*, 2018). Even though technology is not yet regarded as an action field, it is viewed as an empowering influence increasing task productivity (Giffinger and Gudrun, 2010).

Improvements can be made to various fields within the structure of cities (Keshvardoost *et al.*, 2018), ultimately to create better places for humans to live. While a smart city has the potential to improve our cities, it also has the potential to unintentionally exacerbate existing inequities (Wang *et al.*, 2021). Persons with disabilities and elders may face social and digital exclusion in communities if proper inclusion initiatives are not implemented (Wang *et al.*, 2021).

There exists a desperation to address challenges faced by cities, as revealed

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through demographic changes and the financial crises (Keshvardoost *et al.*, 2018). According to Keshvardoost *et al.* (2018) the difficulties faced by smart cities today is not the only significant factor to be acknowledged. The future outcomes of cities because of the suggested actions to address current challenges need to be considered. An idea that also appeared in the record of the European Commission "Cities of tomorrow" (European Union Regional Policy, 2011). The decisions made regarding the urban planning and administration will affect the long-term outcomes. The use of a comprehensive approach allows each of the challenges to be directed in relation to the smart city activity fields, as evident in Table 3.3 (Keshvardoost *et al.*, 2018).

Table 3.3: Current challenges facing European cities (Keshvardoost *et al.*, 2018).

Economy	Governance	Mobility	Environment	People	Living
Unemployment	Flexible governance	Sustainable mobility	Energy saving	Unemployment	Affordable housing
Shrinking cities	Shrinking cities	Inclusive mobility	Shrinking cities	Social cohesion	Social cohesion
Economic decline	Territorial cohesion	Multimodal transport system	Holistic approach to environmental and energy issues	Poverty	Health problems
Territorial cohesion	Combination of formal and informal government	Urban ecosystem under pressure	Urban ecosystem under pressure	Ageing population	Emergency management
Mono-sectoral economy		Traffic congestion	Climate change effects	Social diversity as source of innovation	Urban sprawl
Sustainable local economies		Non-car mobility	Urban sprawl	Cyber security	Safety & security
Social diversity as source of innovation		ICT infrastructure deficit			Cyber security
ICT infrastructure deficit					

Keshvardoost *et al.* (2018) describes the challenges faced by smart cities in Table 3.3. Some of the primary challenges faced by *smart governance* in a city requires a change with regards to the government model. *Smart economy* looks towards improving the productive structure of a city. *Smart mobility*

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progresses towards a sustainable, inclusive, and efficient mobility system for goods and people. On the level of *smart environment* action field challenges related to the environment, whether artificially built or natural are approached. Another action field, *smart people*, aims to enhance social connectedness and the quality of life. The last field is concerned with the flourishing of the community, and attempts to overcome problems regarding housing provision, health conditions and the concerning crime rate (Keshvardoost *et al.*, 2018).

3.15 Urban development

There are several reasons why cities exist, including political, economic, and social factors (Papageorgiou *et al.*, 2021). Cities have traditionally been the primary centres for trade, business, and governance as well as the exchange of goods, ideas, and services (Francis and Thomas, 2022). Cities have played a significant role as centres of religion, culture, and education. Cities have been more significant in recent years due to their role in facilitating access to resources, employment opportunities, and amenities (Papageorgiou *et al.*, 2021; Francis and Thomas, 2022; Snieška and Zykiene, 2014).

Cities keep expanding for a number of reasons, such as economic opportunities, population growth, and resource availability (Tobias, 2013; Shertzer *et al.*, 2018). Urban expansion is often fuelled by economic opportunity since cities typically have more employment and higher wages than rural areas (Helbing, 2009; Perlman and Sheehan, 2007). Urban expansion may also be significantly influenced by the accessibility of resources such as housing, transportation, and infrastructure, as well as people looking for a more diverse range of opportunities and a better quality of life (Juraschek, 2022; Martínez *et al.*, 2021).

Urban economics offers the most comprehensive understanding of the economic geography and structures of urban areas. This area of research examines the factors that influence the formation and growth of cities, as well as the economic activities that occur there (Reicher, 2017). The concept of agglomeration economies, which refers to the propensity of firms to cluster together in cities owing to the advantages of proximity, is one of the most important components of urban economics (Albertí *et al.*, 2017; Currid, 2006). Sharing of resources like capital and labour, as well as of creativity, knowledge, and ideas, may all occur in agglomeration economies.

Shared supplies of intermediate goods, skills marketing, knowledge spill overs, innovation, large common labour markets and similar topics are all important features of urban development, economics and sustainability (Tabibian and Movahed, 2016). Cities with active labour markets allow for the effective deployment of labour resources, as well as access to better incomes and more employment options (Elhadad *et al.*, 2019). Spill overs of innovation and knowledge, which enable the exchange of ideas and the creation of new

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technologies, are significant forces behind economic progress (Neal, 2012; Hodson *et al.*, 2012*a*; Silvestre and Ţîrcă, 2019). It is stated in Denis *et al.* (2021) that these topics are essential and geared towards the establishment of sustainable and economically vibrant cities.

3.16 Smart sustainable city drivers

According to Townsend (2013) many of the urban problems originate from the growth in urban population and given that newer and smarter solutions are sought as means to address the associated challenges. Höjer and Wangel (2015) identified five key drivers for smart sustainable cities, and these are:

- sustainable development and the globalisation of environmental problems;
- urbanisation and urban growth;
- sustainable cities and sustainable urban development;
- information and communication technologies; and
- smart cities.

Cities also play a key role in economic development worldwide (Papageorgiou *et al.*, 2021) as they serve as hubs for innovation (Currid, 2006) and smart sustainable cities can serve to keep them competitive. In Figure 1.2 (Chapter 1.1) the idea of smart sustainable cities is illustrated as an amalgamation of both sustainable and smart city concepts and therefore both concepts should also be understood.

3.17 The role of infrastructure in cities

Cities are of increasing importance in the regional, national, and global economy (Snieška and Zykiene, 2014). According to Monstadt (2007), a city and region's economic, environmental, and social performance is directly influenced by the critical infrastructure.

The efficient functioning of a city's critical subsystems is very important to support future sustainable urban infrastructure development (Bulu, 2011). In this sense, smart ICT approaches provide efficiency, flexibility and real-time management on infrastructures and the resource flows within it (Dong *et al.*, 2017).

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3.18 The fourth industrial revolution

The industrial revolutions map in Figure 3.28 is an illustration of how the first industrial revolution came with steam-powered factories; the second industrial revolution with the introduction of science to manufacturing and mass production; the third industrial revolution with the start of digitalisation; and finally the fourth industrial revolution (Industry 4.0) of which some technologies include genome editing, artificial intelligence, augmented reality, 3-D printing and robotics (Schwab, 2022).

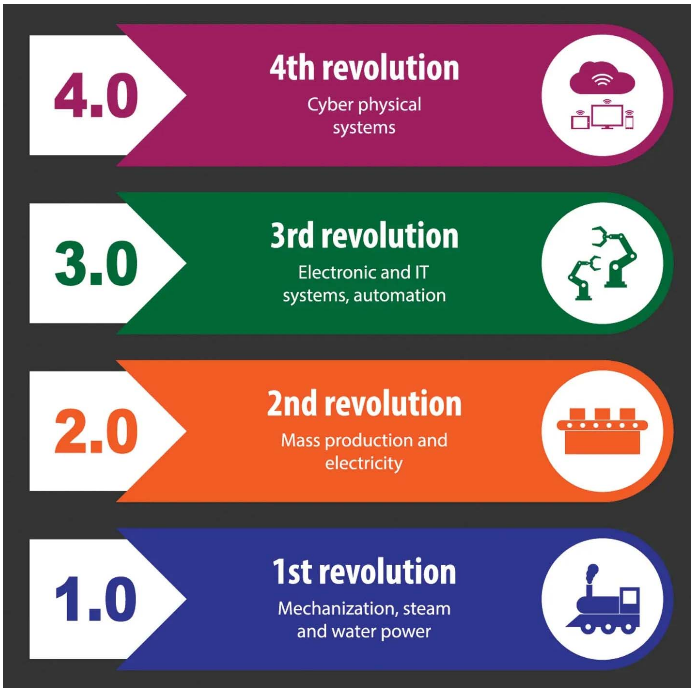

Figure 3.28: The industrial revolutions (Schwab, 2022).

The fourth industrial revolution is predominantly driven by the ability to integrate digital, biological and physical advances, building on the availability of digital technologies brought about by the third industrial, or digital, revolution (Schwab, 2022). As with previous industrial revolutions, the fourth industrial revolution is rapidly altering how humans will produce, exchange, and transfer value (Schwab, 2022). The applicability of industry 4.0 to sustainable cities and the circular economy is illustrated through work in Kurniawan *et al.* (2022), in which the integrated nature of industry 4.0 can be used for better waste management tracking. This allows systems such as the "pay-as-you-throw" system in Taiwan to operate more efficiently and is expected to help towards cutting the usage of virgin materials in Taiwan by 25 per cent in 2030 (Kurniawan *et al.*, 2022).

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Many of the technologies integrated through Industry 4.0 can also be found in smart cities, for example AI and robotics, autonomous machines, cybersecurity and block-chain as means of security, linked sensors, energy capture, storage and transmission, virtual and augmented realities, and neurotechnology, which includes bio-electric interface technologies (El Hamdi *et al.*, 2019; Levin, 2018; Zambrano *et al.*, 2022). In the research study by Wagire *et al.*, five interconnected pillars for Industry 4.0 were identified as: 'smart technologies and standardisation', 'work organisation and design', 'smart factory', 'innovative business model', and 'smart city and smart infrastructure'. As many of the systems involved with Industry 4.0 are linked to smart cities, some of the drivers for Industry 4.0 will indirectly influence and drive the development of smart cities and smart sustainable cities.

Transitioning towards a smart sustainable city requires an understanding of the city's current state and performance (Embarak, 2022). The opportunities and capabilities of integrating technologies brought on by the fourth industrial revolution (Embarak, 2022) will help to better interpret and understand city dynamics and its current state. As integration of technology in various sectors like education, transport, finance, and security to name a few are important for both a smart city and a smart sustainable city (Embarak, 2022) and the outputs from these technologies affect how such cities will develop their urban growth policies (Bakıcı *et al.*, 2013), Industry 4.0 will easily from part of the smart sustainable city movement.

3.19 Smart sustainable city dimensions

According to the ITUT (2016) the general objective for a smart sustainable city is to improve quality of life, competitiveness and urban efficiency while ensuring sustainability throughout social, economic and environmental dimensions of the city.

To achieve the smart sustainable city objectives in ITUT (2016) and maintain the sustainability balance is a complex challenge requiring that the capabilities of ICT and smart technology be used as a leverage according to Ibrahim *et al.* (2016). In Table 3.4, research in Ibrahim *et al.* (2016) adopted the six dimensions for smart cities in Giffinger *et al.* (2007) to be applied to smart sustainable cities. These are now the smart sustainable city dimensions by Ibrahim *et al.* (2016). Each of the six dimensions in Table 3.4 are related to a specific set of factors that are used to identify where initiatives for smart and sustainable cities are needed (Ibrahim *et al.*, 2016). These six smart sustainable city dimensions by Ibrahim *et al.* (2016) are also illustrated in Figure 3.29.

Figure 3.29 was amended from Ibrahim *et al.* (2016) to include a downward and upward arrow. The added downward arrow indicates what Ibrahim *et al.* (2016) illustrated, namely that the six smart sustainable city dimensions provide how to deliver sustainable solutions to societal challenges. This echoes

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Table 3.4: Smart sustainable city dimensions and related factors (Ibrahim *et al.*, 2016; Giffinger *et al.*, 2007).

Dimension	Related Factors
Smart economy *(economic competitiveness)*	Innovative spirit Entrepreneurship Economic image and trademarks Productivity Flexibility of labour market international embeddings Ability to transform
Smart environment *(Natural resource management)*	Attractive natural conditions Pollution Environmental protection Sustainable resource management
Smart governance *(improved participation)*	Participation in decision-making Public and social services Transport governance Political strategies and perspective
Smart living *(Better quality of life)*	Cultural facilities Health conditions Individual safety Housing quality Education facilities Touristic attractivity social cohesion
Smart mobility *(ICT and transportation)*	Local accessibility (Inter)-national accessibility Availability of ICT infrastructure Sustainable, innovative, and safe transport systems
Smart people *(Human and social capital)*	Level of qualification Affinity for life-long learning Social and ethic plurality Creativity Flexibility Cosmopolitanism/open-mindedness Participation in public life

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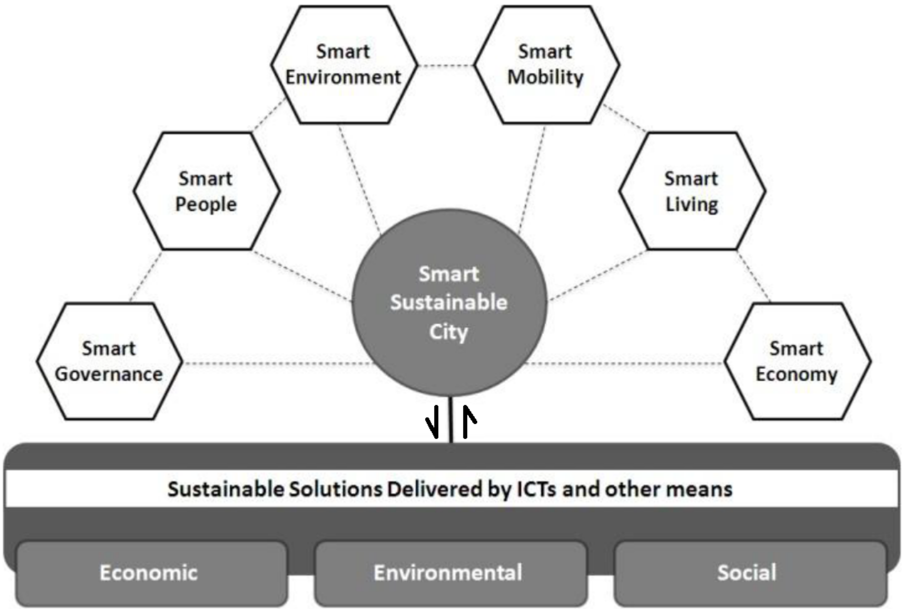

Figure 3.29: The relationship between smart sustainable city dimensions and city sustainability. Adapted from Ibrahim *et al.* (2016).

the statements by Höjer and Wangel (2015). The upward arrow is added to indicate how the economic, environmental, and social pillars of sustainability are a foundation to smart sustainable cities and each of the six dimensions should be rooted in sustainability principles. These principles were illustrated in Figure 1.1 from Chapter 1, Section 1.1.

These dimensions was later narrowed in Schuch de Azambuja (2021) to five dimensions for smart sustainable cities which are the three pillars for sustainability (environment, economy, society), urban infrastructure and governance.

3.20 Towards evaluating smart sustainable cities

The quest for global sustainability has seen cities become a possible leverage point because of the agglomeration of population and subsequently city rankings and evaluation studies addressing sustainability issues have risen form the early 2000s (Grant and Chuang, 2012) and continues today (Mele, 2022).

The rankings and assessment of cities form part of organisation and evaluation tools used by city administrators, politicians, and urban planners in the process of comparing various project/policy alternatives (Grant and Chuang, 2012). Understanding performance in the separate dimensions of urban sustainability compared to other cities within the same region and identifying areas for improvement, proves an important tool for cities (Ahouzi

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et al., 2020; Akande *et al.*, 2019). To the authors knowledge, Akande *et al.* (2019) has thus far been the only author to focus on the development of a rating system for smart sustainable cities.

Many studies in the past decade have used the indicator-based approach to measure different aspects of sustainability and urban smartness; bring the dimensions to an aggregate and lastly have global cities benchmarked based on them (Phillis *et al.*, 2017).

Studies that comprises of indicator-based approaches are the following: Arcadis Sustainable Cities Index 2022 (Arcadis, 2022), IMD Smart City Index (IMD, 2019), the United Nation's (UN) City Prosperity Index (UN-Habitat, 2015), the Mercer Quality of Living (Andersen, 2018), the Global Liveability Index (Economist Intelligence Unit, 2022), the Cities in Motion Index (Berrone *et al.*, 2020), the Global Power City Index (Takenaka and Ichikawa, 2021), the CityCard Index (Grant and Chuang, 2012), the Sustainable Assessment by Fuzzy Evaluation (SAFE) index (Phillis *et al.*, 2017), the Spatially Adjusted Liveability Index (Economist Intelligence Unit, 2012) and the Cities of Opportunity index (PWC, 2016).

Generally, studies aim to benchmark global cities utilising indicators that vary from 17 to 77 indicators with assorted methods for weighting and aggregation (Akande *et al.*, 2019). More specific aspects of urban sustainability have been ranked in other studies such as: urban water management (van Leeuwen *et al.*, 2012), urban air quality (Sheng and Tang, 2016), urban mobility (Bojkovic *et al.*, 2018) and urban economic development (Giffinger *et al.*, 2010).

Numerous city rankings were specifically developed for benchmarking European cities. Among others they include: The European Green Capital Award (Gudmundsson, 2015), the European Smart Cities ranking (Giffinger *et al.*, 2007), the European Green City Index (Shields *et al.*, 2009), European Soot-free City Ranking (Reh *et al.*, 2013), the European Green Leaf Award (European Commission, 2019), Urban Ecosystem Europe (Berrini and Bono, 2007) and the Europe Quality of Life Index (Numbeo, 2019).

3.21 Indicators for smart sustainable cities

The indicators used in Akande *et al.* (2019) are UNECE-ITU developed following meetings with member states in the EU and different collaborators worldwide (UNECE, 2015). The International Standards Organization Indicators for city services and quality of life, is an example of one of the frameworks also containing the 32 developed indicators (ISO, 2018), as well as the EU sustainable development strategy (European Union, 2016). UNECE-ITU indicators were classified under the three pillars of sustainability as the main thematic areas, which are: environment, economy, and society. Each of the sustainability pillars used in Akande *et al.* (2019) were further

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divided into six topics as illustrated in Figure 3.30, producing a total of 18 topics.

Considering the model in Figure 3.30 - it could be argued that the 3 pillars of sustainability used as the main thematic areas for a smart sustainable city, should be extended to the 5 pillars of a smart sustainable city by adding infrastructure and governance before they are divided into topics. The model in Figure 3.30 do address most of the pillars of a smart sustainable city through its topics, but the governance pillar appears to be under-represented. In response to this observation, good governance was listed in Schuch de Azambuja (2021) as one of the most important domains for the success of a smart sustainable city.

Finally, in Akande *et al.* (2019) thirty-two indicators was devised using urban audits and Eurostat databases (national and regional) for rating European cities. These indicators have been applied to rank twenty-eight European capital cities. They can be found in Appendix A where they are tabulated with its formula, description, overarching thematic area and specific topic. The work in Akande *et al.* (2019) is still a valuable contribution, but might require adjustments for the needs of different cities.

Figure 3.30: Breakdown of the 18 categories within the sustainability pillars used with UNECE-ITU indicators (Akande *et al.*, 2019).

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3.22 Benchmarking a smart sustainable city

In rating and ranking the 28 capital cities in the EU for smart sustainability, the data acquired in Akande *et al.* (2019) was processed with the use of a dimension reduction algorithm called the principal component analysis (PCA). Using PCA simplifies the investigation and visualization of high dimensional datasets (Akande *et al.*, 2019). PCA is a statistical procedure used to synthesize numerous variables, transforms the original variables into a new set of orthogonal variables in such a manner that emphasizes differences making strong patterns more noticeable (Xiao *et al.*, 2017).

Before European capital cities are ranked, a necessary single measurement of their smartness and sustainability must be obtained. Akande *et al.* (2019) made use of a two-point approach of feature selection to acquire a smaller number of variables representing the greater group of 32 variables. Feature extraction was then used to build a new set of variables simultaneously reducing both noise and redundancy during the process.

The data processing consists of using ToolPak in Microsoft Excel for several statistics including the median, mean, standard deviation, and correlation matrix of all 32 variables for each of the cities selected. Outlier variables having a distribution with absolute skewness greater or less than one was identified and taken care of as these influence the city rank (Aesaert *et al.*, 2017; Groeneveld and Meeden, 1984). Using the *powerTransform* function in R, the identified variables that had to be skewed, were transformed. This implements the maximum likelihood method of Box and Cox (1964) to appropriately select transformation power, applied on relevant variables. Thereafter the data was normalized, through downscaling values of the indicators and this is vital as it prevents domination from one variable over all others, enabling the data analysis method to handle data "fairly" (Katsiantis *et al.*, 2006).

For feature selection clustering was used in Akande *et al.* (2019) as a robust means to identify a homogenous group of variables referred to as "clusters" which share similar characteristics across all cities being studied such that the particular clusters have "maximum internal homogeneity (inside the cluster) as well as maximum external heterogeneity (between clusters)" (Cruz-Jesus *et al.*, 2017). By applying PCA to selected variables during feature extraction, the data is transformed from a high-dimensional space to a low-dimensional space. The software package R was used for the execution of feature selection and feature extraction (Husson *et al.*, 2017; Lê *et al.*, 2008).

3.22.1 City ranking results

The 28 European capital cities ranked in the spatial pattern from the results lead to an interesting insight regarding how city transformations relate to each other. A closer analysis of Figure 3.31 indicates how similar ranking

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values appear in clusters on the map. Upon testing spatial autocorrelation using Global Moran I, a positive spatial autocorrelation (0.31) among the city ranks was discovered (Akande *et al.*, 2019). The deduction can be made that each city's performance in the ranking is not randomly spatially dispensed but rather each city is influenced by its neighbours' causing cities with similar behaviours to cluster together. This observation indicated a geographical divide between well ranked cities and those that are not. While Western Europe holds twelve of the top 14 cities, 11 of the bottom 14 cities are situated in Eastern Europe. This outcome confirms findings by the European Union which indicated a present developmental gap occurring between western and Eastern European cities (European Commission, 2014).

3.23 Implementation challenges for a smart sustainable city

Normally human and economic activity centre around cities (Ranđelović *et al.*, 2020; Keshvardoost *et al.*, 2018). This can create synergies that allow substantial development opportunities for the people living in cities. This aside, growth in complexity and size causes an ample number of concerns that are often difficult to manage, and this must be acknowledged. The concentration of inequalities in cities is more and requires adequate

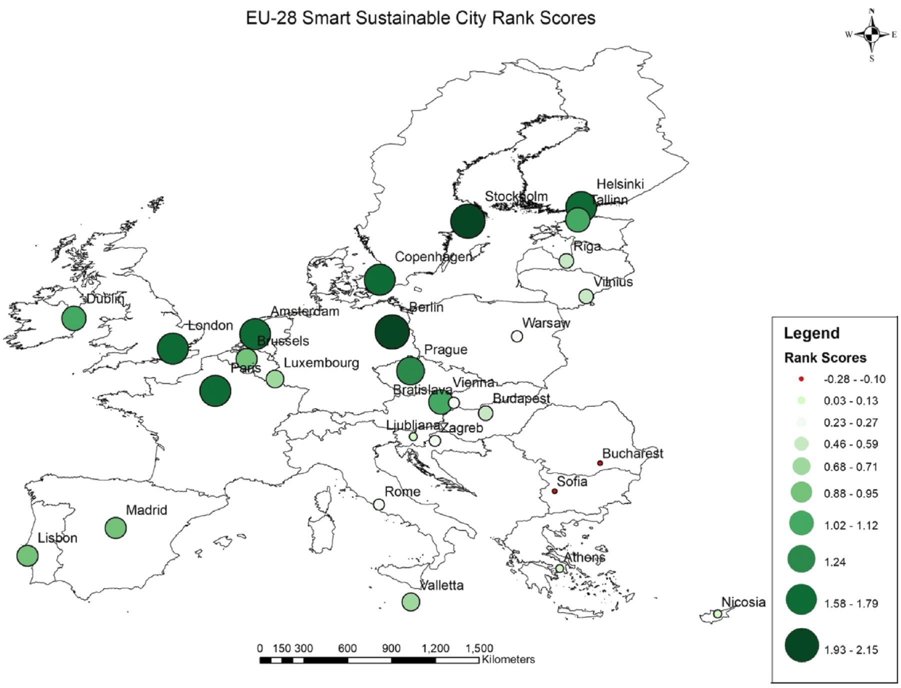

Figure 3.31: European capital cities smart sustainable city ranking (Akande *et al.*, 2019).

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management if the positive impact is to be maintained (Keshvardoost *et al.*, 2018).
For smart sustainable cities to be implemented, consideration needs to be given to five challenges (Höjer and Wangel, 2015):

- strategic assessment.
- mitigating measures.
- top-down and bottom-up.
- competence; and
- governance.

3.23.1 Strategic assessment

In Höjer and Wangel (2015) the importance of evaluating the impacts of proposed solutions in the city is emphasised. This is because initiatives that provide for needs within the city, should do so without negatively impacting future generations' ability to meet their needs or the limited environmental resources. This is part of the definition of smart sustainable cities in Chapter 1, Section 1.2. For this reason, methods and processes that use a systems perspective are useful to evaluate the effects of the proposed solutions to select the most appropriate ones (Höjer and Wangel, 2015).

3.23.2 Mitigating measures

Infrastructure development is in various aspects a corner stone of present-day society and permits the establishment of better systems for different forms of trade and businesses. However, it also offers the possibility to destroy ecosystems and to take advantage of natural resources to a degree that endangers the existence of that same present-day society (Höjer and Wangel, 2015).

In a similar way ICT is becoming ever more important in maintaining and advancing society and has the capability to support a resource-efficient sustainable society, but it can easily be used to make present-day society an even more efficient mechanism for over-exploiting the planet (Höjer and Wangel, 2015). For example, ICT measures may be implemented to facilitate increased traffic flows in cities, which will make it easier to travel, nevertheless causing travel to increase coupled with its unfavourable environmental impacts. Consequently, the optimizations in traffic might need to be coupled with other initiatives and countermeasures to accomplish the sustainability potential of ICT (Höjer and Wangel, 2015).

Urban planners must formulate mitigating steps whilst they promote technology for efficiency optimisation. They must aspire to fully

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understand and monitor how ICT is reshaping society (Höjer and Wangel, 2015). Mitigating measures will in all probability be required during the implementation of the smart sustainable cities policies to avoid rebound effects that might undo the positive effects.

3.23.3 Top-down and bottom-up

A top-down approach may be defined as one where the actual products, services and systems of the smart sustainable city may emerge from large businesses who generally have the economic capacity to ensure full implementation of the required assessments, however their strength can empower them to control smart sustainable city development to the level that it kills creative thinking (Höjer and Wangel, 2015).

The bottom-up approach can be constituted by hacker associations and other types of smaller scale enterprises (Höjer and Wangel, 2015). A vulnerability of this approach is that it can be extremely challenging to advance the solutions to the next level, thereby leading to many disconnected small-scale solutions lacking the ability to make a substantial change and making it really hard to evaluate the actual outcome (Höjer and Wangel, 2015).

3.23.4 Competence

In general, the top-down initiatives from larger companies can be highly effective with best practices of putting good solutions into practice. Regrettably at the present time the ICT awareness and expertise within companies are far greater than amongst municipal officials, to the extent that the cities become exploitable customers due to their inability to properly specify their requirements or to correctly evaluate the tenders they receive. This situation will inevitably lead to either poor investment decisions or hamstrung decision making (Höjer and Wangel, 2015).

It is clearly in the best interest of both ICT companies and municipal government to raise the competences within municipal governments about ICT solutions for smart sustainable cities (Höjer and Wangel, 2015). For this reason, the EU Smart Cities Stakeholder Platform has drafted guidelines with regard to public procurement for smart cities (British Standards Institution (BSI), 2014*a*).

3.23.5 Governance

The smart sustainable city is not only about interconnecting devices, but it also requires organizations to reconsider which stakeholders need to participate in the planning and governing of the city (Kramers *et al.*, 2014; ITU, 2014; European Union, 2013*b*; Anthopoulos and Vakali, 2012; Schuch de Azambuja, 2021)

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A specialised smart city team, developed with diversified roles and competencies to promote smart city development, that is also accepted by other city's agencies coordinating authority, needs to be established to ensure that the diverse ICT in the city works through coherent action (Anthopoulos and Vakali, 2012). This dedicated team would be able to fulfil the aforementioned need to strategically assess and evaluate the effects of ICT investments from the perspective of sustainability (Lee *et al.*, 2014).

The specialised smart city team may be entrusted to promote smart sustainable city development and as leaders in the field should be able to investigate offers from ICT enterprises as well as contribute to balancing the bottom-up and top-down approaches.

3.24 Standardisation and policy making

It is encouraged in Wang *et al.* (2021) that smart city policymakers and practitioners should evaluate smart city ideas based on their inclusivity of all populations and groups. Citizen needs, particularly those of under-represented populations, elderly and with disabilities should be accounted for (Wang *et al.*, 2021). According to Caragliu and Del Bo (2016), there is currently no accepted framework for evaluating smart city policies.

3.24.1 Standards

The market can be optimised through the support of standardisation in the industrialisation of solutions; alignment of approaches between city systems; speed replicability and helping to create scale (European Union, 2013*a*). It is necessary for various forms of standards (technical specifications, protocols, frameworks and guides) to be implemented adequately to the life cycle of any system. Smart cities, face particular contextual challenges, such as diverse systems, the rising incorporation across them, and increasing volumes of shared data (European Union, 2013*a*). Struggling to reach agreement on a way to support interoperability across city systems hinders cities from effectively advancing towards incorporating renewable energy sources into existing grid systems and enabling more dynamic operations; optimised real-time multi-modal transport data; genuine utilization of location-based data; minimizing difference in building systems; strengthening citizen participation, or providing regular platforms for developers (European Union, 2013*a*).

A reference architecture that fits certain standards would at many levels enable interoperability between entities and city systems (European Union, 2013*a*). It is of importance that new smart sustainable city standards be developed swiftly using full consultation and consensus from applicable stakeholders and moving from the principle of adoption/adaption of existing materials. Examples for smart cities include standards for building energy

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performance, internet protocols (IPv6), radio frequency identification (RFID) tags and data formats (jpeg, xml) (European Union, 2013*a*).
The European Union recommend the following actions for smart city standards (European Union, 2013*a*):

1. The CEN-CENELEC-ETSI Smart Cities Coordination Group should set up a committed general technical committee and share close involvement in integrating the work associated with the Partnership. This can be done in a way that is almost the same as the Smart Grid Coordination Group.

2. It is advised that current existing/planned standards landscape for communities and smart cities be mapped out and gaps identified, involving the participation of different stakeholders and consortia in the process.

3. The development of a general architecture for smart city information platforms is necessary to demystify and advance the uptake of interoperable information platforms within cities.

4. Active involvement at an international level regarding standardisation matters is required from Europe (e.g., with ISO or the International Telecommunications Union) in order to ensure Europe's pre-eminence in standards development, and support the advancement of Europe's competitive advantage in developing Smart Cities and Communities.

3.24.2 City policies

In an expanding urban world, it is firmly believed in UN-DESA (2020) that policies affecting population spatial distribution and urbanisation may help to ensure a more sustainable and equitable future for everyone. Keshvardoost *et al.* (2018) believes policy development can serve as a departure point in designing smart and sustainable city strategies. In the European strategic implementation plan for smart cities, certain challenges regarding policies and regulations were indicated as needing attention (European Union, 2013*a*):

- *Regulatory barriers for smart city implementation:* Difficulties with national benchmarks and standards, regulations, local grants for industry, lawful acts and orders that represent expansive arranging, and more are examples that has the potential to obstruct the execution of smart city systems.

- *Silo thinking:* City authorities and members of municipal administration tend to focus on their area of specialisation as they were each allocated into specific functional silos, but problems arise with

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horizontal integration when there is a lack of willingness to collaborate across functional borders.

- *Uncertainty:* Uncertainty in policies generally influence private organisations to delay investment in new technologies and infrastructure and will restrict the integration of technology in the city. Difference in technical standards for technology across countries also hinder deployment of smart city concepts in the large scale.

- *Ambitions:* To ensure commitment and a holistic city transformation process requires a strategic vision that is supported by all stakeholders and long-term based frameworks, policies, and regulations. Alignment is important in both horizontal (various types of policy fields) and vertical (local, regional, and national levels).

The European Union (2013*a*) recommends innovative forms of governance as this will assist in integrating different stakeholders throughout the process. Forums (both formal and ad-hoc) as well as platforms can unite experts with policy makers to discover and map gaps, hurdles and conflicts; make improvements to the regulatory framework (improve, consolidate, remove and simplify); and to start a process of education for city stakeholders and training (best practices and knowledge sharing).

Lastly, on the policy level the European Union (2013*a*) identified the following required actions to be executed:

- Motivate cities to develop an official smart city strategy and implementation plan, to prioritise smart cities on policy agendas and induce greater recognition across policy domain thinking.

- Regulation and policies should be challenged to allow innovative funding model applications that combine existing private and public funding sources with novel types of funding, that simultaneously allow cities to have more control over their own finances.

- Innovation zones should be implemented in cities that allows cities to test and evaluate the consequences of revised regulations and policies, also considering reduced or different forms of regulation in specific fields.

For instance, as in Section 3.12.1 (Chapter 3) on sustainable transportation, it was found in Göddeke *et al.* (2021) that private car ownership is a better indicator than car-sharing membership numbers in German cities for indicating sustainable transport behaviour. Therefore, it was recommended in Göddeke *et al.* (2021) to change policies aiming at reducing the private ownership of a car and thereby reducing carbon emissions.

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3.25 Stakeholders

Ibrahim *et al.* (2017) did research on the engagement of stakeholders during the development of a smart sustainable city. According to Ibrahim *et al.* (2017):

- Stakeholders can contribute with their experience, skills, and knowledge towards a more successful transformation if they are well managed.
- The quality of decision making can be improved but will require the stakeholders to be well informed.
- Citizen buy-in and transparency can be improved with stakeholder involvement and by using stakeholder opinions for the benefit of the transformation.
- Complaints and urgent modifications can be reduced at a later stage of the transformation by ensuring a good stakeholder relationship.
- Chances of neglecting local needs and interests during the transformation can be avoided.
- Stakeholders can help monitor and evaluate the outcomes of the transformation process afterwards as means to help ensure the continuous sustainability of the city.

Stakeholders come in many forms and can include: a single person, a group of people, public/private organizations, institutions, neighborhoods, societies, citizens in a city, the natural environment (Mitchell *et al.*, 1997), local community organisations, government, advocates, media, unions, environmentalists, consumers, associations, political groups, financial community, employees, suppliers, education, and research institutions, and more (Freeman, 1984).

The stakeholders that are selected for the smart sustainable city transformation should be those who have a stake in the transformation process (Ibrahim *et al.*, 2017). In Ibrahim *et al.* (2017) it is motivated that the term 'stake' in a smart sustainable project should differentiate between "those that have direct influence on a smart sustainable city transformation process and its outcomes" and "those who have interest with no power but are important and should be involved in a transformation process."The selection of stakeholders for a smart sustainable city project is simplified in Ibrahim *et al.* (2017) into two classes:

- *Primary stakeholders:* are known as the *key stakeholders* and include all groups which, without their involvement, the smart sustainable city project may cease to exist.

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- *Secondary stakeholders:* are all stakeholder groups who are being affected or who can affect the smart sustainable city project.

Ibrahim *et al.* (2017) proposed a stakeholder engagement model for smart sustainable cities in Figure 3.32 and can be fully or partially adopted by smart sustainable city teams. The model is based on "stakeholder theory" engagement aspects in (Freeman, 1984; Freeman *et al.*, 2010), stakeholder engagement components from the International Finance Corporation (IFC) in (Sequeira and Warner, 2007), model phases in (Bal *et al.*, 2013), and recommendations by the International Telecommunications Union (ITU) focus group on smart sustainable cities in (ITUT, 2016).

The model in Figure 3.32 was designed to help guide a smart sustainable city project with the engagement of different types of stakeholders. The model consists of eight stages and can be summarised as follows (Ibrahim *et al.*, 2017):

1. *Stakeholder identification:* In this stage all possible stakeholders are identified that are impacted by the project or can themselves influence the project. The stakes for each of the identified stakeholders should be defined and according to their roles in the transition, be divided into groups of primary (key) or secondary stakeholders.

2. *Prioritising stakeholders:* Stakeholders are ranked according to their importance based on their potential to influence the success of the smart sustainable city project. This depends on various factors to be considered, such as their characteristics, the project's need,

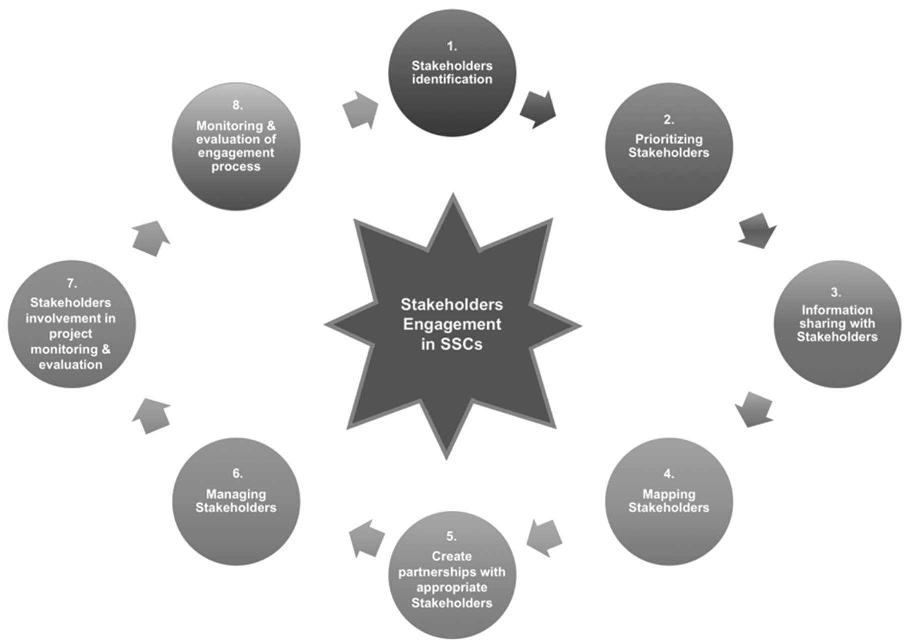

Figure 3.32: Proposed stakeholder engagement model for smart sustainable cities (Ibrahim *et al.*, 2017).

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decision-making power, economic, social, environmental and political contribution to the project. Stakeholders that are not directly associated with the project but are interested in the project's outputs should also be noted.

3. *Information sharing with stakeholders:* The smart sustainable city project team shares all the required information concerning the smart sustainable city transformation activities with the stakeholders. The team also communicates to the stakeholders how they can help to contribute to the success of the project. This also helps the project team to better identify to what level each stakeholder is willing to contribute to the transformation and as well as understanding complaints and insights with certain activities. The decision-making process should also be communicated at this early stage as this will help to better plan and map stakeholders. It is recommended to maintain this communication throughout the whole project.

4. *Mapping stakeholders:* Each stakeholder or group of stakeholders is mapped by the project team into a transformation process's strategies and their associated steps or activities. The impact level of each stakeholder accomplishing a certain activity should also be included.

5. *Create partnerships with appropriate stakeholders:* According to Ibrahim *et al.* (2017) and other authors it is important to seek partnership with relevant stakeholders after the stakeholders were mapped to transformation activities (Freeman, 1984; Sequeira and Warner, 2007; Freeman *et al.*, 2010). Transforming towards a smart sustainable city impacts many city levels and is a costly exercise, requiring real partnerships at national and international levels to be successful (ITUT, 2016). These partnerships can help the transformation project to achieve its desired outcomes.

6. *Managing stakeholders:* The relationships that stakeholders have with the smart sustainable city project should be well managed. This will not only help to raise awareness but help the project deal with the changing needs of stakeholders during the project life-cycle. Project responses to issues raised will be more efficient and difficulties that may arise during the transformation may be resolved effectively. Managing stakeholders is a continuous integration and balance of objectives and multiple types of relationships.

7. *Stakeholders' involvement in project monitoring and evaluation:* This stage ensures that the relevant stakeholders are in full collaboration and coordination with the monitoring and evaluation of the smart sustainable city transformation process. By allowing stakeholders directly affected

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by the project to assist with assessing the impacts of transformation, activities will improve the projects' accountability and transparency.

8. *Management and evaluation of the engagement process:* It is important to measure and evaluate the quality of impact that each stakeholder has on the smart sustainable city project. This information will be useful in discerning whether a stakeholder can be kept on the project or should be excluded from future activities.

In Al-Nasrawi *et al.* (2017) it is believed that to adequately engage a citizen, the citizen should be involved in the iterative and interactive communications on programs and policies. Presented in Figure 3.33 is a smart sustainable city citizen engagement model as developed in Al-Nasrawi *et al.* (2017). Moving from left to right throughout the spectrum in Figure 3.33, indicates an increasing expectation of effect and public participation. As individuals progress along the engagement spectrum, they reach the "Empower" phase, at which point citizens are given the chance to make final decisions, altering their surroundings and reaching subjective well-being (Al-Nasrawi *et al.*, 2017). The research in Al-Nasrawi *et al.* (2017) is based on the belief that a city's perceived *smartness* increases in the direct proportion to citizens' degree of participation and their capacity to contribute meaningfully during the decision-making process of SSC solutions.

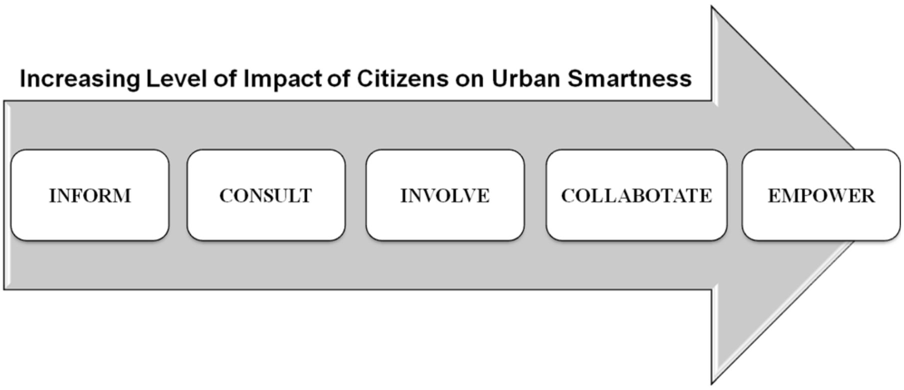

Figure 3.33: Smart sustainable city citizen engagement smartness model (Al-Nasrawi *et al.*, 2017).

3.26 Sustainability management

To achieve a balance between environmental, economic and social growth for current and future generations, it is necessary to manage existing and newly constructed cities efficiently (Elhadad *et al.*, 2019). The study in Elhadad *et al.*

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(2019) presents an urban sustainable management strategy utilising integrated assessment to analyse two potential growth scenarios (agricultural development and tourism development) for new development zones in Egypt based on distinct economic components. The urban sustainable management model presented in Elhadad *et al.* (2019) consists of three parameters: indicators, scenarios, and targets governed by the economic, environmental, and social pillars of sustainability. This model can be seen in Figure 3.34.

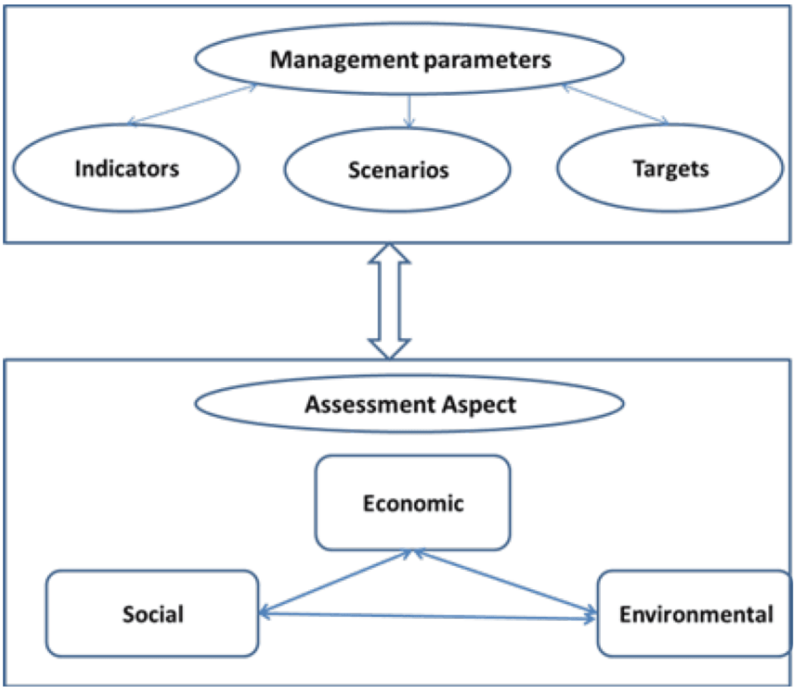

Figure 3.34: Approach for urban sustainability management as found in Elhadad *et al.* (2019).

Research in Sevryugina *et al.* (2020) drives the notion of ecosystem sustainability management of small communities and cities. Proposed is a conceptual risk management model of urban development that focuses on the mechanism for managing projects for the rehabilitation of water bodies through risk factor analysis. Using anticipatory diagnosis of risk-failures on threats such as environmental disturbance, a system has been created for returning water bodies to a state of balanced functioning. A new digital indicator is introduced that improves accuracy on planned project's environmental impact evaluations, by determining the stability in engineering systems of the local water protection complex. New tools and indicators continue to develop according to the contextual needs and issues that arise in cities as time progresses.

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3.27 Urban dynamics and resource flows

From as early as 1841, J. Reynaud suggested that cities are systems within systems of cities. The spatial and hierarchical structure within which cities function and the diverse interdependencies between them became clear (Bretagnolle *et al.*, 1998). As the spread of urbanisation increases, and interdependence among infrastructure rises, large complex 'systems of systems' are formed (Zhao and Fang, 2018; Mansoori, 2021).

The founder of system dynamics, Forrester (1999), was thereby known for applying feedback control system approach to management through feedback loops, stocks and flows. This approach was used to model and simulate real world systems. It has been applied to climate change decision making by forecasting outcomes based on possible mitigation actions.

Cities present great opportunities to structure systemic change regarding resource use (Hodson *et al.*, 2012*a*; Mansoori, 2021), of which an example is provided in Figure 3.35. Complex empirical dynamics of city resource flows can be better understood by using the systematic application of material flow analysis (MFA) (Hodson *et al.*, 2012*a*).

The concept of urban metabolism entails the analysis of stocks and flows. Stocks refer to the urban fabric and internal city resources (buildings, roads, infrastructures), and flows refer to resource inputs from within and outside the city and outputs from the city to areas within and outside its borders.(Hodson *et al.*, 2012*a*). The urban metabolism methodology has shown robustness in several published cases (Lanau *et al.*, 2021; Ipsen *et al.*, 2019; Kennedy *et al.*,

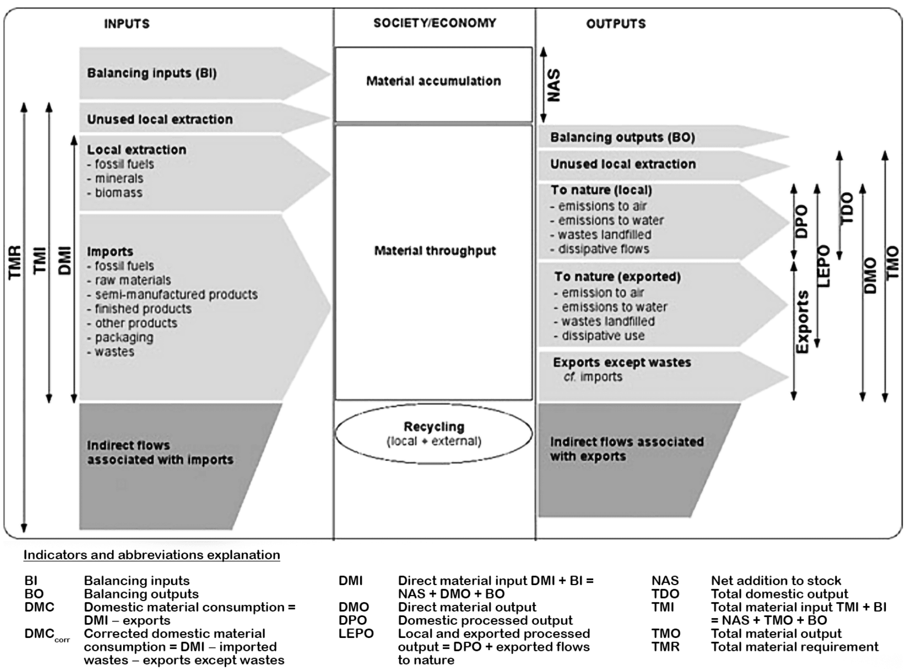

Figure 3.35: Main flows and indicators for urban material balance, (Barles, 2009).

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2011; Barles, 2009; Hammer *et al.*, 2006; Burstrom *et al.*, 1997; Daxbeck *et al.*, 1997).

Currie *et al.* (2017) studied the resource consumption of the City of Cape Town by means of an urban metabolism assessment. From the study Currie *et al.* (2017) recommends integration of a municipality's departments to aid holistic intervention strategies for city and resource planning. Research in Currie *et al.* (2017) was planned regarding the differential urban metabolism and system dynamics modelling of the resource nexus focussed specifically on Cape Town (Currie *et al.*, 2017).

A global perspective on city sustainability is required that considers how the local action or failure of action has global effects (Kramers *et al.*, 2013). This implies that urban metabolisms that are delimited to the city boundaries cannot effectively determine a city's distributed environmental impact (Höjer and Wangel, 2015).

Cities are regarded as the world's centre for global economic production and consumption as 80 per cent of the world's gross domestic product (GDP) is produced in cities (Papageorgiou *et al.*, 2021; Dobbs *et al.*, 2011). Six hundred of the world's cities, together hosting a fifth of the world's population, are responsible for 60 per cent of the world's GDP. Dobbs *et al.* (2011) forecast that in the next few years a shift in economic power is expected from the developed world to emerging economies. By 2025 middleweight cities (consisting of populations between 150 000 and 10 million) is expected to contribute 40 per cent to the global growth, thus outperforming all megacities (cities consisting of populations of over 10 million) (Dobbs *et al.*, 2011).

UN-DESA (2015*a*) expects the global population to increase, hereby increasing urban populations due to most people moving to cities. Dobbs *et al.* (2011) project that the average number of occupants per household will decline past 2025, implying that the number of housing units required in cities will increase. This will cause a reduction in efficiency of resource use per capita due to increased land and building material demand compared to shared household demand (Liu *et al.*, 2003).

Considering that resource consumption in cities is predicted to increase and that cities mostly depend on finite resources, Hodson *et al.* (2012*a*) suggest that for economic growth to continue globally, it is important that such economic growth be decoupled from increasing resource consumption.

Urban population density (UPD) dynamics has gained interest from both academics and policymakers since it could be used to help determine the sustainability of a city development (Song *et al.*, 2021).

Through indicators, energy and material studies may measure resource flows based on volume or physical weight, considering the size or connection between outputs and inputs (Martínez *et al.*, 2021). Thus, the primary energy and material flows that exit and enter Bogotá city are quantified and defined, providing a holistic picture of the city's operations, and allowing

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for the determination of the metropolitan area's efficiency, productivity and sustainability (Martínez *et al.*, 2021).

The findings of the study in Martínez *et al.* (2021) (A case study of an emerging economy: dynamics and trends of energy and material flows in an urban context) are critical for advancing our understanding of the trends in energy and material flows in cities, and they donate to the emergence of a benchmark that enables the evaluation and definition of the various impacts of public policy while promoting Bogotá's sustainability in the future decades (Martínez *et al.*, 2021).

System dynamic simulation is well-established in analysing "hard systems" like power grids, supply chains and monetary systems. However, it is challenging to apply to complex, unpredictable "soft systems" with various influences not entirely understood, such as human behaviour (Lane, 2008). Thus numerical modelling of urban metabolisms and resource flows using city data is meaningful to understand certain sub-system behaviours in order to monitor, forecast and plan physical resource dynamics to a certain degree.

3.28 Infrastructure transitioning in cities

A series of ecological, economic, institutional and population constraints have brought new challenges and put pressure on urban growth and the management of a city's critical infrastructure (Hodson and Marvin, 2010). Urban infrastructure and the system it function in comprises of both social and technical components and can therefore be characterised as a socio-technical system. For a city to address these challenges requires systemic changes of systems (e.g., transport, energy) referred to as *socio-technical transitions*, involving technology, infrastructure, policy, culture and scientific knowledge (Elzen *et al.*, 2004). Transitions are complex long-term processes with various actors (for example industries, consumers, society, policy makers, researchers, and engineers) that develop, maintain and transform these components (Geels, 2011).

It is evident in literature that urban infrastructure transitions are crucial for the transitioning of a city to both a smart city (British Standards Institution (BSI), 2014*b*,*a*) and a sustainable city (Dong *et al.*, 2017; Höjer and Wangel, 2015). This need for urban infrastructure transitioning transcends to smart sustainable cities, an amalgamation of both smart city and sustainable city aspects as illustrated in Figure 1.2, Section 1.2, Chapter 1.

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3.29 Urban networks from a multi-level perspective

Cities can be seen as systems within systems and can therefore be approached at various nested levels of analysis (Neal, 2012; Geels, 2010; Mansoori, 2021). The multilevel perspective (MLP) interrelates a three-level framework of landscape (macro), regime (meso), and niche (micro), as illustrated in Figure 3.36.

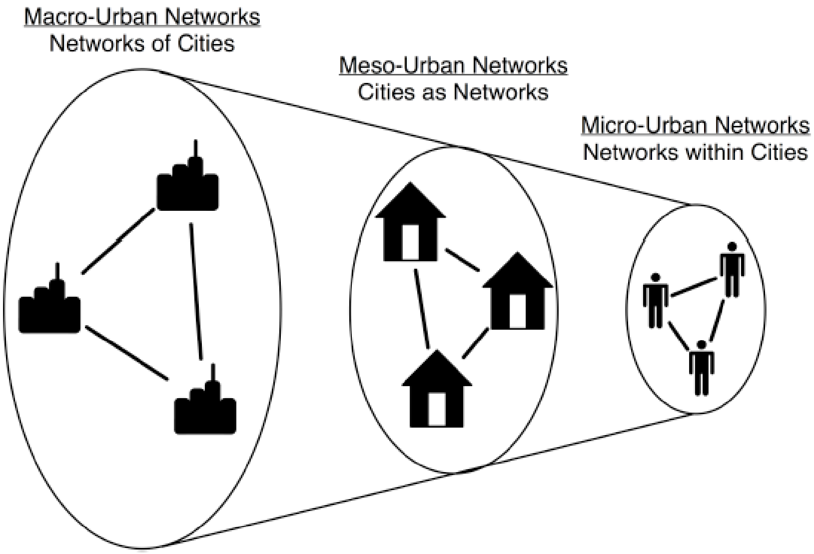

Figure 3.36: Nested levels of urban networks (Neal, 2012).

Micro-urban networks are the smallest scale of urban networks, connecting the individuals in the city through personal social networks (Neal, 2012).

Meso-urban networks looks at the city as a collection of interrelated, interacting networks that provide form and function to the city. The components are not people but spaces and institutions (Neal, 2012). The physical infrastructure and layout guide the way the city is used. Service delivery (for example waste removal, health care and recreation) are most seldom performed through a centralised plan. Most often it is driven by complex inter-organisational networks wherein providers either compete for domination or combine forces by collaborating (Neal, 2012). Regimes (meso) are seen as socio-technical in that technologies and technological functions co-evolve with social functions and social interests (Hodson *et al.*, 2012*a*).

Macro-urban networks entail how cities are linked with one another to form networks in three geographic domains: regional, national, and global. Regional city networks form through business partnerships, local government cooperation and workers commuting between cities.

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The MLP neglects the spatial dynamics of cities, raising the issue of where cities blend in the multilevel perspective, specifically within the landscape-regime-niche hierarchy. The positioning of a city's location relative to governance arrangements and urban hierarchies is also key to this potential, implying that cities may consist of distinguished capabilities to either be shaped by or shape national transitions (Hodson *et al.*, 2012*a*).

Defining urban areas entail more than the amount of people or density (Juraschek, 2022). Terms that are also used in relation to 'city' are urban settlement, urban agglomeration, urban area, and city-region (Albertí *et al.*, 2017). The built environment comprises of many varied components that differ in functionality and scale. To define a systems border of an urban area the requirements may vary. Most of the time the difference between urban and non-urban is determined by form, function or administrative factors (Juraschek, 2022). Figure 3.37 shows example criteria used for classification of urban scales.

Urban responses will vary as cities and other geographies will not only experience the challenge differently, but their provision of historical infrastructure is different, and they have different capacities to respond to emerging pressures at an urban scale (Hodson *et al.*, 2012*a*).

Complexity science is becoming more popular for studying cities (Schiller, 2016), it is also the basis from which ICT systems for smart cities were founded (Bibri and Krogstie, 2017). *Scaling analysis* can statistically compare different patterns over various scales, however there is a lack of understanding regarding the social processes generating these patterns. These specific scaling phenomena of urban systems are compared according to the population size of cities (Schiller, 2016). Urban transition research can benefit from various physical and social network scaling phenomena.

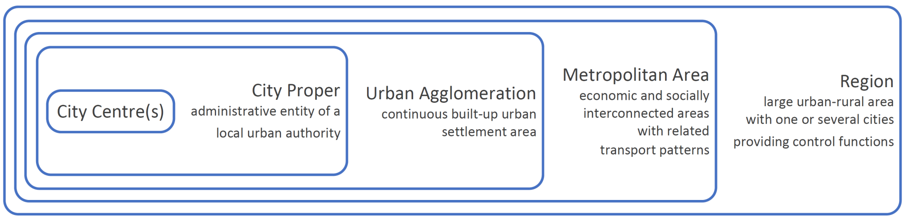

Figure 3.37: Urban classification. Recreated from Juraschek (2022).

3.30 Urban space and zoning

People are drawn to cities for several unique reasons. Amongst possible motivations are economic possibilities, culture, educational prospects, accessible services, social systems, and healthcare (Juraschek, 2022). The concentration of people and their activities results in the perception of the

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advantages of living in a city, which may again attract more residents and so contribute to urban development. On the other hand, if one or more of a city's offers deteriorates, such as a receding economy or unemployment, communities may suffer shrinkage (Juraschek, 2022). Densification of urban space also creates tensions and rivalry for limited space and the need for essential infrastructure, city services, transportation systems, mobility and presenting significant difficulties to urban planning. As a result, cities may have a significant impact on the evolution of society and vice versa. Additionally, many studies demonstrate their potential and ability to generate and maintain economic development (Juraschek, 2022).

According to Juraschek (2022) in urban theory, the components that make up a city are examined, which includes a variety of descriptive methods. When considering various types of urban spaces, a difference between populated areas, forest areas, agricultural areas, traffic areas, and water meadows may be established. One area of convergence across the methods is that they all begin with the premise that all physical things are immersed in the functional and spatial structural layers of a city and are connected to them via immaterial and material exchanges (Juraschek, 2022). It is asserted in Reicher (2017) that the placement of functional components throughout the city has a significant impact on functional operations of the city. The mix of uses (e.g., housing, retail, and education all in close proximity), built environment's density (e.g., buildings), social density (e.g., diverse population groups), and urban design (e.g., the form and silhouette of buildings) all influence urbanity. Findings in Shertzer *et al.* (2018) suggest that zoning had a key influence in the development of residential areas free of industrial and commercial activities. The zoning ordinance's division of uses is still evident today, as seen by housing prices, the placement of polluting industrial sites, and population density (Shertzer *et al.*, 2018). Additionally, rather than just "following the market", zoning seems to be an effective strategy for establishing use separation. It was found in Shertzer *et al.* (2018) that, in the long term, urban planning has been successful at establishing residential districts away from unwanted industrial uses, thus increasing the value of homes in these communities.

However, according to Keshavarzi *et al.* (2021) under the human smart city's idea, which entails smartness at the local and community level (De Oliveira, 2016), smart communities and neighbourhoods lack distinct geographical boundaries and usually come in a variety of sizes. Additionally, even though smart communities operate on lower geographical sizes, they may not qualify for microscale research. Census tracts, being the lowest geographical scale commonly utilized in spatial research, may not always have the same size as neighbourhoods (Keshavarzi *et al.*, 2021). Rather from having inconsistent neighbourhood borders or tracts, smart urban places may function effectively with equivalent and constant bits of urban space such as hexagonal cells with comparable areas. As illustrated in Figure 3.38, an area may be split

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into hexagons of equal size and arranged next to one another without overlap or gaps using tessellation (Keshavarzi *et al.*, 2021). Depicted in Figure 3.38 block A is the borders of census tracts, which are often applied in spatial analysis. Figure 3.38 block B to D depicts the tessellation of the same region with hexagonal borders of varying sizes (Keshavarzi *et al.*, 2021). Within each hexagon, preferred data may be gathered at the chosen micro level. A smart urban place may be represented by each hexagon and as such be a smart urban place that functions as a subsystem of a larger smart system (Keshavarzi *et al.*, 2021).

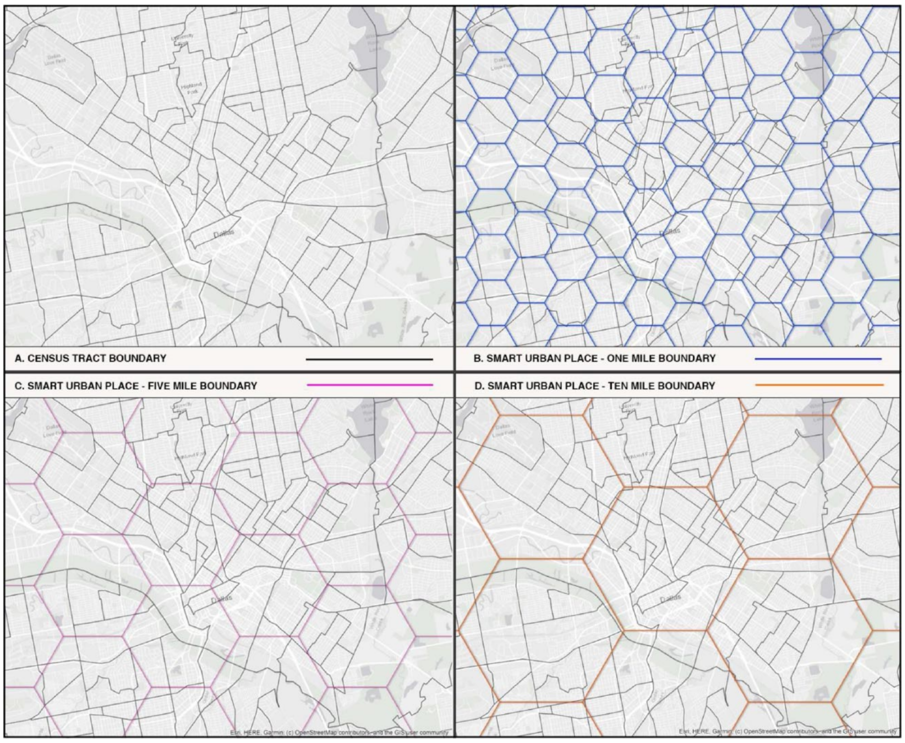

Figure 3.38: Example of envisioned smart project boundary sizes shown graphically (Keshavarzi *et al.*, 2021).

3.31 The role of sustainable urban places in transitions

Decades prior to 2000 cities underwent a transformation known as the ‘renaissance’, ‘entrepreneurialism’ and ‘re-emergence’. At the core of that urban transformation supporting the ‘re-emergence’ was the critical infrastructure like water, electricity, transportation, and waste management. Then infrastructure planning was only seen as an administrative and engineering task (Hodson and Marvin, 2010).

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Sustainable urban transitions are increasingly seen as an important topic in literature (Hansen and Coenen, 2015; Coenen *et al.*, 2012; Hodson and Marvin, 2010; Raven *et al.*, 2012). For cities to achieve urban sustainability, sustainable urban places are required (Pickett *et al.*, 2013; Meijer *et al.*, 2011; Quitzau *et al.*, 2013) and forms part of a sustainable urban transformation (SUT) (Camagni, 1998; McCormick *et al.*, 2013). Many urban sustainability issues can be related to sustainable urban transitions such as over-population, poverty, inadequite infrastructure, unhealthy housing conditions, hygienic problems, solid waste generation, poor water quality and uncontrolled pollution, traffic problems, social tensions and high usage of material and energy (Ernst *et al.*, 2016). According to McCormick *et al.* (2013) these urban problems are of a multi-scale and multi-level nature.

The characteristics of cities themselves enhance these challenges and imply context-dependencies, large scales, complex socio-spatial structures, inertia of built environment (De Graaf and Van Der Brugge, 2010; Næss and Vogel, 2012), and interrelated environmental, economic, socio-cultural, political, physical, and institutional features (Wamsler *et al.*, 2013). Urban sustainability can be a daunting task and as the requirements in cities constantly changes with complex interdependencies at play and little opportunity for a trial-and-error approach to learn, there is almost no right or wrong solution for a sustainable urban transformation (Ernst *et al.*, 2016). Unfortunately given the life span of an urban development, it is not easy to correct negative consequences (Woolthuis *et al.*, 2013). Urban sustainability transitions can help to solve these problems with purposive, systemic, vision-led and long-term change towards sustainability in the present junction of urban practices, infrastructures, technologies, markets and institutions who effectively determine patterns of consumption of resources and production (Hamann and April, 2013; Nevens *et al.*, 2013; Van den Bergh *et al.*, 2011). They require long-term oriented approaches from governance and adaptive, flexible and reflective policy designs to focus attention to probing, deliberations, experimentation and learning (Hamann and April, 2013; Nevens *et al.*, 2013; Van den Bergh *et al.*, 2011).

Different perspectives on achieving sustainable urban places surface in transition literature according to Ernst *et al.* (2016). One, the focus of sustainability transitions can be on creating sustainable urban places (Næss and Vogel, 2012) and is referred to as infrasystem transitions in Frantzeskaki and Loorbach (2010). Two, urban places can be subjected to sustainability transition initiatives, for example a roofs transition initiative to transform single-function roofs into multi-purpose spaces (Quitzau *et al.*, 2013; Hodson and Marvin, 2010; Hamann and April, 2013). Thirdly it is important to realise that sustainable urban places form an integral part of sustainability transition processes (Peek and Troxler, 2014). In Ernst *et al.* (2016) sustainable urban transitions were divided into three subsets:

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1. Sustainable places and their associated management and usage.

2. Urban development regime sustainability transitions.

3. Societal sector sustainability transitions.

In Ernst *et al.* (2016) sustainable urban places were specifically related to urban sustainability transitions to simplify part of the complex nature of sustainable urban transitions by addressing the regime-level which is under-explored in literature (Nevens *et al.*, 2013). The research in Ernst *et al.* (2016) was also focused on helping with the sustainability transition program in Rotterdam in the Netherlands by facilitating the process of determining transitioning goals for selected areas and defining the process to be followed.

3.32 Investigating complex adaptive systems

Planning for dynamic cities is a long-standing issue continuing to gain importance in an ever-changing environment. In the article by Nel *et al.* (2018), a conceptual framework for comprehending city transformation through a complex adaptive systems (CAS) lens is proposed. The framework provides urban planners with a tool for addressing some of the complex problems of urban transformation. It also serves as a basis from which to address the issue of creating alternative models for sustainable development capable of dealing with the real-life dynamics and complexities of intertwined urban systems. It is beneficial to manage change in a manner that utilises regenerative design and develops resilience. This Urban System Description Framework in Nel *et al.* (2018) entails the following steps:

1. defining the system by specifying its boundaries and recognizing its attributes, and

2. finding patterns of change across the scales, and

3. laying out the changes on a timeline.

Temporal boundary: The active and changing aspect of complex adaptive systems makes it inefficient to attempt studying them as stationary objects (Norberg and Cumming, 2008). A temporal scale is thus defined in the time dimension as follows:

- A finite stretch of time is selected over which the system needs to be studied.

- The selected time frame is then broken up into smaller time steps that are easier to manage (Holland, 1992).

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- Time frames should encompass a clear set with a start and finish. An example could be the following: a span of a century is divided into 10-year intervals, or additional time intervals aligned with shifting political or structural anomalies.

Spatial boundary: Spatial change observed within the city is often indicative of basic structural changes which is hard to detect non-spatially (Salat *et al.*, 2011; Salat and Bourdic, 2012). Urban development, traffic, densification, and planning strategies are some of the matters associated with spatial change. Establishing spatial limits adapts the study of these matters and structural changes at a scale that is manageable. A scale is thus defined in the spatial dimension as follows:

- The chosen spatial scale by which to perceive the system will be dependent on the level of detail required for the study (Nel *et al.*, 2018). For example, it could be a territory or region, city, block, street, lot, or building (Cortes, 2009; Moudon, 1997).

- It is suggested by Norberg and Cumming (2008) to assess the system properties at different scales and compare these results to guide the selection of an appropriate scale for the level of detail required. For example, it is proposed in Landman and Nel (2012) that the neighbourhood level is possibly a good measure to evaluate a sub-system. Using this scale as a departure makes it possible to look up and down onto the greater and smaller scales of the city, including single entities and the subsequent effect on this sub-system.

- Spatial borders are not solely defined by physical anomalies (like rivers or roads) but can also be demarcated by institutional separation.

- System's context, environment or simply put the external factors define patterns and processes existing outside this boundary (Norberg and Cumming, 2008).

3.32.1 CAS components and properties

The components from which a CAS is formed are known as agents, and the networks through which they interact. Here follows a swift overview:

Agents: Characteristic agents within the city context include individuals who collectively amass to make up families, organisations, companies, cities, governments, and countries (Portugali *et al.*, 2012).

Networks: A network consists of various nodes with connections between each other, a conceptual representation of the populace of interacting agents (Waldrop, 1993). These networks allow information and resources to move or be transferred between nodes (seen as agents or processors).

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Flows: CAS are not constant as they exhibit patterns indicative of shifting adaption associated with the passing of time and the amassment of experiences (Holland, 2012). These flows are not constant but future dependant on history as an action or event in a certain place can cause new nodes and links to form. These changes influence the structure of the overall network. Structural changes generally entail changes in behaviour. These structural changes can occur by removing or creating connections, in the overall structure, or just by strengthening or weakening connections. An example in traffic systems can be modifying the traffic flow. Interventions range from closing or opening new roads, widening road, or closing smaller access roads (Nel *et al.*, 2018).

The importance of having insight regarding the CAS properties are as follows (Nel *et al.*, 2018):

- It provides guidance on determining which scales are appropriate for the investigation.
- It is proposed that by recognising the agents, network and structure, emergent behaviour, and adaptation through changes in redundancy and diversity of a bound system at a given time window, one can start to evaluate the system to the point where, when the same method is used for the same system at another window in time, the resulting differences in the system can be identified.
- Partly dividing the system into sub-components or subsystems provides a more straightforward process.

Recognising the properties of complex adaptive systems enables one to develop a holistic perspective on the dynamic functioning of unique systems-of-systems. These properties are described and linked to urban change in the following paragraphs.

Emergence is observed when individual agents undergo self-organisation, forming a collective structure that possesses characteristics that might not have been possessed by individual agents and that cannot be predicted from the characteristics of its parts (Waldrop, 1993). Emergent behaviour generally spans further than the lifespan of individual agents (Johnson, 2002; Batty, 2007). General examples of emergence in urban settings include the natural formation of groupings among people in a city or the clustering of businesses or factories in an area (Batty, 2007; Mitchell, 2009; Helbing, 2009). Changing patterns and behaviour in the city causes adaptation of the urban structures, flows, or agents themselves to meet new niches and opportunities (Holland *et al.*, 1992). In the city adaptation can be visible, for instance, in building and land-use change, or the introduction of new networks and technology such as cell phones or new modes of mobility Nel *et al.* (2018).

Diversity: Diversity is both a result and driver of adaptation. Different forms of land use (Jacobs, 1961), building types and functions (Fainstein, S.S.,

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2005), population and language groups as well as various modes of transport are all examples of diversity within cities (Talen, 2008; Allen, 2012; Salat *et al.*, 2011). The concept of redundancy links strongly with diversity.

Redundancy: The ability of various entities within the system to perform the same or similar functions and activities is known as redundancy (Page, 2011). Once failure of a certain component occurs within the system, something else can substitute its role to mitigate the effects (Nel *et al.*, 2018). Redundancy is an important component of well-functioning cities. For example, in the transport systems, a road closure due to an accident can be addressed by using alternative routes. Traffic congestion may instead lead to people using public transport. Changing redundancy or diversity either advances or diminishes the system's ability to adapt, making these two characteristics closely tied to adaptation (Roggema, 2012; Page, 2011).

Hierarchies: CAS naturally generate hierarchies of nested systems inside systems (Gunderson and Holling, 2001) that impact and interact with one another across their hierarchy. The characteristics of these hierarchies are that each of the elements are both considered a whole that can stand as an entity containing smaller subsystems within itself, or as an element part of a bigger whole (Cilliers, 2001). As can be seen in Figure 3.39 (Keshavarzi *et al.*, 2021). The transport system is a subsystem of the metropolitan system. Transport also consists of smaller subsystems such as cycling, metro, pedestrian and bus transit which can each be considered a self-contained system that interacts with the other subsystems within the larger system (Gunderson and Holling, 2001; Portugali *et al.*, 2012). Hierarchy plays a significant role when determining the appropriate size by which to investigate a specific system without discounting its part in the greater whole (Cilliers, 2001; Norberg and Cumming, 2008).

Partial decomposability: This concept ties in closely to the phenomena of hierarchies that form naturally in a system of systems (Nel *et al.*, 2018). Decomposability entails the nested way systems fit together, with lower levels forming part of higher levels (Gunderson and Holling, 2001; Holland *et al.*, 1996; Ostrom, 2007). Connections joining subsystems are weaker and occur less frequent than the interactions linking elements inside the subsystem itself (Mitchell, 2009). This is a natural clustering of elements and groups. For example, with traffic a clustering of travellers is observed with short distance journeys (between home and workplace) which is more frequent than long distance journeys (between cities). The strength and frequency of connections between places reveal the subsystems within the city context (Salat *et al.*, 2011). Another example is instances where a specific type of land-use that clusters around an area can form distinguishable precincts of the city (Nel *et al.*, 2018).

The systems encountered in practice can conceptually be divided into smaller subsystems or components. Hereby the components can be studied individually aside from the system (Mitchell, 2009; Ostrom, 2007). It is because of this decomposability that various fields and categories of urban

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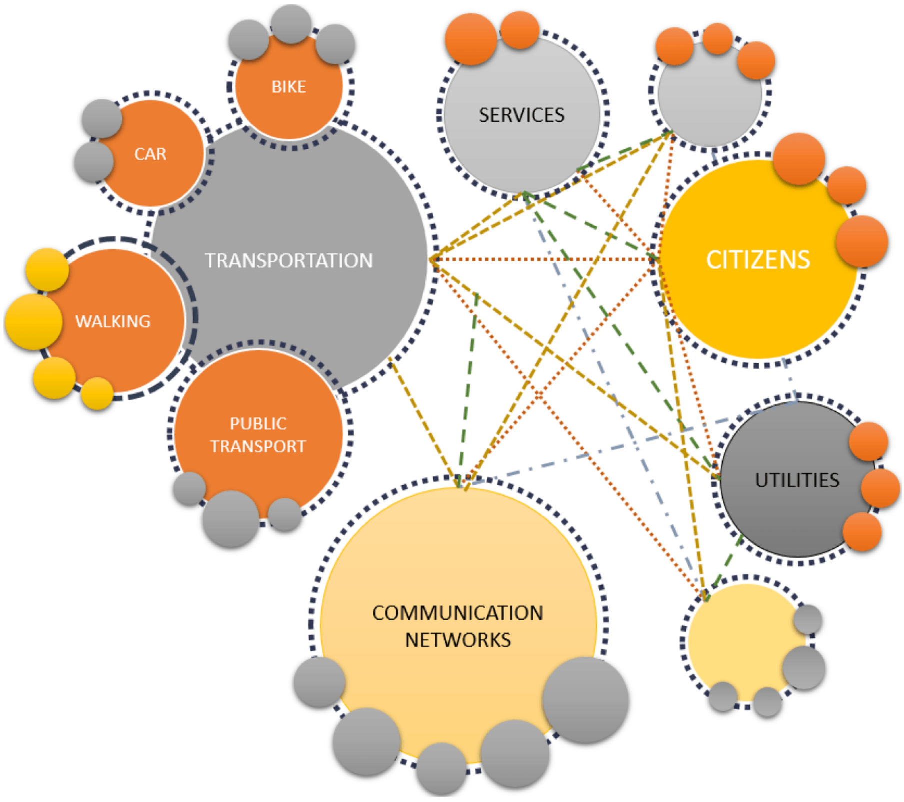

Figure 3.39: Graphical representation of the smart city concept and the relationships between the components based on the system-of-systems theory (Keshavarzi *et al.*, 2021).

studies were able to develop, such as economic, social, environmental, or political studies (Ostrom, 2007). This property also allows us to conceptually bind off subsystems from the whole for study in semi-isolation by means of defining boundaries and a suitable scale at which to perceive it, making it easy to handle (Nel *et al.*, 2018). The decision regarding the extent to which the system should be decomposed or compartmentalised depends on what it is that needs to be investigated, and how much detail is required (Holland, 2012). If it is required that the broader dynamics of the city be understood, it would not be ideal to focus on individuals or on a family level for that specific study (Nel *et al.*, 2018). It is also made clear in Ostrom (2007) that the objective is not to forget that the subsystem forms part of its greater contextual whole.

3.32.2 Tracing urban change

The boundaries and properties that were defined initially are used to describe the system at each of the selected time intervals that make up the study period. From this set of description frames across time, one can trace the changes that occurred within the system as time progressed. The changes identified can be grouped or categorised according to magnitude (small, medium or large),

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impact and type (e.g., economic, political, institutional, physical or social) (Nel *et al.*, 2018). It is also helpful to observe to which degree systems or subsystems at a certain level influence other levels on the spatial scale, and the history of the greater system (Gunderson and Holling, 2001; Norberg and Cumming, 2008). For example, to understand what influences levels at higher spatial scales, such as national- or city-level, have over lower scales such as a building or block.

The framework was demonstrated through the analysis of two neighbourhoods in the city of Tshwane, South Africa, named Irene and Lyttleton. The neighbourhoods were analysed over a hundred-year period divided into ten-year intervals. A sample of three decades is provided in Figure 3.40 focusing on various subsystems such as economic, physical, institutional, and social changes.

The final step in the framework entails interpreting the changes according to the adaptive cycles of urban change, illustrated in Figure 3.41. It consists of four phases, known as growth (r), conservation (K), release (Ω) and reorganisation (α), each described in Table 3.5.

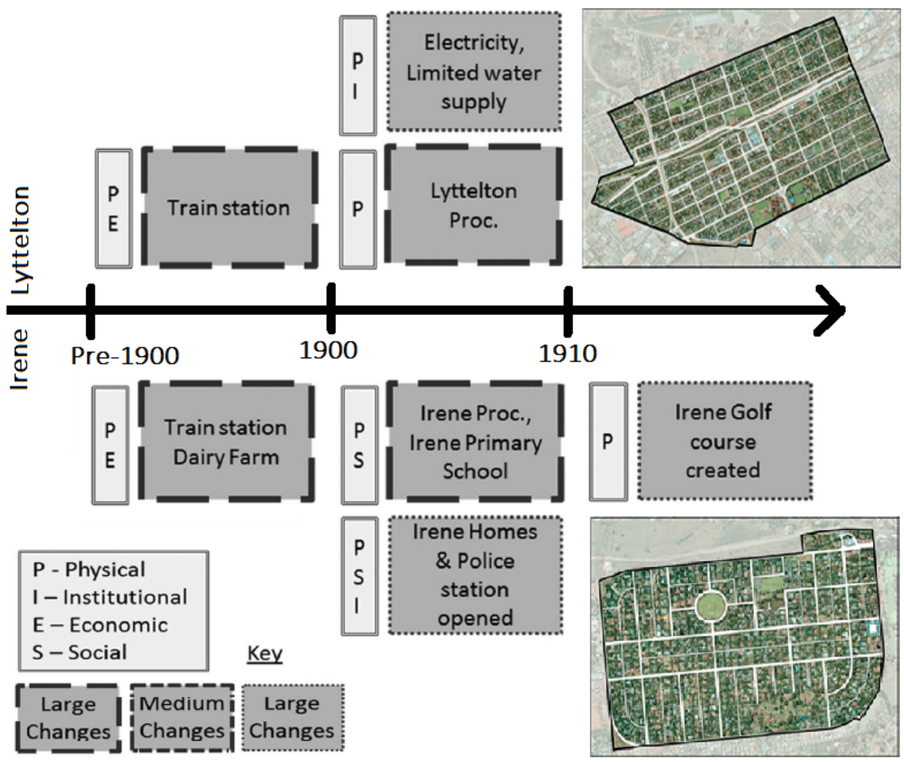

Figure 3.40: Changes identified from the first three interval frames of the analysis of the neighbourhoods Irene (bottom) and Lyttelton (top), adapted from Nel *et al.* (2018).

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Table 3.5: Characteristics and examples of the four adaptive phases of urban change. Compiled from work in Nel *et al.* (2018).

Phase of the adaptive cycle	Description of each phase	Examples in cities
Growth (r)	The initial stage of the cycle and system features a term of rapid growth and more competition where agents utilize opportunities and gather resources while maximizing small, specialized sections present in the system. Although diversity increases, vulnerability is still found in surprises, due to component connections being young and weak.	• Instituting a new area or neighbourhood. • business nodes being created. • instituting and establishing the services and buildings; and • influx of new citizens.
Conservation (k)	Movement from growth stage towards conservation stage is gradual and results from the system gathering resources. An increasing shift towards conservation causes growth to slow and accordingly, agents that reduce uncertainty are favoured. A stage of stability with increased regulation decreases the system's capacity to react to various scenarios. This inflexibility leaves the system fragile to shocks.	• Citizen's age, might be conservative and change-resistant; • infrastructure ages; and • the development of monopolies, embedded and rigid bureaucracy.
Release (Ω)	This stage can happen swiftly due to a shock forcing the system (in conservation stage) past tipping point. The latter reduces regulations managing the system and thus resources accumulated up until now are liberated. The system seems chaotic.	• Demolition of buildings. • consolidating or subdividing land; and • forming of specific economic zones.
Reorganisation (α)	This stage is marked by frail internal linkages, due to disruption of the release stage. The system exhibits vast potential and opportunities for innovation. The system experiences high uncertainty and susceptibility to outside influences. Renewal or collapse are both possibilities for the system at this point.	• Shifts in demographics, e.g., influx of youth in population; • land-use changes. • disruptive tech. and innovation; and • re-development of land.

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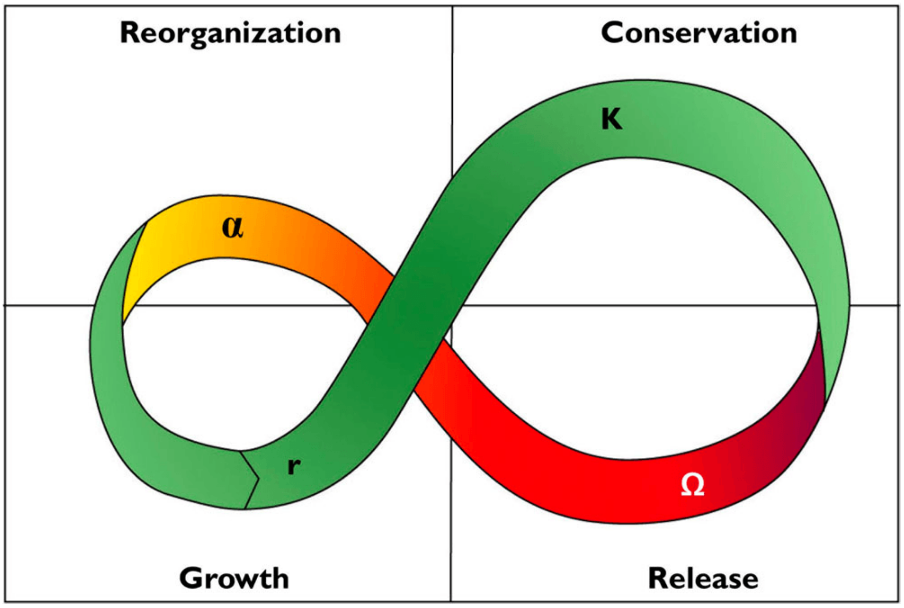

Figure 3.41: Adaptive cycle of urban change (Nel *et al.*, 2018), adapted from Gunderson and Holling (2001).

3.33 Public opinion

Visser (2019) is a humanities scholar specialising in Chinese urban literature and believes that China's policies for smart, creative, and eco-cities research, neglect in some ways to consider citizens. Visser (2019) believes that important infrastructure and employment opportunities are lacking, and spontaneous cultural activities are limited by municipal sanctioned activities. De Oliveira (2016) regards city transformations as crucial in managing environmental and societal challenges but warns against primarily focussing on technical and physical dimensions as this overlooks the essential premise that "cities are made of people". This statement reminds the author, of this doctoral thesis, of a direct discussion he had with Akel Biltaji during the 2017 Forum on Global Cities in Chicago. At the time Akel Biltaji was the vice chairman of the Royal Jordanian Airline and just finished his 2017 term as the mayor of Greater Amman Municipality in which he signed an agreement with Microsoft to transform Amman into a smart city (The Chicago Forum on Global Cities, 2017; Optimiza Consulting, 2015). In discussing the scope of this research and learning from his experience he reminded the author that during the design of a smart sustainable city it should always be clear that the main reason cities are there is for the people. It is therefore important during the design of a smart sustainable city to always acknowledge how different technologies and interventions influence the quality of life and other important aspects of city occupants.

In research by Tanda and De Marco (2018) a regional analysis was done to help determine the drivers for the public demand of IoT-enabled smart

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city services in Italy. Their analysis was done using a survey and had a response rate of 5.49 per cent equating to 242 respondents. Ninety per cent of their responses was from the northern central regions of Italy which is coincidently also the part of Italy where most smart city developments has already taken place while other regions where noticeably behind schedule at the time of the survey. Also, only responses from public managers and directors from two large cities in Italy were included in the sample to ensure homogeneity. Their goal was to better understand smart city services and the potential effect it has on the quality of life, environmental protection, city competitiveness and efficiency in an austere economic environment. Three main survey questions were formulated by Tanda and De Marco (2018) where participants had to respond using a 1 to 5 Likert scale, 5 being the most positive value. Smart city classifications or incentives derived from work done in Neirotti *et al.* (2014) and Borgia (2014) was rated regarding the following aspects: people mobility, pollution control, waste management, renewable energy, info mobility, housing quality, public safety, city logistics, public space management, public lighting, smart grids, hospitality, entertainment, cultural heritage management, building services and facility management.

The first question of the survey asked whether the investments made in smart city technologies for each of the specified domains allowed the city to save money. The second question identified whether these technologies in each of the domains could in effect have improved the quality of life of city occupants. Lastly, the third question dealt with the expenditure on each of the smart city domains compared to the total budget spent on the city (Tanda and De Marco, 2018).

According to the Italian Observatory for Digital Innovation, Italian cities are investing significantly in the smart city domains (Osservatori Digital Innovation, 2016). Survey data in Tanda and De Marco (2018) from question three regarding perceived expenditures for smart city domains was converted to an investment index and ranked in decreasing order in Figure 3.42 on the horizontal axis. The smart city domains from Figure 3.43 that received the highest ratings are “public lighting”, “entertainment”, “waste management”, “people mobility” and “hospitality”.

Figure 3.43 was graphed from survey data in Tanda and De Marco (2018). The potential quality of life for city occupants is compared with the potential economic savings for the city for each of the smart city domains on the horizontal axis, with 1 being the highest rank and 16 the lowest rank. In Figure 3.43 it can be seen that “public lighting” is ranked first for potential economic savings and was also shown earlier in Figure 3.42, to be the domain that was potentially the highest invested in Italy. “People mobility”, “pollution control”, “waste management”, “green or renewable energy” and “info-mobility” were the top-rated domains for improving city occupants’ quality of life.

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3.34 Infrastructure financing

One of the most important drivers of the smart city is the government's financial capability (Tan and Taeihagh, 2020). Transforming a city towards a smart sustainable city is a large-scale process requiring adaptations at multiple city levels. This requires vast financial support and very large investments (Ibrahim *et al.*, 2017). Such a transformation includes (however not limited to): building new or improving current infrastructures, building innovation labs, technical training provision for citizens, implementing attractive tourism projects to promote tourism, developing an index for the city and project to measure and evaluate its smart sustainable performance with, and other projects (Ibrahim *et al.*, 2017).

The definition of infrastructure has recently evolved to include social structures, and in some instances also cyber-structures, but still with a focus on everyday use (Austin *et al.*, 2015). Infrastructure according to the American Society of Civil Engineers (ASCE) can be categorised into the following categories: environment and water (drinking water, dams, levees, hazardous waste, wastewater, and solid waste), transportation (inland waterways, bridges, aviation, ports, transit, rail, and roads), public facilities (schools, public parks, and recreation), and energy (ASCE, 2017). In Figure 3.44 the traditional ways that infrastructure projects are financed is illustrated.

Understanding the difference between and levels of public and private infrastructure becomes important when making infrastructure investments, constructing new national infrastructure and is important when doing maintenance (Austin *et al.*, 2015). In Austin *et al.* (2015) it is believed that the end user does not really care about who has ownership over infrastructure but is rather more concerned with whether the infrastructure is available, working,

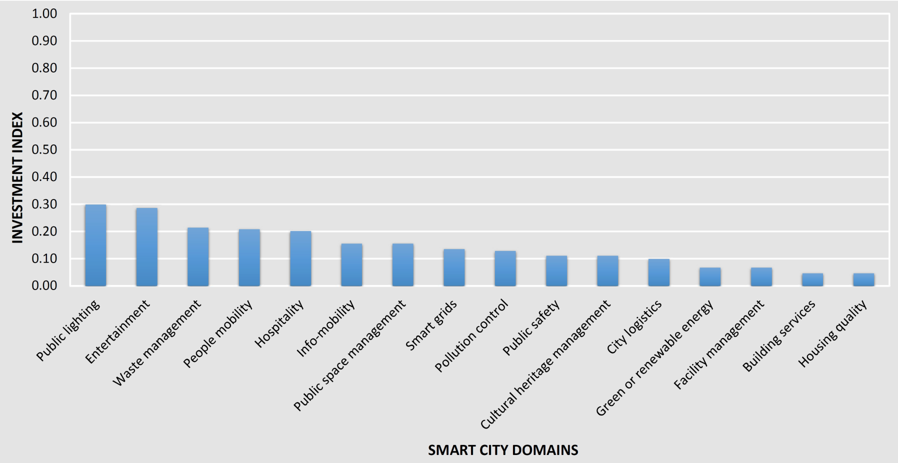

Figure 3.42: Potential spendings per smart city domain. Amended from Tanda and De Marco (2018).

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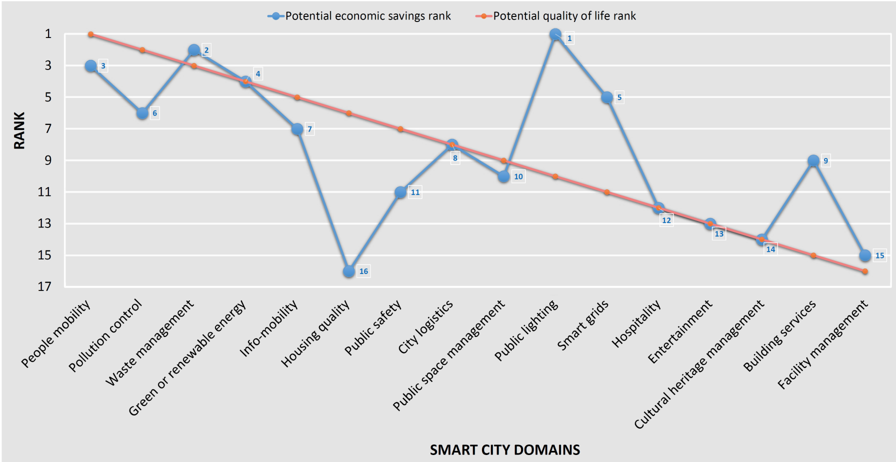

Figure 3.43: Potential economic savings vs potential quality of life ranking per smart city domain comparison. Data in Tanda and De Marco (2018).

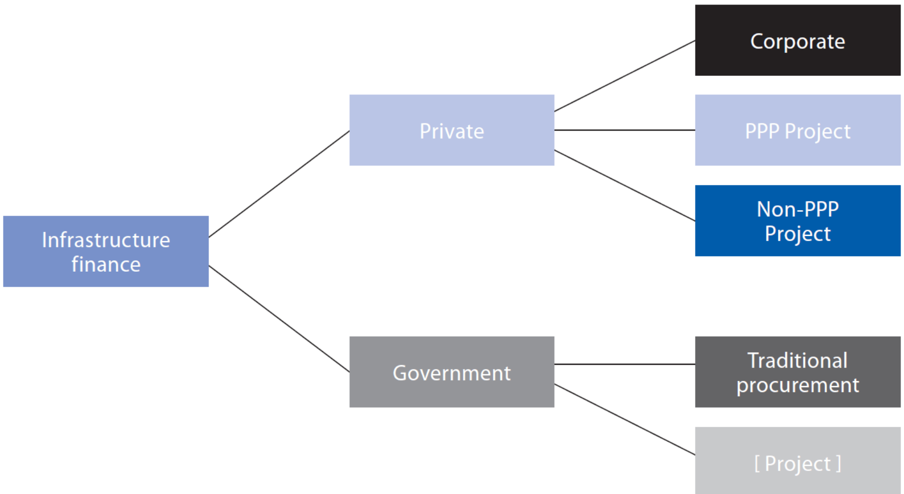

Figure 3.44: Traditional sources of infrastructure financing (Wagenvoort *et al.*, 2010).

and to elaborate on Austin *et al.* (2015), offered at a competitive or reasonable cost. Railway stations in America are many times public buildings, but the supporting railway infrastructure and track can be owned by private entities. There are many governments owned and managed transit systems and ports, nonetheless there are many of them partially owned or managed by the private sector. In America up to 85 per cent of energy infrastructure is held by the private sector (Austin *et al.*, 2015).

Developing nations are more likely to be budget restricted, necessitating a variety of traditional and novel finance methods to boost capital expenditures in smart city development (Zhan and de Jong, 2018; Vadgama *et al.*, 2015; Mishra, 2019). The optimum combination for the government to finance smart cities in India is land-based financing tools (e.g., taxation on real

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estate, development impact fee, taxes on empty land, and charging for improvement); crowding or congestion charging tools (e.g., taxes on motor vehicles, fuel and toll highways), as well as debt financing (Mishra, 2019). Other new financing methods mentioned include earmarking government funds, crowdfunding, monetising huge data sets, creation of smart government bonds, and carbon offsets (Vadgama *et al.*, 2015). China's experience in establishing the International Low-Carbon City in Shenzhen has seen the implementation of a broad spectrum of novel funding tools (Ahmad and Colenbrander, 2020).

Under the notion of *developing the village area*, local community residents, as well as real-estate firms and industries, are included in the renovation of land for high-end industrial means. These individuals are also considered as shareholders in the renovation package agreement and are included in the redevelopment advantages. The *metro and property development approach*, on the other hand, includes three major players: the regional government, the subway corporation, and property developers. The regional government grants the subway company a license to develop and run the metro. The real-estate development rights are then subcontracted by the subway company to real-estate developers on a profit-sharing basis. Under this profit-sharing agreement, the local government and the subway operator can divide land premiums and operational earnings from real-estate development. The subway company might then reinvest part of its profits on subway construction and upkeep, enhancing the real estate development's utility (Zhan and de Jong, 2018; Tan and Taeihagh, 2020).

3.34.1 Budget constraints and financing issues

Budget restrictions and financing matters among others, are crucial obstacles related to smart city development in emerging countries (Chatterjee and Kar, 2015; Kumar, 2017; Cheng and Hu, 2010; Hamza, 2016; Mital *et al.*, 2018; Mboup and Oyelaran-Oyeyinka, 2019). Budget restrictions limit the ability of governments to implement smart cities, even when it is determined that smart cities would be more economical in the long term (Chatterjee and Kar, 2015). In some countries with many levels of legal control on tax related resource distribution, over-reliance on state and central government's money for development interferes with the ability of city governments to create their own income through levies and taxes to fund a large-scale project such as a smart city (Kumar, 2017; Tan and Taeihagh, 2020).

The responsibility of dealing with other developmental obstacles, serve as contending developmental priorities to the government when working on smart city projects (Ahmad and Colenbrander, 2020). Such challenges include (widespread youth employment in Africa (Mboup and Oyelaran-Oyeyinka, 2019) and the economic destitution and disparity seen through the growth of slums in some Egyptian cities (Hamza, 2016). These developmental challenges

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are a contributing factor to urban poverty and are directly linked to other social challenges, such as increases in crime and the rise of the informal economic sector ruled by unskilled jobs or low-level employment. A labour pool dominated by the informal sector and a scarcity of skills and knowledge for smart city implementation hinders the government's efforts to expand the formal sector requiring higher-level technological and scientific skills for developing smart cities (Tan and Taeihagh, 2020).

The high costs to residents and the government are another barrier to the government being able to fund smart city implementation as a financially feasible endeavour (Cheng and Hu, 2010; Mital *et al.*, 2018). The cost of the Dong-tan eco-city project in China, for example, was anticipated to be approximately $1.3 billion USD, and this sum was unlikely to be covered only by the government or private sector. The matter was worsened by concerns about the eco-city project's ability to provide long-term profitability. This did not entice developers to invest capital in the project, limiting governments' capacity to accelerate the development of several eco-city initiatives in China (Ahmad and Colenbrander, 2020; Cheng and Hu, 2010). The high cost associated with owning a smart device and higher electricity bill due to smart device use were proven to be deterrents to smart city adoption in India (Uppenberg *et al.*, 2011).

3.34.2 Increasing income and diversifying sources

In most developing nations, competing developmental objectives are prevalent, and this frequently leads to financial limitations among governments (Ahmad and Colenbrander, 2020). It is critical for governments to collect more income to allow smart city development in developing nations. This is a paradigm change in terms of diversifying funding sources and considering more creative finance alternatives for smart cities. While foreign direct investment and multilateral development banks remain attractive in terms of infrastructural and socio-economic development, governments should also examine more feasible and creative ways for raising money. Other creative approaches that are used capitalize for example on the concept of *congesters pay* to enhance income for the government in addition to land-based financing instruments (Mishra, 2019; Tan and Taeihagh, 2020). The *metro plus property development approach*, as demonstrated in Shenzhen, China, also illustrates a realistic way to collect money for local governments, independent property developers and subway corporations, through mutually beneficial arrangements (Estache *et al.*, 2015; Zhan and de Jong, 2018).

3.34.3 Fostering business ecosystems

A smart city is an ecosystem made up of a variety of subsystems, role players, organisational logics, and activity layers, all of which interact via

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technologically enabled applications (Pierce *et al.*, 2017). As a result, governments must foster a supportive smart city ecosystem that benefits all stakeholders. Creating a more friendly and open business climate for start-ups, supporting pilots and trials for new technologies and allowing transparent and equitable public-private collaborations in technology development, are some of the steps that may be done to implement innovative technologies in the process of realizing smart city ideas (Tan *et al.*, 2021; Estache *et al.*, 2015).

3.34.4 Government's role and policymaking

Long-term growth and infrastructure investment have a strong relation (Ahmad and Colenbrander, 2020). To satisfy the rising demand for infrastructure expenditure, it is critical to make the best use of limited public budgets and tap into every available source of private capital (Ahmad and Colenbrander, 2020). The National Infrastructure Plan 2010 (HM Treasury 2010) lays out a comprehensive vision of the infrastructure investment needed to support the UK's growth, considering the opportunities presented by new technologies, such as offshore wind arrays, high-speed internet deployment and high-speed rail. A government's responsibility in this effort is apparent. It is necessary to describe what infrastructure is required, identify the major impediments to investment, and mobilize the necessary public and private resources, to make it happen (Ahmad and Colenbrander, 2020). Stewart claimed that the United Kingdom was one of the costliest countries in which to construct infrastructure at the time. Civil engineering tasks, for example, cost almost two thirds more than in Germany. To overcome this problem, the UK planning system had to be improved, building costs reduced, data quality improved to guide decision-making, and programs that looked at engineering innovation, resilience, and cross-sectoral independences, had to be initiated (Uppenberg *et al.*, 2011).

It has become known which factors contributed to increased infrastructure expenditures in the United Kingdom. There were problems in the commissioning, early project conceptualization, and pre-implementation phases. Policy aspects, such as the UK planning and consents framework, and regulatory requirements, had an early influence on the whole infrastructure industry, including private- and public-sector investments (Uppenberg *et al.*, 2011).

3.34.5 Investor confidence and regulatory aspects

Because many infrastructure assets are connected to networks and systems, they have the characteristics of a public good. Governments are deeply involved in infrastructure supply because of these features. The use of a social optimization standpoint determines which systems and frameworks are chosen (Ahmad and Colenbrander, 2020). Governments are also in charge of

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planning. Typically, the private sector does the work (capital expenditures, or CAPEX), and all funding is ultimately private, either directly or through the tax system. Infrastructure entails the development of long-lasting assets with large sunk costs, followed by low marginal costs for each subsequent user. Once finished, the gap between the marginal and average costs is consequently quite substantial, because only the latter accounts for the sunk cost. Private investors can only recoup their original outlays if they receive a sufficiently significant cash flow that reflects average rather than marginal cost (Ahmad and Colenbrander, 2020). Historically, one answer has been to recognize that much infrastructure provision has monopolistic power. In theory, a private investor can recoup sunk costs by relying on monopoly rents. Tolls on roads and bridges, for example, played a role in the early development of highways. However, such market dominance may not persist long enough for the investor to recoup his or her initial investment. One issue with monopoly rents is that they attract new entrants and the development of alternative technologies that may reduce monopoly rents. Technological advancement is a genuine threat in nearly all major network systems. The longer the asset's life, the greater the danger of stranding. Long-term contracts and regulatory frameworks are thus required to provide investors with certain income assurances. To prevent governments from breaking their promises to private investors, predictable legislation and long-term contracts are also required (Uppenberg *et al.*, 2011; Ahmad and Colenbrander, 2020).

The government must promise prices based on average cost for private investors to recoup their initial fixed costs, but once the network or asset is operational, it becomes tempting for the government to compromise their commitment by lowering prices to marginal costs in order to attract more users and thus consumer welfare. If governments do not assure compliance regarding not expropriating assets once they are in place, there will be little motivation for investors to create them to begin with (Ahmad and Colenbrander, 2020). Fundamental time inconsistency problems have often been addressed with a focus on transferring ownership of infrastructure assets to the private sector, along with the development of arms' length legal frameworks to offer mechanisms for genuine commitment (Uppenberg *et al.*, 2011). These issues have been addressed practically through organisational design - through the legal framework and the establishment of regulatory organizations that are independent. In nations such as the United Kingdom, where pragmatism about the public interest trumps courts and legal limitations, the focus has been on establishing independent organisations to act as go-betweens between investors and the government. A slew of new regulatory organizations has been established in the utility sector, some of which were formed with this goal as their focus. The regulator acts as a go-between, ensuring that the government follows through on its promises. Typically, such safeguards have not been extended to public-private partnerships (PPPs) and private financing initiatives (PFIs). This has resulted in greater capital expenditures, but also in

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the adoption of alternative methods to provide investors with security, such as claims on additional contracts and assets on maintenance and auxiliary income streams (Uppenberg *et al.*, 2011).

Because infrastructure has a long lifespan, it is critical to implement sustainable infrastructure (Ahmad and Colenbrander, 2020). However, the lengthy lead time brings significant ambiguity into the decision-making process. There is considerable ambiguity, for example, about the spatial distribution of the effects of climate change. Other unknown considerations include the rate and direction of technical advancement, as well as the amount of future carbon pricing, each influencing optimum infrastructure design. Increased uncertainty necessitates more decisive decision-making. Rather than pursuing a single *optimal* approach, it may be preferable to pursue the one that is most likely to produce consensus among stakeholders and/or to mitigate the effects of an unpleasant surprise (Uppenberg *et al.*, 2011; Ahmad and Colenbrander, 2020).

3.34.6 Business models and procurement

The challenge of the vast uptake of smart solutions in European cities require new investment initiatives according to the European Union (2013*a*). Increased public services demand (shifting demographics, the transfer of responsibilities from central government levels, care, etc.) and an economic crisis in the EU, implies that there are limited budgets available for the public sector locally and centrally (European Union, 2013*a*). The latter situation requires the development of new market-oriented and sustainable strategies of public-private cooperation and challenges cities to seek greater levels of investment from external entities. Although the investment community seeks certainty, and scale, most cities, at an individual level, are currently unable to deliver either. Continuing with the 'business as usual' perspective will however not create the necessary value and scale required for city administrations, businesses, cities, and solution providers (European Union, 2013*a*).

According to the European Union (2013*a*) local demand in Europe will have to be aggregated along with the development of common solutions for smart cities to form an integration between local solutions and the global market. The European Union identified the following priority areas that needs to be worked towards (European Union, 2013*a*):

- Business models: A more modular approach is required with regards to local ecosystem solutions for smart cities and communities, which can be utilised throughout European cities, and helps to define a European market for smart city solutions, products, and technologies. Local ecosystems consist of partnerships formed between citizens, governmental structures, and industry to achieve common objectives.

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- Finances: Smart city solutions will be viable if investing in these smart asset's lower operational expenditures (European Union, 2013*a*). Cost per implementation can be more affordable by combining the investments from various stakeholders. This can be done through the creation of a European market for widely usable solutions (aggregated demand), and by establishing a long-term perspective regarding investments. Participating in innovative "crowdfunding" structures, will enhance their sense of awareness through the tangible results obtained from smart cities initiatives.

- Procurement: Change within current procurement procedures as well as the creation of new procedures is required. The advancement of smart city solutions requires cities to participate in local governance institutions, in addition to joint investments and joint ventures. The potential means to steer and accelerate smartness and innovation into cities include city cooperation; amalgamating requirements and targets across Europe; and lastly engaging and stimulating technology suppliers and value chains (for example from the development and manufacturing of new materials, ICT solution systems and energy storage).

Cities are innovation hubs that drive global economic development according to Currid (2006). For several reasons traditional ways will not be sufficient in the vertical priority areas for cities to achieve their goals (European Union, 2013*a*). Firstly, smart solutions developed in partnership between citizens, local and global industries, municipal utilities, and general public agencies is a necessary requirement - this often goes against conventional procurement and tendering procedures (European Union, 2013*a*). Secondly, despite those solutions are intended to be local, conventional small-scale individual solutions are unnecessarily costly and prohibit the development of a business case for advanced and innovative smart technological solutions in cities at a broad scale. Finally, the corresponding and combining of complex city needs with industrial needs for extended term product and process innovation can be greatly improved (European Union, 2013*a*).

3.35 Discussion

Resource limitations and carrying capacity are important priorities that surfaced. Predictions that urban populations are growing and will most likely continue to increase their resource use per capita, turned the spotlight to decoupling growth of economic and social activity from the result of increased resource use. It is understood that although decoupling on a city level is possible, it is likely that the amount of decoupling that will eventually be achieved might not be enough to fully achieve the level that is required for sufficient sustainability. It is advised that sustainable and smart innovations

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that advance decoupling be encouraged and incentivised, as it is still an effective means to advance sustainability. Tracking resources and performing material flow analysis provides a means for evaluating progress of decoupling initiatives. Monitoring urban metabolisms will also provide insight into the most promising intervention points.

It is a recurring fact throughout the literature that urban change and city systems and dynamics entail complex and hard to predict phenomena and responses. This is due to the interconnectedness and interdependence of city systems on a technical and social dimension. When a change or event occurs, it has cascading effects to various systems and actors. The actors (from citizens, committees, families, organisations, and governance) have unique attributes as well as commonalities which influence their responses. Clustering, self-organisation, emergent behavioural patterns, and initiatives from among urban actors are all anomalies that occur and influence the city functioning and evolution. These patterns and linkages are characteristic of complex adaptive systems. The various components and properties of complex adaptive systems were discussed, as well as approaches that are useful for understanding complex urban dynamics on various levels and dimensions, such as the urban change descriptive framework (USDF) demonstrated in Nel *et al.* (2018). It can be adapted in various ways for specific applications or enquiries.

Government's role in development planning is to specify the infrastructure needs, identify barriers to securing investment, and mobilise the public and private resources to achieve a solution. Robust decision making should receive consensus among stakeholders and minimise impacts of unexpected events or dynamics. Long lifespans of infrastructure assets are coupled to increased risk due to uncertainty of geographical distribution of climate change impacts over time, and uncertainties regarding pace and direction of technological development, that might become a threat to current infrastructure investments. Therefore, it is important to model and understand infrastructure needs and dynamics to better plan infrastructure solutions, policy changes and institutional changes. Analysis of the population's ability to pay for services is a very important consideration while deciding on the most suitable financing approach. Improved contract design and regulatory frameworks may be helpful regarding the time inconsistency problems by transferring the ownership of infrastructure assets to the private sector and establishing arms' length regulatory frameworks to guarantee that commitments are honoured. To improve the credibility of government agreements with financiers and investors, independent intermediary institutions between government and investors can act as regulators to guarantee that the government delivers on its commitments. Improved coordination among various external financiers and donors are needed as a collective effort to deal with institutional and policy challenges like greening sectors, corruption, improved monitoring and performance evaluation of development initiatives, infrastructure systems, resource use and sector governance.

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3.36 Conclusion

The first part of this chapter provides the approach and findings of a structured literature review of the available literature related to transitioning an existing city's infrastructure to become a smart sustainable city. The aim of the review conducted is to investigate the nature of available research, discern which work has been done and what the knowledge gap is. It was found that the majority of the article published before January 2020, focused on sustainable cities, smart cities, and climate change, with only a few focusing on smart sustainable cities as an urban concept. Research after January 2020 has shown an increasing shift towards smart sustainable cities.

A wide variety of deliverables were provided in the literature selection, most of which were insights, frameworks and models. This coincides with the aim of this research study to develop a framework, as these deliverables are the main sources from which the proposed framework is to be synthesised.

The most relevant research from the literature selection entails a high-level transformation readiness roadmap for smart sustainable cities in Ibrahim *et al.* (2018), which outlines the main phases. In the article Ibrahim *et al.* (2018), future research is encouraged to build and expand on the roadmap by developing a transition framework for smart sustainable cities. Work in Pereira and De Azambuja (2022) confer, as future research is suggested to build on existing roadmaps towards a comprehensive and detailed guide or framework for transitioning towards a smart sustainable city. Thus far there is an absence of a comprehensive framework to guide the planning, management and implementation of a smart sustainable city transition.

Infrastructure was identified as a meaningful point of intervention for transitioning urban systems. Throughout the literature collected, a systems-of-systems perspective was indicated as a very relevant analytical lens for matters concerning city dynamics, infrastructure transitioning and urban planning. Consequently, this study pursues the development of a strategic framework with infrastructure as the main intervention point, approached holistically using a systems perspective regarding urban systems.

The second part of the chapter presented a conceptual review of literature relevant to the research problem which entails transitioning urban infrastructure with the aim of making an existing city a smart sustainable city. To understand the research problem, various concepts, approaches and perspectives have to be studied and considered, as well as how they interrelate.

The two urban development paradigms, smart cities, and sustainable cities, which are foundational to the smart sustainable city concept, were each explored with regards to their dimensions, technology, differences and shortcomings. The emergence of the smart sustainable city concept is explained, as well as existing indicators, benchmarking methods and city ranking approaches. The multidisciplinary topics that influence urban development and infrastructure planning were reviewed, and included aspects

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such as stakeholder engagement, policy making, financing infrastructure, standardisation, public opinion, governance, and strategic matters.

Many factors have an influence on the city and effective planning towards infrastructure that can serve the city in a smart sustainable way. This is illustrated in Figure 3.45. The following conclusions were drawn from the literature that was studied to aid infrastructure transitioning planning for smart sustainable cities.

- A systems perspective and complex adaptive systems theory can be used to study and understand complex or vague phenomena for which a solution design requires deeper insight in an area's unique history, internal dynamics, external influences or change patterns.
- Sustainable and smart innovations, that advance decoupling of economic and social activity from resource use, should be encouraged or incentivised.
- Enriched information regarding urban resource flows will be a valuable aid for infrastructure planning. Opportunities to perform material flow analysis that present worthwhile gains should be considered. Technology can be a powerful tool to collect and interpret data, as well as enforce efficiency.
- Determining what type of data would assist in evaluating the technical, social, and financial feasibility for specific projects or interventions, is an

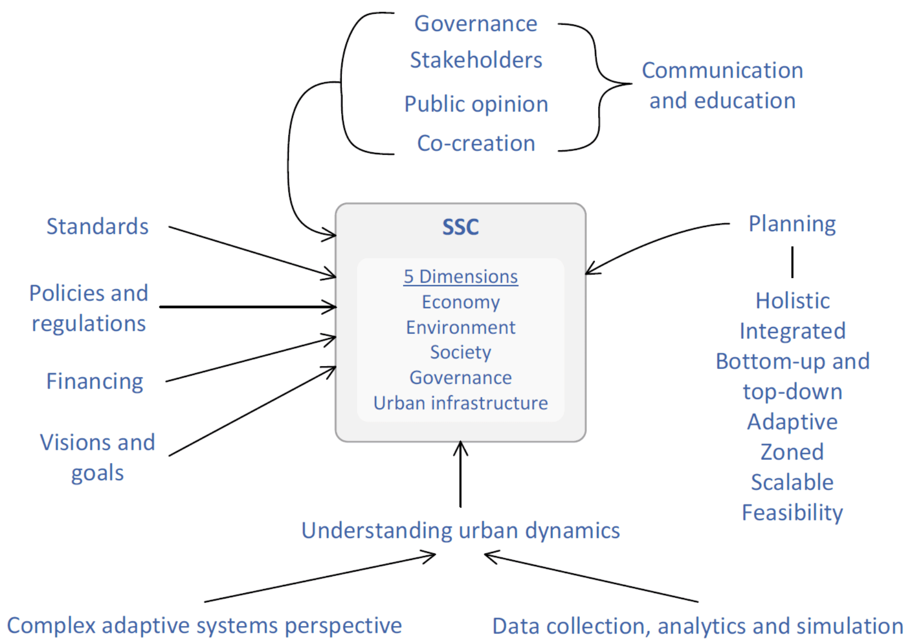

Figure 3.45: Important influencing factors in planning smart sustainable urban infrastructure from the conceptual literature review.

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important step.

- Barriers to acquire finance and private investment for infrastructure should be identified.
- Legal and financial advisory should be consulted regarding optimal regulatory framework mechanisms and contractual design required for various financing options, for instance, public-private partnerships.
- The ability of the population to pay for services should be determined and considered.
- Model, test and refine solution concepts within context by involving universities, the private sector, innovation hubs, establishing living labs and pilot projects.
- Risk and uncertainty should be reduced through adequate risk analysis and decision support.
- Clear requirements for tender, mechanisms to track performance, control scope and budget are also needed.
- Good reporting, communication and collaboration between stakeholders is crucial.

Another observation from the literature was that there are differences between smart city and sustainable city aspects and approaches with regards to holistic sustainable development principles. Sustainable city frameworks tend to focus more on the environment than the other two sustainability dimensions, whereas smart city frameworks show lower priority to the environment, focusing more on economic and social welfare. There exists a definite need for a smart sustainable city framework to guide urban development on a path that is balanced and holistically sustainable. The knowledge and insight obtained during this conceptual review of the literature will be incorporated in the development of the framework.

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Chapter 4

The Development of the Smart Sustainable Urban Infrastructure Transition (SSUIT) Framework

In this chapter a detailed framework, synthesised from literature, is presented with infrastructure as its focus of intervention. The developed framework builds and extends on previous work and enables urban planners and local government to plan and execute a purposeful and effective transition towards a smart sustainable city. The design of the transitioning framework for smart sustainable cities forms part of the second phase of the research illustrated in Figure 4.1.

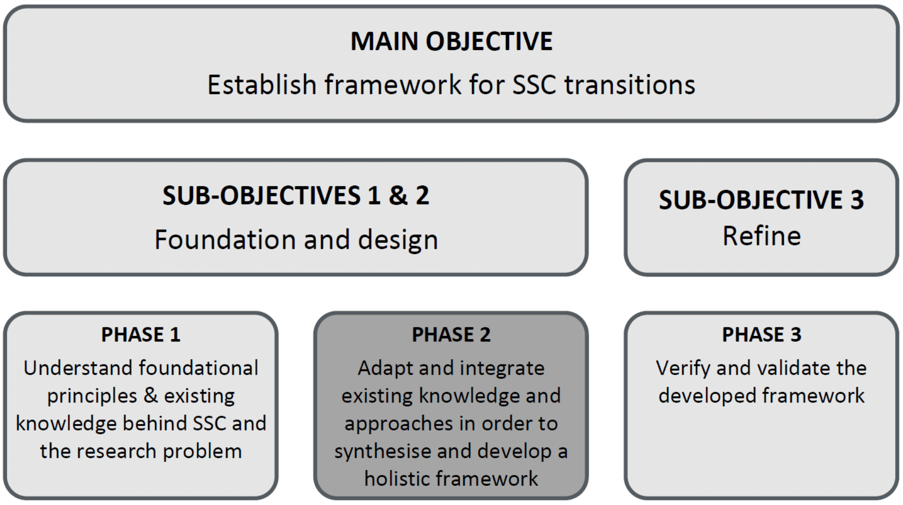

Figure 4.1: Approach followed during the research.

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4.1 Framework stages

For the theoretical framework, key components from existing roadmaps, frameworks and models that relate to a smart sustainable city transition will be looked at to identify the main stages. In Table 4.1 eight studies are listed along with their main stages. These studies are what were available to the research during the literature search and relates to smart sustainable urban transitions. The criteria for selecting these studies include that they are structured as a model, roadmap, framework or at least contain clear steps. The studies are long term focused and multi-project based. For instance, a framework that only focuses on a single project such as implementing cycle lanes was considered and understood, but not included to derive the high level stages. With limited research available, these eight studies span over

Table 4.1: Overall main stages of available roadmaps and frameworks and their relationship.

Source	Main Stages	Stage Relations
Sustainable cities implementation planning (Fu and Zhang, 2017)	· External influences and drivers	1
	· Master plan	2 3 4
	· Implementation	5
	· Operation	6
SSC governance roadmap (Pereira and De Azambuja, 2022)	· Planning	2 3 4
	· Implementation	5
	· Monitor and evaluate	6
SSC roadmap (Ibrahim et al., 2018)	· City vision	1 2 7
	· City readiness	1 2
	· City plan	3 4
	· City transformation	4 5
	· Monitor and evaluate	6
	· Sustain change	7
SSC cycle (ITU-T FG-SSC, 2015)	· City vision	1 2 7
	· SSC targets	1 2 3
	· Political cohesion	1 2 3 4 7
	· Build city	5
	· Measure progress	6
	· Ensure responsibility and accountability	6
	-> Return to first stage	7
Sustainable urban design framework (Boyko et al., 2005)	· Form teams, goals and appraise situation	1 2
	Intermediary stage - reflect and communicate.	
	· Design and develop	3 4
	Intermediary stage - reflect, iterate alternative solutions.	
	· Evaluate and select best solutions and create plan	3 4
	Intermediary stage - reflect on the plan.	
	· Implement, monitor and follow up	5 6
	Intermediary stage - Continuing process, could go back to	7
	Stage 1 for adaptations or improvements.	
Pre-project planning (Gibson Jr et al., 1995)	· Perform pre-project planning	1
	· Organise	2
	· Select alternatives	3
Roadmap for smart cities (EPIC Consortium, 2013)	· Vision	1 2 7
	· Plan	2 3
	· Design	4
	· Build	5
	· Deliver	6
	· Operate	6
Integrated and adaptive transition model for sustainable and resilient cities (Mendizabal et al., 2018)	· Vision, impact and risk analysis	1 2 7
	· Adaptation options	2 3
	· Planning	4
	· Implementing	5
	· Monitoring	6
	-> Return to first stage	7

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many themes which include: smart sustainable cities; sustainable cities; smart cities; implementation planning; governance; urban design; project planning, and integrated and adaptive transitions. The number of studies selected were manageable to work with and provided a well-rounded knowledge base. These studies stood out as the most relevant, informative and well positioned.

When exploring the main stages in Table 4.1 and understanding their workings, general themes surfaced such as: evaluate; set targets; consider and select possible alternatives; design; implement; evaluate; operate and monitor; and, adapt where necessary. Seven stages in Table 4.2 were established based on these themes and research. The stages in Table 4.2 were further colour coded to relate to the main stages in Table 4.1. The stage relations in Table 4.1 were determined based on the intent and context behind each of the main stages in the studies investigated.

Table 4.2: Framework stages

Main stages		
· Stage	1	Pre-project preparation
· Stage	2	Teams, city state, readiness and assessment
· Stage	3	Project(s) identification and selection
· Stage	4	Design
· Stage	5	Implementation
· Stage	6	Maintenance, evaluation and innovation
· Stage	7	New initiatives and upgrades

The overall flow of the stages was based on a sustainable urban design framework in Boyko *et al.* (2005) with the combined knowledge of the studies in Table 4.1 as can be seen in Figure 4.2. The framework in Boyko *et al.* (2005) is frequently used as a structure for research in urban design, sustainable cities, ICT and project planning (Arslan, 2021; Gün *et al.*, 2020; Dias *et al.*, 2018; Mneimneh *et al.*, 2017; Cooper *et al.*, 2009) and is a balanced representation of the general themes identified in Table 4.1. Each of the stages in Figure 4.2

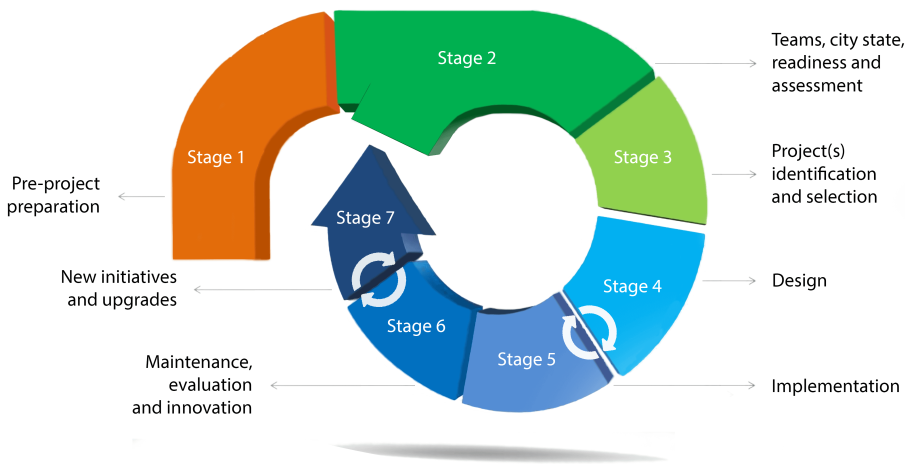

Figure 4.2: Overall flow of the stages within the framework.

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are expanded in Figures 4.3 to 4.6 and explained in more detail later in this Chapter.

In Figure 4.3, Stage 1 of the transition is shown, which is the pre-project preparation stage. Stage 2 in Figure 4.4 entails the team preparation, determining the current state of the city and assessing the readiness for transitioning. Stage 3 in Figure 4.4 represents the process of identifying and selecting viable projects. Stage 4 in Figure 4.5 focuses on the design of the smart sustainable city, while Stage 5, also in Figure 4.5, focuses on the construction and implementation of the designed solutions. Stage 6 in Figure 4.6 is aimed at maintaining and evaluating the current infrastructure and city state and pursuing ongoing innovation. Stage 7 in Figure 4.6 is the last stage and entails pursuing new initiatives and upgrades to maintain current infrastructure, accounting for the changing dynamics in a city and ensuring the city continues to function as a smart sustainable city.

Each of the developed stages in Figure 4.2 are discussed in further depth in this chapter, to better understand their functioning and integration in the holistic framework. For more detailed versions of the framework, also see Appendix C, Section C.1, Figures C.3 to C.5.

4.2 Stage 1: Pre-project preparation

Stage 1 in Figure 4.3 consists of ten steps that was based on the sustainable city planning research in Fu and Zhang (2017), the urban design process in Boyko *et al.* (2005), a smart sustainable city roadmap in Ibrahim *et al.* (2018) and an infrastructure asset management framework in FHWA (1999). The main flow of Stage 1 agrees with the complex adaptive system's (CAS) multi-project environment systems-model in Aritua *et al.* (2009) which starts by determining the context or environment which influences change (Steps 1.1 to 1.2.d and 1.5), and determining the vision, mission and opportunities as an iterative process (step 1.6 to 1.8).

In the framework (Figure 4.3), Stage 1 starts with possible driving pressures that could lead to the initiation of a smart sustainable city transformation. The stage then later evolves from feasibility studies to selecting the right teams to drive the transformation, determining the visions and goals, identifying possible investment and funding options and opportunities. Eventually consensus regarding the transitioning of the city will be reached in Step 1.9, followed by initiating SSC education and awareness programs.

4.2.1 Drivers

There are several drivers or pressures that can motivate a government to consider transitioning a city to become a smart sustainable city. Research used in this section include urban dynamics and sustainability research in

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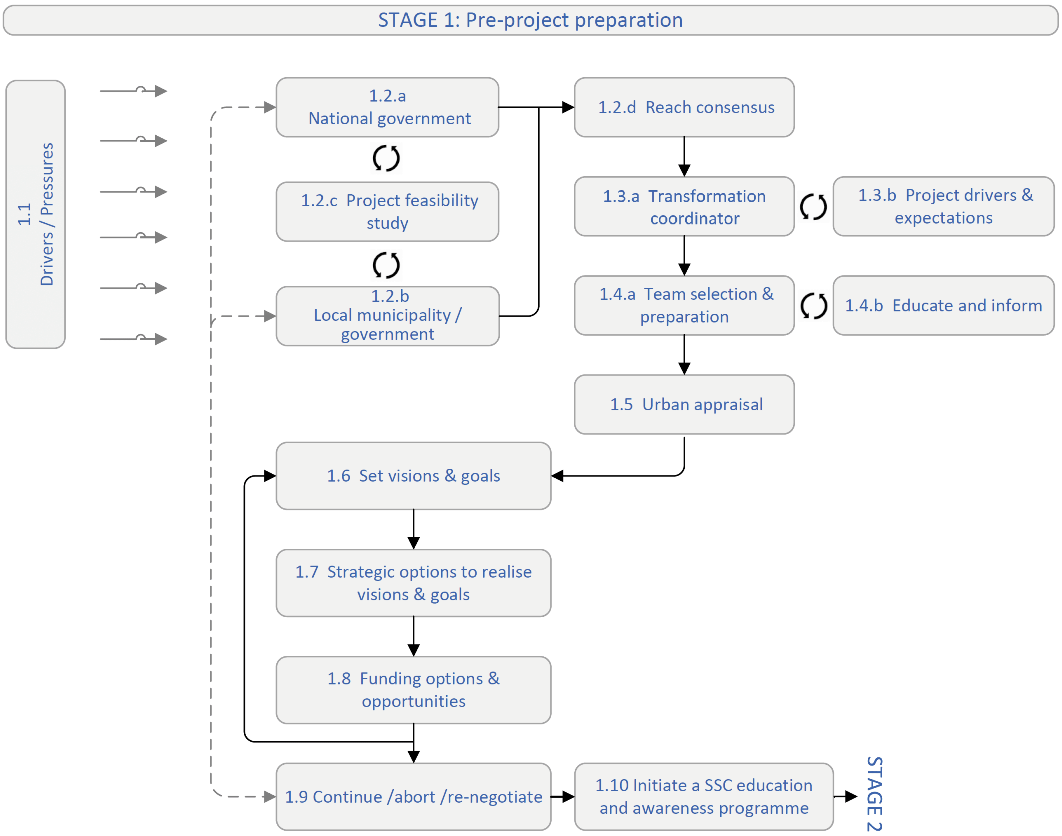

Figure 4.3: Pre-project preparation as Stage 1 of the framework.

Wann-Ming (2019), urban population, development and economics research in UN-DESA (2022, 2019a,b), smart sustainable city development research in Schuch de Azambuja (2021), smart sustainable city challenges research in Höjer and Wangel (2015), smart city governance research in Tan and Taeihagh (2020), urban greenhouse emissions research in Khansari and Hewitt (2020), and infrastructure and economics research in Goodman and Hastak (2015). Many factors surface through these studies, with the most common identified and sorted according the five smart sustainable city dimensions:

- Environmental dimension: Pollution prevention, waste management and recycling, resource usage and availability management, air and water quality, urban space quality, biodiversity and mobility factors for more efficient transportation systems.

- Economical dimension: Portfolio-thinking, knowledge and shared-based economy, strengthening of human capital, circular economy, competition from surrounding regions, innovation, crowdsourcing, multi-sector synergies, availability of skilled and non-skilled workforce availability and to attract skilled workers, tourism and urban attractiveness.

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- Social dimension: Urban services provision, urbanisation, urban growth, and urban sprawl, social inclusion, literacy rate, informed citizens and public safety.

- Urban infrastructure dimension: Integration of physical infrastructure, integration and interoperability of ICT in infrastructure, IoT, big data and data processing, intelligent urban services, data analytics and business intelligence, security features, and providing affordable connectivity, water and energy in the city.

- Governance dimension: Urban planning, transparency, communication channels, political will and policies, regulation development, assessment of key performance indicators (KPIs), models for collaborative and better decision-making, stakeholder engagement, real time data for decision-making, future projections and capacity planning, and context adaption.

4.2.2 Initiation

The early project feasibility study in Step 1.2.c will commence once the pre-project preparations stage is initiated by the higher-level authorities, Step 1.2.a and 1.2.b, as suggested in Fu and Zhang (2017). For the project feasibility study in Step 1.2.c, work in Göpfert *et al.* (2019), Fu and Zhang (2017) and Kivilä *et al.* (2017) were used and the project feasibility studies can include, but is not limited to:

- Potential stakeholders involved.
- Financial investment potential.
- Early budget allocations and potential investors.
- Alignment with strategic goals at local or national level.
- Impact studies and expert opinions.
- City selection and scope.
- Potential policy adaptions required.

After reaching a preliminary consensus in Step 1.2.d regarding continuing with the SSC transformation from the data obtained in the feasibility study, appointing a transformation coordinator in Step 1.3.a can begin.

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4.2.3 Selecting a transformation coordinator

In Step 1.3.a of Figure 4.3, a transformation coordinator or body should be appointed to oversee all the future activities in the smart sustainable transitioning stages. This stage agrees with work in Fu and Zhang (2017) on the planning of sustainable cities. The transformation coordinator should also be responsible to keep open communication with the relevant parties and governmental structures during the execution of the stages (Cooper *et al.*, 2009; Boyko *et al.*, 2005). As in Step 1.3.b, the transformation coordinator should be in communication with the government (Pereira *et al.*, 2017) on the transformation drivers, expectations, potential transformation limitation, early timelines and planned budget allocations.

4.2.4 Transformation team and orientation

The process of selecting the steering committee or team in Step 1.4.a, Figure 4.3, should originate by determining the skillsets required for a smart sustainable city transformation and the skill required to address the preliminary expectations set in Step 1.3.b. The role that each member will fulfil on the multi-disciplinary team, how well the members will be able to co-operate and function together, and finally, how well members will be able to coordinate other subordinate teams of various disciplines is according to Leger *et al.* (2013) also of importance when selecting members. Boyko *et al.* (2005) recommends that as many stakeholders as possible should be involved during the selection of the steering committee. A multi-disciplinary body of experts should also be selected, if not already included in the steering committee, that can be consulted at any time during the project.

According to Chourabi *et al.* (2012) an important critical success factor and well-known challenge to smart city projects is the lack of alignment with the overall goal of the project and resistance to change. Therefore, the orientation and education activity in Step 1.4.b is significant to the success of the project. This is also supported in the smart mobility framework by Peprah *et al.* (2019) and work done by Gil-García and Pardo (2005). All members of the steering committee and the expert team should be orientated to understand the core principles, dimensions, components, and functions of smart sustainable cities and how each member's role can contribute towards a successful smart sustainable transition. It is further important that the steering committee and experts should thereafter discuss and evaluate the drivers, expectations and other items in Step 1.3.b that were initially formulated for the transition. Key stakeholders in the government should also be educated and informed to understand core principles, dimensions, components, and functions of a smart sustainable city as this will help with the collaboration throughout the project. After all teams and the government are fully informed, the steering committee and experts should now confer with the key governmental stakeholders and

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re-visit items from Step 1.3.b to discuss possible concerns, and where necessary, negotiate new terms.

4.2.5 Urban appraisal

Step 1.5 in Figure 4.3 is to appraise the current city state. Urban appraisal is a necessary step supported by Pereira and De Azambuja (2022), Ibrahim *et al.* (2018), Boyko *et al.* (2005) and (Mendizabal *et al.*, 2018). Activities in this step can include evaluating existing city sensors if available and other sources of city data such as location-based transactional data, utility usages, socio-demographic profiles, census data, and institutional records, such as police files and more. Both Zhong *et al.* (2021) and the Construction Industry Development Board (CIDB, 2011) regard the asset register as an important element for transformation of the city and should thus be kept up to date. Infrastructure asset management is not a simple task due to high density population and interdependencies increasing unanticipated failure due to cascading effects (Zhong *et al.*, 2021). An infrastructure asset management framework developed in Zhong *et al.* (2021) can be utilised to help with interdependent systems in high-density cities.

Projection of the city's service and resource supply and demand relationships (for example: water and energy resources, pollution rates, land use, food security, public transport, traffic density, safety, etc.) is also of importance according to Goodman and Hastak (2015). The cities' expected population growth and urban expansion should also be determined. City information should help with identifying potential needs, problems, issues, and opportunities in the city, some of which could have been overlooked otherwise and will help to potentially better understand the city state and dynamics (Dana *et al.*, 2022). The information can also be of importance when preparing for the next activity in Step 1.5, which is identifying stakeholder requirements by means of surveys, town hall meetings etc. The findings from these activities should be reviewed against the drivers, expectations, timelines, budgets, and limitations set for the transformation. Finally, these findings are to be reported to the government or higher-level authorities and key stakeholders.

4.2.6 Setting the transition's visions and goals

Setting the visions and goals in Step 1.6 of Figure 4.3 is seen as an important step of the pre-project preparation stage helping the transition to succeed overall. Forming visions and goals is well supported in literature for the early stages of a transformation project (Al-Gindy *et al.*, 2021; Ibrahim *et al.*, 2018; Malekpour *et al.*, 2017; Mersal, 2017; ITU-T FG-SSC, 2015; Too and Weaver, 2014; EPIC Consortium, 2013; Boyko *et al.*, 2005), and an example of setting visions and goals for an eco-city can be found in Mersal (2017).

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4.2.7 Strategic options to realise the visions and goals

Step 1.7 in Figure 4.3 entails the strategic options to realise the visions and goals and was designed according to the recommendations of Malekpour *et al.* (2017), which is to determine the possible paths to realise the visions. This step adds to visions and goals by further investigating what visions and goals might be workable. This theory agrees with work in Mendizabal *et al.* (2018); Ferguson *et al.* (2013); Nevens *et al.* (2013); and Haasnoot *et al.* (2013). A PESTLE analysis (political, economic, socio-cultural, technological, legal, and environmental factors) can be used as recommended in Fouché and Brent (2020) to explore the potential strategic options and the potential consequences. A set of future scenarios can be constructed through the PESTLE analysis by understanding the factors that have an influence on the future context. The set of possible futures will be used as backdrops against which the proposed strategies can be evaluated.

4.2.8 Funding options and opportunities

Stage 1.8 in Figure 3 was designed according to work by Fu and Zhang (2017) and Fay *et al.* (2021) and agrees with work in Dana *et al.* (2022). The step focuses on finding funding, investment opportunities or potential business opportunities to help finance and realise the visions and goals. According to Dana *et al.* (2022) and Hodson and Marvin (2010) it is important to have sustainable broad-based funding to prevent the project direction from being dictated in future by the pursuit of funding. This idea is also elaborated and supported by Zhan *et al.* (2018) who also recommends not to rely on governmental funding as the only option for a city transformation. Funding plays a crucial role in determining whether infrastructure would be able to be implemented, completed, and successfully operated (Fay *et al.*, 2021). If no viable financial solution is possible, it might require revisiting and adapting the visions and goals in Step 1.6.

4.2.9 Continue, abort or re-negotiate

After completing the iterations between Step 1.6 and Step 1.8 for viable transformation options in Figure 4.3, all findings regarding these steps should be presented to the key governmental stakeholders and a decision should be made whether the project can continue to the final Step 1.10 before entering Stage 2, or whether it should be completely aborted, postponed or if the project can be re-negotiated and restructured as in previous steps. This part of Stage 1 closely resembles the first intermediary stage, 'reflecting and communicating' in Boyko *et al.* (2005).

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4.2.10 SSC education and awareness

Before continuing to Stage 2, an education and awareness program in Step 1.10 is initiated to help prepare city occupants towards understanding the smart sustainable city concepts, how it can be utilised, and the potential visions and goals set for the city. This step was chosen according to recommendations in Giffinger *et al.* (2007).

4.3 Stage 2: Teams, city state, readiness, and assessment

Stage 2 in Figure 4.4 was introduced in Boyko *et al.* (2005) as part of a sustainable urban design framework, and was further amended for smart sustainable cities with the work in Ibrahim (2019), Ibrahim *et al.* (2018) and Gibson Jr *et al.* (1995). The stage consists of four steps and involves preparing the team, developing a draft charter, determining the city state and readiness for transformation, and doing a city assessment.

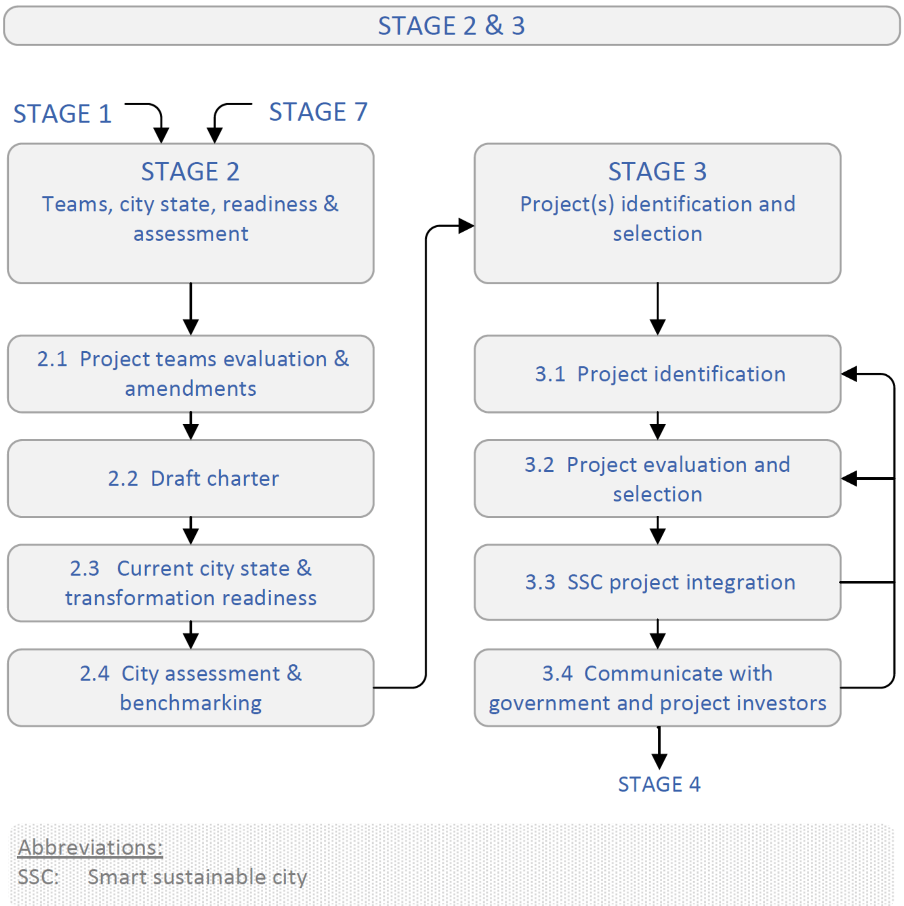

Figure 4.4: Stages 2 and 3 of the developed frameworks.

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4.3.1 Team preparation

As more information has surfaced from the results of Stage 1 since the first team selection, it could be beneficial to re-evaluate the team and adjust it to include new members for additional expert knowledge required. Also ensure that all team members understand their roles, project goals and visions. Both Boyko *et al.* (2005) and Gibson Jr *et al.* (1995) make use of similar activities.

4.3.2 Draft charter

According to Gibson Jr *et al.* (1995) the draft charter defines the pre-project planning and transforms the initial project concept into a workable, project-based concept. The draft charter includes items such as: project motivation, objectives and constraints, assumptions, in- and out-of-scope items, risks, high-level budget, spending authority, and so forth. As the project continues remember to continuously update the draft charter. Components of the draft charter are a combination of those present and found throughout the initial stages in the roadmap in Ibrahim *et al.* (2018) and the framework in Boyko *et al.* (2005).

4.3.3 City sensing and transition readiness

The city sensing, state and transitioning readiness steps (Step 2.3 and 2.4) is based on a combination of work done by Ibrahim (2019); Ibrahim *et al.* (2018); Boyko *et al.* (2005) and recommendations from Bibri (2021). This step comprises of:

- Revisiting findings from Stage 1 in Figure 4.3.
- Discussing smart sustainable city benchmarking/ranking requirements and possible sensors required. Work in Akande *et al.* (2019) serves as an example showing how 32 European capital cities were evaluated and ranked according to smart sustainability.
- Seeking possible ways to implement the sensors required that can deliver the information required yet potentially also generate revenue or value (Al-Gindy *et al.*, 2021).
- Implementing the required sensors.
- Discerning if any smart city, sustainable city, or smart sustainable city initiatives have been attempted in the city and evaluating their outcomes.
- Evaluating the readiness of the available ICT-based infrastructure and non-ICT-based infrastructure to be integrated/adapted/renewed/substituted in the planned smart

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sustainable city transition. This activity also features in the transformation roadmap in Ibrahim *et al.* (2018). Bibri (2021) emphasises the importance of compatibility when integrating older or different technologies into a new system and established that sometimes it requires replacing infrastructures due to incompatibility so that the city can function as planned.

- Assessing the level of awareness and vulnerability regarding security features on current ICT-based designs. Maintaining high security is a high priority, especially where smart infrastructure is involved (Abbas *et al.*, 2021; da Silva *et al.*, 2021).

4.3.4 City infrastructure assessment

The city infrastructure and assessment step are based on work done in Ibrahim (2019), Ibrahim *et al.* (2018) and Akande *et al.* (2019) and entails the following activities:

- Determine the critical success factors (CSF) that represent and ensure a successful transition project that meets the visions and goals set out for the city. These success factors can be used as a control measure throughout the project to evaluate progress, detect and correct deviations and communicate progress and confidence to key stakeholders.

- Determine the key performance indicators (KPI). Many studies in the past decade have used the indicator-based approach to assess different aspects of urban performance in sustainability and smartness, aggregate the scores with linear models and lastly have global cities benchmarked accordingly (Phillis *et al.*, 2017; Mulyawan *et al.*, 2020). Akande *et al.* (2019) utilised thirty-two indicators that were developed by the International Telecommunication Union of the United Nations Economic Commission for Europe (UNECE-ITU) and were used for smart sustainable cities ranking in Europe. The indicators in Akande *et al.* (2019) corresponds to ISO indicators for city services and quality of life (ISO, 2018), as well as to the EU sustainable development strategy (European Commission, 2018; European Union, 2016).

- Determine the current SSC performance by ranking the city. See Akande *et al.* (2019) for examples and further details.

- Identify areas of improvement.

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4.4 Stage 3: Project(s) identification and selection

Stage 3 in Figure 4.4, project(s) identification and selection, consists of four steps and incorporates project management theory of Goodman and Hastak (2015) and project selection techniques from Marcelo *et al.* (2016).

4.4.1 Project identification

Identify all plausible infrastructural projects that fall under the five dimensions of a smart sustainable city (environment, economy, social, urban infrastructure, governance) (Neumann, 1997; Ibrahim *et al.*, 2018; Schuch de Azambuja, 2021) to address specified transformation aims:

- Upgrades and changes to the current structural and non-structural ICT-enabled and non-ICT-enabled infrastructure.
- New infrastructure that needs to be built or installed.
- Short-and long-term projects (FHWA, 1999).
- Projects that emerged from the latest data, including basic services.

Lastly, determine each of the projects' criticality and desirability, as well as the way each project will integrate under the five dimensions of an SSC.

4.4.2 Project evaluation and selection

The project evaluation and selection step helps to determine which projects to select from all the possible projects for the smart sustainable city transformation. The World Bank Public-Private Partnerships Group, presented an Infrastructure Prioritisation Framework (IPF) for project selection in Marcelo *et al.* (2016) and was incorporated into this step. The following activities apply:

- Criteria identification - consult and deliberate with experts and decision makers to determine the criterion for project selection (Marcelo *et al.*, 2016; Goodman and Hastak, 2015). Neumann (1997) suggests that consistent criteria must be kept for the evaluation and selection of the proposed projects.
- Determine the social and environmental index (SEI) for each project (Marcelo *et al.*, 2016; Goodman and Hastak, 2015).
- Determine the financial and economic index (FEI) for each project (Marcelo *et al.*, 2016).

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- Where possible conduct a cost benefit analysis (CBA) for each project (Marcelo *et al.*, 2016). A good example of a cost benefit analysis for a smart sustainable city was done in Al-Gindy *et al.* (2021).
- Determine each project's risks, assumptions, constraints (Ibrahim *et al.*, 2018), and the spatial and technical overlaps with other projects.
- Set up a priority matrix with SEI and FEI coordinates with the budget as the constraints, as demonstrated in Marcelo *et al.* (2016).
- A sensitivity analysis can also be performed to better understand the sensitivity of the outcomes with regards to changes in the variables and inputs (Marcelo *et al.*, 2016).
- Select the best fit projects based on the transformation aims and expert opinions. Take note that quadrant A in the priority matrix should indicate high priority for investment (Marcelo *et al.*, 2016). Also as recommended in Balkaran (2019), when identifying and selecting projects avoid solutionism and rather select projects for purpose, not for demonstration.

4.4.3 Smart sustainable city (SSC) project integration

The project integration Step 3.3 in Figure 4.4 is aimed at determining how well the resulting solutions and systems of the projects selected in Step 3.2 will integrate and function in conjunction for the purpose of a smart sustainable city (Al Sharif and Pokharel, 2022). This step must consider the interconnected and interdependent nature of city systems and the systemic functioning needed to bring together different chains of processes and ecosystems (Al Sharif and Pokharel, 2022; Nel *et al.*, 2018; Hodson *et al.*, 2012*b*; Hodson and Marvin, 2010) while holistically achieving the objectives set out for the smart sustainable city. The following activities are included in Step 3.3:

- Assess the integration of projects.
- Assess the projects selected against the objectives set out for the transformation.
- Set project priorities and map their interdependencies.
- Devise the possible order of project execution (Goodman and Hastak, 2015).

If it is found that the projects selection needs to be adjusted, Step 3.3 can at any time revert into Step 3.1 or 3.2 before continuing into Step 3.4.

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4.4.4 Communicate with government and project investors

Findings from Stage 3 should be presented to key governmental stakeholders and investors in Step 3.4 and a decision should be made whether the project may continue to Stage 4 or requires further iterations in Stage 3 before continuing to Stage 4. It can be noted that Step 3.3 and 3.4 and the way they feed back into previous steps of Stage 3, closely resembles the second intermediary stage in Boyko *et al.* (2005), 'reflecting and iterate alternative solutions'.

4.5 Stage 4: Design

Stage 4 in Figure 4.5, the design, consists of five steps and is based on features in Boyko *et al.* (2005), Ibrahim (2019), Ibrahim *et al.* (2018), Pereira and De Azambuja (2022), ITU-T FG-SSC (2015), EPIC Consortium (2013) and Mendizabal *et al.* (2018). Features to design a business case for infrastructure as introduced in Rogers (2018) was also included. Research in Dana *et al.* (2022) further illustrates how businesses in a smart sustainable city can leverage smart technologies in the city and increase their financial sustainability.

4.5.1 Resources

The resources step consists of allocating the required resources for the design stage of the projects and procuring the design teams (Ibrahim, 2019). Finally set and verify contracts with the involved design teams and decide on the means of tracking the design progress (Harris *et al.*, 2013).

4.5.2 Business case design

The business case design step was adapted from an assessment framework for infrastructure interventions in Rogers (2018) that focused on quality-of-life, sustainability, futureproofing and value creation in a city. The following activities is set out for this step:

- Think about each project suggested and identify potential business models (BM) that can provide financial and other value with minimal adverse impacts.
- Analyse adequacy of business models, impacts on the transformation objectives and the potential financial benefits.
- Set out the best business model suggestions that can potentially be incorporated into the designs.

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A validated urban data business model framework from McLoughlin *et al.* (2021) can also be utilised to identify value creation opportunities in smart cities. Research in Dana *et al.* (2022) and Ebin *et al.* (2022) further illustrate the benefits of businesses incorporating smart sustainable city technologies for financial sustainability, improving quality of life and maximising efficiency.

4.5.3 Design

During the design stage in Step 4.3, multiple designs by various teams for different parts of the transformation and of the city will be developed. It is important that design teams are aware of each other's projects in terms of possible technical conflicts or overlapping designs that could influence the implementation and proper functioning. This requires proper communication

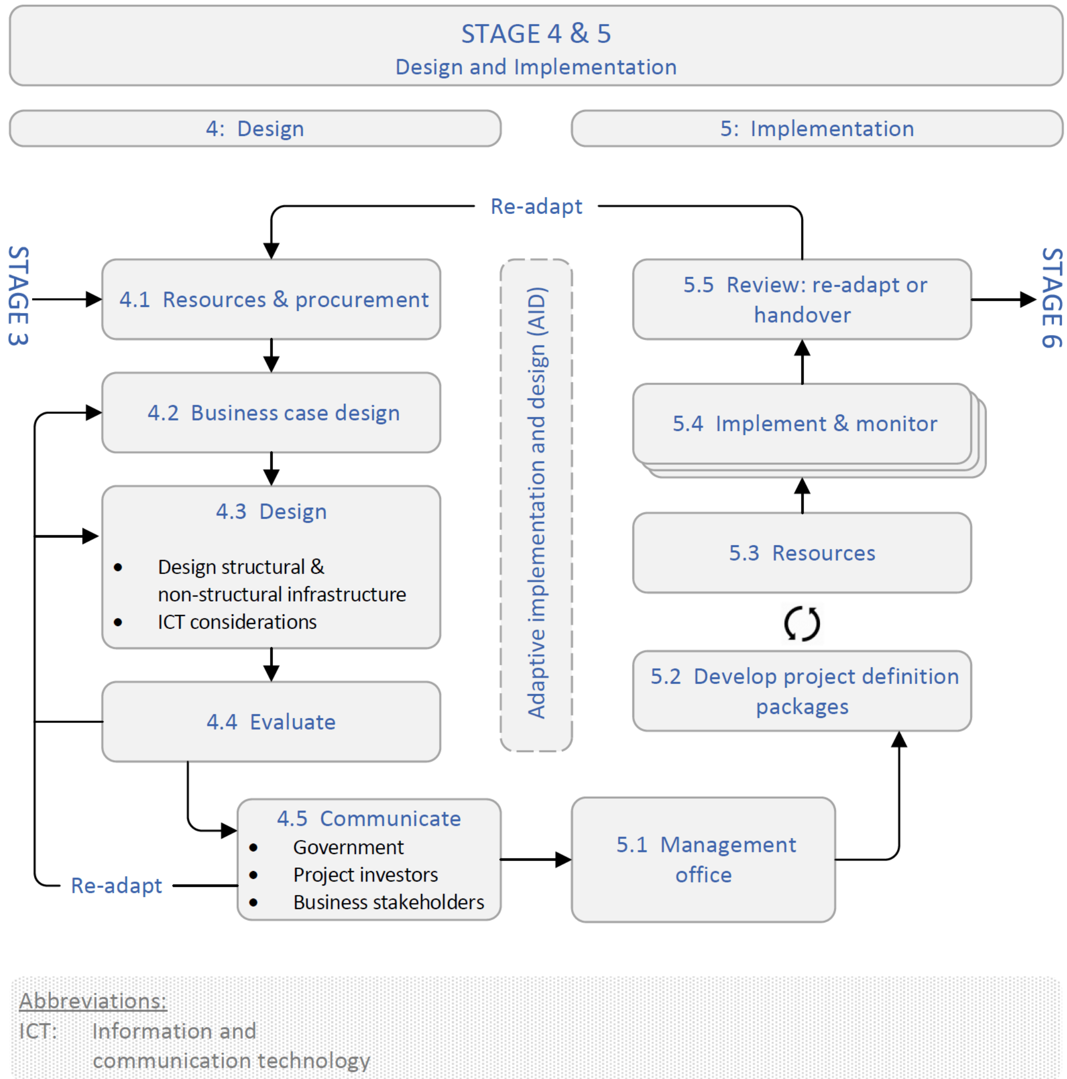

Figure 4.5: Stages 4 and 5 of the developed frameworks.

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management and use of intermediaries or knowledge brokers. The design stage entails developing structural solutions as well as management solutions (non-structural) that function together effectively to serve the city (Goodman and Hastak, 2015). Engineering teams and specialists' model technical and infrastructural solution alternatives and evaluate their appropriateness by comparing benefits, possible future impacts, financial feasibility, sustainability and resilience in future extreme events and scenarios (Rogers, 2018). The most viable option is then selected and designed. The remaining alternatives might be reconsidered if a conflict or unforeseen complication arises in the project integration. It is important that the engineers and design team not only provide the technical plans for their designs, but also communicate the guidelines for managing, operating, and maintaining these systems, including the requirements for support from policy, regulations, adapting user behaviour and incentives (Rogers, 2018) to ensure the success of the proposed solution in the future urban system.

For the structural and non-structural infrastructure designs it is recommended to design to replicate, scale, have spare capacity and to be able to rapidly expand. It is important to keep in mind the increased migration towards cities (UN-DESA, 2022) and for cities to handle increased urbanisation trends, their designs must make provision for future expansion in terms of capability and additional capacity for increased resource and information flows. Proper planning should be in place so that designs are scalable and replicable. It is ideal to build security into the way the system is designed, instead of adding security as a layer on top of the system (Toçilla, 2021). ICT solutions should be based on the latest but validated industry standards to stay relevant, compatible and provide seamless integration. Design requirements regarding data ethics, platform accessibility and business ecosystem needs should be addressed. ICT solutions should also be platform independent as exclusive solutions may come with closed contracts and agreements could entail lock-in (Koo and Kim, 2021). Solutions should enable interoperability of systems and be user friendly and easy to manage.

4.5.4 Evaluate

The evaluation of the designs in Step 4.4 focuses on determining if the proposed projects are still viable and that the transformation objectives will be met if implemented (Rogers, 2018). Any possible conflicts that a project has with other projects, or the desired outcomes of the smart sustainable city should be addressed. If it is found that the project designs need to be adjusted, Step 4.4 can at any time revert into Step 4.2 or 4.3 before continuing into Step 4.5 in Figure 4.5. Existing policies should be analysed to see if adaption is required or if new policies will have to be formed (Peprah *et al.*, 2019). If the design solutions proposed are found to be satisfactory, findings may be

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communicated to key stakeholders including government and project investors in the next Step 4.5.

By comparing project success across cities, the proposed evaluation framework in (Kourtzanidis *et al.*, 2021) can also be utilised to help assess the effectiveness of the interventions selected against sustainability, city needs, future project designs (with predictions and reverse engineering), benchmarks and assess various temporal and spatial scales.

4.5.5 Communicate with key stakeholders

Findings from Step 4.4 should be presented to key governmental representatives, business ecosystem stakeholders and project investors. A decision should be made if the project may continue to Stage 5 or requires further iterations of Step 4.2 or 4.3 before continuing to Stage 5.

4.5.6 Adaptive implementation and design

This step is displayed in the column between Stages 4 and 5 in Figure 4.5 and must be taken into consideration throughout both Stage 4 and 5. The guidelines in the Strategic Implementation Plan by the European Innovation Partnership on Smart Cities and Communities encourages infrastructure solutions and urban interventions be designed and implemented in such a way that allows for and utilises scalability and replicability (European Union, 2013*b*; Del Esposte *et al.*, 2019). An iterative design process is used whereby original designs are first tested on a small area or zone, adapted, and prepared for gradual adaptive implementation of the solution to a larger scale, similar to the process followed by Tahvonen (2018). In Ernst *et al.* (2016) the principle of dividing the city into spatial zones and focusing an intervention's initial execution steps on one or two zones can be observed. Nel *et al.* (2018) provides guidance regarding the process of establishing spatial boundaries in the city based on a complex adaptive systems perspective. These zones can be established according to physical, economic, or social characteristics and help to organise and segment the implementation into manageable pieces. The implementation of each zone can also be scheduled according to political timelines and agendas where possible. The Beavercreek Road Project of Oregon City provides a basic example of project area zoning and categorisation, as well as overlay mapping to maintain cognisance of other systems and features present such as a powerline corridor, geological hazard areas and natural resources for example. The feedback and lessons learned regarding each design's practical feasibility and adaptions for adequate functioning should be captured after each implementation. These insights could be useful for zones of similar types or characteristic groupings, assisting the scaling process as more implementation cases contribute to a set of generalised designs that are context-appropriate for specific zone types.

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Another method for how zoning can be applied to smart neighbourhoods is depicted in Keshavarzi *et al.* (2021). It is argued in Keshavarzi *et al.* (2021) that smart cities might perform better if they had uniformly sized urban space units like hexagonal cells instead of arbitrary neighbourhood boundaries or tracts. Each hexagonal area is allowed to be shaped according to the needs of the occupants within its boundaries (Keshavarzi *et al.*, 2021). Hexagonal areas with similar attributes might also be used to learn from each other.

4.6 Stage 5: Implementations

Stage 5 which entails the implementation, consists of five steps and starts in Step 5.1 from the bottom of Figure 4.5 and ends at the top with Step 5.5. The stage was based on the work in Boyko *et al.* (2005), Kivilä *et al.* (2017), Harris *et al.* (2013) and Aritua *et al.* (2009), but show similarities with many of the studies listed in Table 4.1. The steps in Stage 5 are explained as follows:

4.6.1 Management office

The programme manager must appoint a cost manager, performance manager and scope manager for the projects in the implementation stage, as suggested in the Infrastructure Programme Management Plan (IPMP) provided by the Construction Industry Development Board (CIDB, 2006).

4.6.2 Develop project definition packages

The development of project definition packages in Step 5.2 was designed from the project planning framework in Gibson Jr *et al.* (1995) and work in CIDB (2011). The development of project definition packages is defined by project constraints and transformation objectives being the inputs on this stage, along with expert opinions and the finalised designs from the design stage (Gibson Jr *et al.*, 1995). This step includes the following activities taken from Gibson Jr *et al.* (1995) and similar work in CIDB (2011):

- Analysing the construction risks of the project.
- Documenting the project implementation scope.
- Defining the project execution approaches.
- Establishing the project control guidelines.

A zoning strategy and disruption analysis of the project can also be included. Finally, compile the project definition package. The project definition package can aid as a guide to determine the resources required for the implementation step.

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4.6.3 Resources

The resources step consists of allocating the required resources for the implementation stage of the projects and procuring the construction teams (Ibrahim *et al.*, 2018). Contracts are set and verified with the involved design teams and decisions are made on the means of tracking the design progress (Harris *et al.*, 2013).

As more information becomes available in Step 5.3 it may be necessary to adjust or amend some of the activities in Step 5.2 before commencing to Step 5.4.

4.6.4 Implementation and monitoring

The implementation Step 5.4 consists of the following activities:

- Initiating the implementation of multiple projects (indicated by a multi-layered block in Step 5.4 in Figure 4.5) according to the determined schedule (Aritua *et al.*, 2009).
- Monitor and control projects, track progress, adjust schedules and resources accordingly while keeping all projects informed and involved regarding changes (Harris *et al.*, 2013).
- Communicate project and transition progress to key governmental stakeholders and investors.
- Update relevant documentation with any changes during the implementation (Babatunde *et al.*, 2014).

Project adjustments together with inadequate planning, organisation, control, and communication was identified as dominant causes of poor performing megaprojects and the implementation thereof (Babatunde *et al.*, 2014). According to CIDB (2011) it is highly unlikely to avoid change during the implementation of a project. It is very important that changes that occur during implementation are understood and communicated horizontally (e.g., other projects, etc.) and vertically (e.g. investors and key governmental stakeholders, etc.). The relevant plans and documents regarding these changes should also be updated accordingly (Babatunde *et al.*, 2014).

4.6.5 Re-adapt or handover

Step 5.5 in Figure 4.5, review (re-adapt or handover) is based on the work of Boyko *et al.* (2005) and Ibrahim (2019) with the following activities:

- Evaluate completed projects for compliance to project specifications and smart sustainable city goals (Boyko *et al.*, 2005). Assess the completed projects for complying to:

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  - construction specifications set by the design team (CIDB, 2005; Boyko *et al.*, 2005), and
  - discerning if the completed projects, individually or in a system of systems, achieves the smart sustainable city goals set for the city transformation, and if not, if there are strong indicators of doing so as soon as partner projects are completed (Boyko *et al.*, 2005).

  If the construction deliverables of a project do not comply to the specification agreed with the design teams, reasonable means for solving the problem(s) or ways to compensate will have to be negotiated (CIDB, 2005). The direct and indirect effect that this construction flaw(s) has, as well as the emergent and cascading effects that manifest due to other flaws present in interdependent systems, will have to be taken into consideration (Zhong *et al.*, 2021).

- Capture the lessons learned to inform current projects in design, future endeavours or completed projects that require adaptations (Ibrahim, 2019).
- If a project is built to construction specifications and achieves the set smart sustainable city goals:
  - Compile operation and maintenance documents.
  - Prepare and ensure necessary training, skills and resources are in place for handover to the maintenance and operation teams in Stage 6 (Pereira and De Azambuja, 2022; Boyko *et al.*, 2005).
  - Update the asset register (Goodman and Hastak, 2015; CIDB, 2005).
- If a project is built to construction specifications and does not achieve the set smart sustainable city goals:
  - Design and implement the necessary adaptations by returning to Stage 4.
- Make sure any outstanding finance and accounts are settled (Boyko *et al.*, 2005; CIDB, 2005). There are many ways of settling finances and accounts, but usually it will be managed and monitored continuously throughout the city transformation.

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4.7 Stage 6: Maintenance, evaluation, and innovation

Stage 6 in Figure 4.6, the maintenance, evaluation, and innovation is based on Ibrahim (2019), Pereira and De Azambuja (2022), Mendizabal *et al.* (2018) and Boyko *et al.* (2005) and consists of five steps:

4.7.1 Monitor, manage and respond

This step is about identifying problems regarding the functioning of the city and making use of the smart functions available to better manage and respond to triggers.

4.7.2 City assessment

Step 6.2 in Figure 4.6 is like Step 2.4 in Figure 4.4. The performance evaluation can show progress with regards to other cities. This process can also be

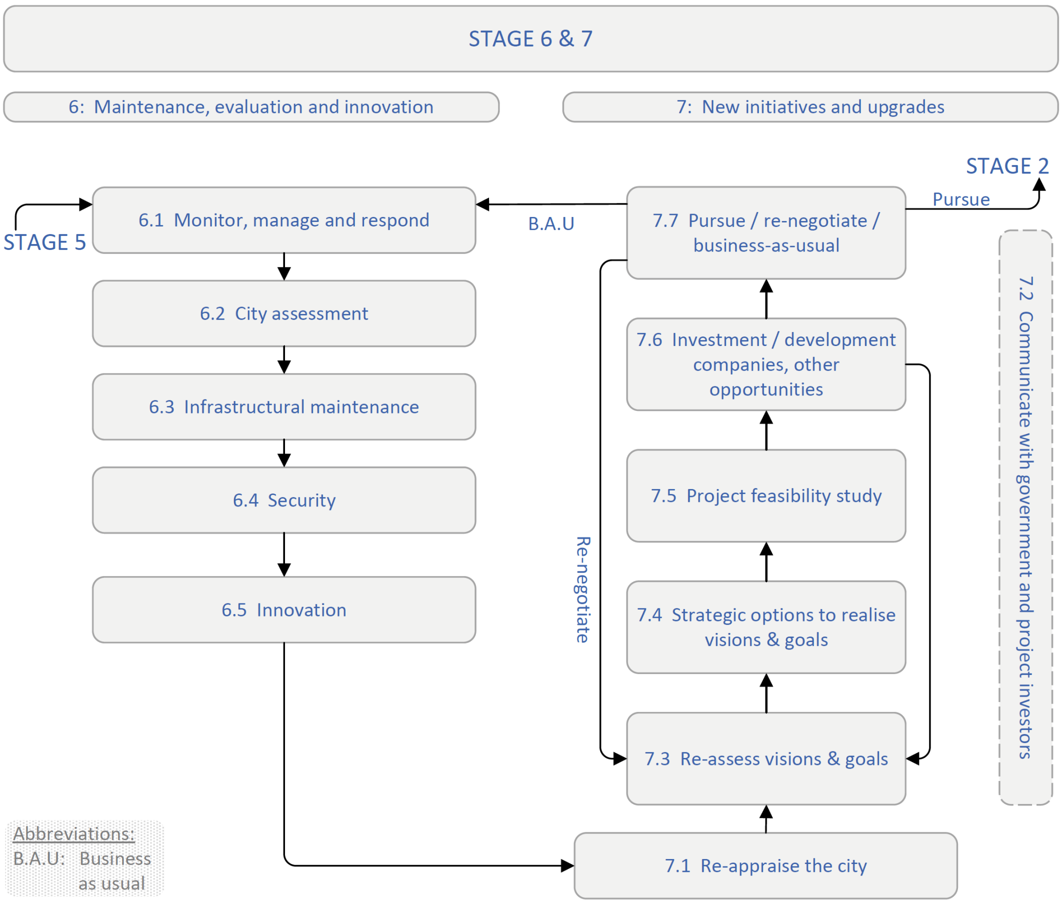

Figure 4.6: Stages 6 and 7 of the developed frameworks.

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beneficial in detecting faults or required maintenance to systems and in FHWA (1999) illustrated as means to further maintain and improve assets.

4.7.3 Infrastructural maintenance

The infrastructural maintenance in Step 6.3 consists of doing preventative maintenance (structural infrastructure) and deciding whether to revise and adapt non-structural infrastructure (management practices, policies, incentives, etc.) to ensure effectiveness and educate the public. The maintenance management plan and contingency plan must also be kept up to date.

4.7.4 Security

High security is always of utmost importance and should be kept up to date with emerging threats (Antonopoulos *et al.*, 2017). Continuously make improvements without compromise or delay and keep the emergency response plan for security breaches up to date.

4.7.5 Innovation

In Step 6.5, constant city innovation is required to account for the changing city dynamics, changing technological paradigms, staying compatible with society, and also aligning or complying to the evolving requirements for a city to keep functioning as a smart sustainable city. Ibrahim *et al.* (2018) recommend to constantly improve and Boyko *et al.* (2005) to re-evaluate the context continuously and make the necessary adaptions.

4.8 Stage 7: New initiatives and upgrades

Stage 7 in Figure 4.6, new initiatives, and upgrades, consists of seven steps to deliberate on proposed innovations and major maintenance actions such as phase-out or replacing older infrastructure or technology. The steps in Stage 7, follow a similar process as to the steps presented in Stage 1, Figure 4.3 and is based on Ibrahim *et al.* (2018), Mendizabal *et al.* (2018), ITU-T FG-SSC (2015), and Boyko *et al.* (2005).

4.8.1 Re-appraise the situation

Use the data and analytics available to evaluate the smart sustainable city performance and identify problems, opportunities, and other needs for Step 7.1. Also discuss and evaluate the latest requirements and expectations for a smart sustainable city. Further identify the latest stakeholder requirements through surveys and town hall meetings.

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4.8.2 Communicate with government and project investors

Key governmental representatives and current project investors should be well informed about the city state and the proposed initiatives and upgrades in Step 7.2.

4.8.3 Review city visions and goals

During Step 7.3, update the visions and goals for the smart sustainable city according to the findings. It is recommended to involve experts experienced in holistic and strategic infrastructural planning with an understanding of the current and future economic, environmental, societal, technical, technological, and possible emergent dynamics involved in the decisions to be made. This will provide guidance that is informed.

4.8.4 Strategic options to realise the visions and goals

Determine the possible paths to realise the visions and goals in Step 7.4.

4.8.5 Project feasibility study

A feasibility study should be conducted as part of Step 7.5 on each of the interventions suggested.

4.8.6 Investment or development companies and other opportunities

Seek funding or investment opportunities or potential business opportunities during Step 7.6 to help finance and realise the visions and goals of new innovations or significant upgrades. Funding plays a crucial role in the implementation of innovations or upgrades in a city and the financial sustainability of the city (Dana *et al.*, 2022). If no viable financial solution is possible, it might be required to revisit and adapt the visions and goals in Step 7.3, or to disregard the suggested proposal. Maintenance actions on current infrastructure will however have to receive priority.

4.8.7 Pursue, re-negotiate or business-as-usual

During Step 7.7, all findings regarding the planned maintenance or innovations or upgrades should be presented to the key governmental representatives and project investors so that a decision can be made whether the project(s) suggested should continue to Stage 2, be completely aborted, postponed, or re-negotiated and restructured.

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Stage 6 will always continue to execute, while new initiatives and upgrades are pursued during Stage 7. A city should never stop monitoring, evaluating, managing, protecting, maintaining and innovating infrastructural systems.

4.9 Conclusion

In this chapter the design of the framework to transition existing city infrastructure to become a smart sustainable city, is presented and explained. The purpose of the framework is to serve as a generic guide to urban planners and developers, municipal or city council managers on how a smart sustainable urban transitioning of infrastructure is planned, managed, implemented, and maintained from a strategic standpoint. There is an absence of a holistic and comprehensive framework for this specific purpose.

Seven main stages (pre-project project preparation; teams, city stage, readiness and assessment; project(s) identification and selection; design and implementation; maintenance, evaluation and innovation; and new initiatives and upgrades) were established for the smart sustainable urban transformation framework. These stages were based on available roadmaps, frameworks and models relating to smart sustainable urban transitions and cover research on smart sustainable cities, sustainable cities, smart cities, governance, implementation planning, urban design, project planning, and integrated and adaptive transitions.

In this chapter a theoretical framework was successfully synthesised from existing knowledge and approaches gathered from relevant academic literature and integrated according to insights formed during the study. The framework undergoes verification in the next chapter that follows against case studies for refinement of the components and design, and adaptation where needed.

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Chapter 5

Verification and Adaptations

In this chapter the framework developed in Chapter 4 will be verified against case studies. The verification of the framework forms part of sub-objective three of the research, illustrated in Figure 5.1.

Aspects learned from case studies in smart city, sustainable city and/or smart sustainable city initiatives will be investigated for success and failure factors. These factors will be used to see if the developed framework in Figure 4.2 to Figure 4.6 in Chapter 4 is able to address these challenges or correspond to the successes identified. The case studies are used to test the framework against real world examples. The goal will be to ensure the completeness of the framework and to supplement it and learn from the case studies analysed.

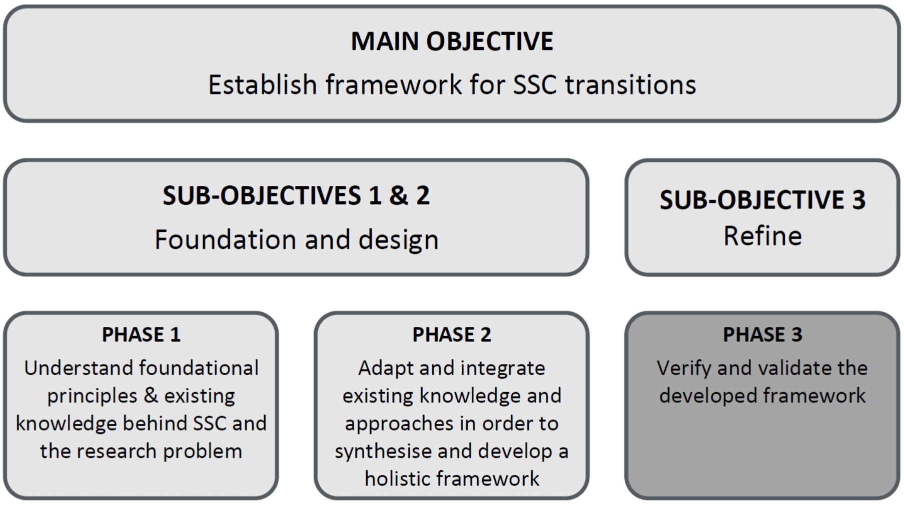

Figure 5.1: Approach followed during the research.

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5.1 Case studies

When selecting smart city, sustainable city or smart sustainable city case studies from the literature, it can be noted that there is little to no case studies on smart sustainable cities. It can also be observed that even in a purely smart city or sustainable city case study, it is never just strictly smart city or sustainable city aspects that are incorporated. This supports the notion that smart sustainable cities are becoming a more natural form of a city. Smart sustainable cities encapsulate the concepts of smart cities and sustainable cities to be implemented harmoniously. Nevertheless innovative, successful, current and well-established case studies and research were selected as described in Section 2.5.1 of Chapter 2.

Copenhagen is a unique city and case study as it is likely the only city that has fully committed to being a smart city and a sustainable city. Copenhagen's initiatives for sustainable cities is well documented in Samuels and Karasapan (2014) and Copenhagen (2022)and smart cities in Doody *et al.* (2016).

To further test the developed smart sustainable city framework presented in Chapter 4, the framework will also be tested to collective case studies in Boorsma (2017) and Pereira and De Azambuja (2022). The guide in Boorsma (2017) was composed by an urban innovation and community digitalisation specialist with twenty years of experience in city transformations. As there are no case studies available on smart sustainable cities, the work in Boorsma (2017) provides an insiders perspective as practitioner who has worked and experience on urban transition projects entailing smart and sustainable technologies in cities. The purpose of the guide is to determine the essential requirements to develop a city transition strategy with a fair chance of success. A large number of community digitalisation projects that were implemented in smart cities and sustainable cities around the world were studied, with most of the observations being remarkably consistent regardless of the location, culture, or the size and type of the community (Boorsma, 2017). Table B.1 lists the real-world endeavours from various smart and sustainable cities that were involved in the development of the guidelines. The cases involve successes and failed projects at various urban scales, for example adoption and scaling efforts of solutions taken abroad that have succeeded and others that have failed. Many of the cities used in the guide by Boorsma (2017) are regarded among the top sustainable cities in the world. These cities are Copenhagen, Amsterdam, Stockholm, San Francisco, Singapore, Rotterdam, Dubai, Seoul, Paris and Abu-Dhabi (Rondolat, 2013; Butten, 2018; LUX, 2021).

Case studies used in Pereira and De Azambuja (2022) were selected from the various CAP4CITY (strengthening governance capacity for smart sustainable cities) projects on smart sustainable cities. Six cities from Latin America and six European cities make up the selection of Pereira and De Azambuja (2022). These cities are Vienna, Tallinn, Copenhagen, Helsinki, Gdansk, Barcelona, Buenos Aires, Curitiba, Santiago, Bogota, Panama City

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and Montevideo. The case studies selected in Pereira and De Azambuja (2022) was focused towards the collective requirements for a smart sustainable city governance roadmap. The goal of adding Pereira and De Azambuja (2022) is to triangulate what was done in Boorsma (2017), offering a smart sustainable city perspective.

A table with a summary of the three case studies used is provided in Table 5.1:

Table 5.1: Three case selections chosen for the verification.

City of Copenhagen	Boorsma (2013)	Pereira (2022)
Leading global example	Failures and successes	Most successful cities
City integrated in regional, national & global agenda		
	Multi-case study	Multi-case study
	Asia (3), Arabia (5), Europe (8), North America (3)	6 Europe & 6 South America
Sustainable city	Smart cities	Smart sustainable cities
Green & regenerative city (ecological)	Amsterdam (main focus)	CAP4CITY projects
Livable city	25 Urban technology & system experts involved	
Smart city		

5.2 City of Copenhagen

Copenhagen is a Danish coastal city that is at the forefront of sustainable development. Through innovative technology and legislation, they serve as a paradigm for reducing the human impact on the planet (Samuels and Karasapan, 2014).

The case study presented in Samuels and Karasapan (2014) shows of the initiatives executed towards becoming a sustainable city and carbon neutral, initially aimed at 2025. Work in Copenhagen (2022) presents some aspects that are implemented in Copenhagen for sustainability. Some of the key features targeted in Copenhagen for sustainability was narrowed to the following:

- Setting policies and motivating new building constructions and renovations of existing buildings to apply energy saving techniques to reduce its carbon footprint. One method suggested was to make use of the seawater from the canals when designing the buildings' cooling system. The 'heat island effect' in the city can also be reduced as the seawater can aid or potentially replace some of the cooling in buildings, which in turn releases less heat into the city (Samuels and Karasapan, 2014).

- Driving sustainable transportation. Designing to accommodate electric, hydrogen and hybrid vehicles in the city will help to reduce the city's carbon emissions while the air quality is being improved (Samuels and

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Karasapan, 2014). Copenhagen also invested in public transport (more specifically its' bus, train and boat systems) which provides accessibility to city occupants and lowers the need for citisens to own a motor vehicle (Copenhagen, 2022).

- Switching energy supplies to renewable sources such as wind power. A target was also set to replace 40 percent of the coal power stations with biomass by 2025 and also finding innovative ways for heating in the city using available geothermal energy. Funding for the wind power was substituted by allowing citizens to buy shares in the wind turbines and in return offer them yearly returns (Samuels and Karasapan, 2014).

- Planning for the future climate. As Copenhagen is a coastal city and affected by sea level rise, introducing green roofs, parks can help to restore the natural water cycle and relieve the sewage system (Samuels and Karasapan, 2014). Significant investment was made on bike lanes in Copenhagen and surrounding regions (Copenhagen, 2022). Installing accessible bicycle routes can ease traffic and improve the overall occupant health in the city (Samuels and Karasapan, 2014).

- Inspire and create accessible culture, quality of life, local tourism and outdoor activities to help improve the well-being of city occupants and visitors (Copenhagen, 2022).

- Adaptive urban planning methods, such as designing streets to redirect flooded water back to the harbor and planting trees next to roads which increases the permeability of the soil. Trees also help to create a habitat for biological life (Samuels and Karasapan, 2014).

- Improve sewage systems and wastewater treatment plants. The improvements has shown to reintroduce biodiversity, reduce urban flooding, create space for recreation, and save energy. By using rainwater reservoirs, rainwater can be stored until the sewage system has the capacity to accommodate it. Sludge from the wastewater plant is converted into energy and heat which fuels 77 percent of the treatment plants energy consumption. Freshwater resources are regulated against overexploitation by working with neighboring coastal cities (Samuels and Karasapan, 2014).

- Water stations for easy refilling of water bottles to encourage re-use and reduction of water bottle waste. The accessibility to bins throughout the city was also improved to prevent littering (Copenhagen, 2022).

- Awareness campaigns for a human-centered retrofit. City occupants are encouraged to participate in the sustainability movement (Copenhagen, 2022).

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- Encouraging local food sourcing and production. An example of this view is their propoganda for 'eating organic is the logical choice, not a luxury.' They also lead by example as 88 percent of Copenhagen's public institutions food consumed is organic (Copenhagen, 2022).

From the key sustainability features in Samuels and Karasapan (2014) and Copenhagen (2022) implemented in Copenhagen the following applies to the developed framework in Chapter 4:

- Setting policies: During Step 4.4 policies are required to be adapted to accommodate the master plan of the smart sustainable city, which includes environmental aspects such as reducing the carbon footprint in the city. Policies are re-evaluated to see if adaptions are required in Step 6.4.

- Sustainable transportation, renewable energy, improved water systems, reducing waste and local food sourcing and production initiative: Step 4.3 incorporates sustainability as it is one of the five pillars of a smart sustainable city design. This can include many aspects for instance, sustainable public transport and electric, hydrogen and hybrid vehicles, including renewable energy into the energy supply mix of the city, water systems and local food sourcing and production.

- Opportunities for renewable energy funding: Step 1.8 and 7.6 focuses on finding new ways to help fund the transformation projects while Step 4.2 is focused on designing the business case.

- Future climate planning: The framework does account for future impact designing, potential extreme events and scenarios and future expansions during the initial designs in Step 4.3 the design, Step 4.4 the evaluation and reviewing the city's visions and goals in Step 7.3 to account for any new and future economic, environmental, societal, technical, technological and dynamics that changed in the city.

- Culture, quality of life and local tourism form part of the human wellbeing aspect of sustainable development and the basis on which sustainable cities and smart sustainable cities are based as presented in Figure 1.1 in Chapter 1.

- Adaptive urban planning methods are included as part of the sustainability initiative in the framework and is also included in the adaptive implementation and design Step between Stage 4 and 5.

National governments are intensifying their attempts to eliminate hurdles that hinder the adoption of innovative city initiatives by state and metropolitan governments and local companies from creating and exporting these relevant

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goods and services (Doody *et al.*, 2016). It is recognised that governmental involvement is needed in order to draw international business, expertise and investment in Denmark (Doody *et al.*, 2016).

Smart urban initiatives have been done in many of the Danish cities and towns, typically by the local city government in cooperation with the private sector and universities (Doody *et al.*, 2016). However, smart city operations in Denmark are primarily small in size and fail to expand their application to a wider area or other cities. This inability to scale up smart urban pilot projects in Denmark represents a global problem. Arup has identified five primary requirements that are necessary to allow widespread smart city initiatives in a nation. Examining these five requirements in Denmark, offers understanding into why ventures in smart cities do not grow (Doody *et al.*, 2016).

The case study presented in (Doody *et al.*, 2016) shows of the initiatives executed towards becoming a smart city. Some of the key features targeted in Copenhagen for sustainability was narrowed to the following:

- Capable municipalities: Danish municipalities have both the authority and finance to initiate smart city activities as they are allocated fifty per cent of the national government budget. Initiatives related to smart cities have been performed in more than half of Danish municipalities, of which a few have attracted international acknowledgement. Yet several lack the resources, expertise, and a cross-departmental organisation to establish and expand these ventures. Municipalities are unsure about which smart urban solutions to choose, which vendors and suppliers to purchase them from, and how to purchase in a manner that reduces vulnerabilities such as technology becoming redundant.

- Certainty for investment: The obstacles facing municipalities in Denmark, which includes failure to scale up past the pilot project, present uncertainty and risk for the private sector. In Denmark, companies have created advanced products and services for smart cities, often by working together with one another and with municipalities, academia and residents. Nevertheless, the market for such solutions is constrained by indecision and minimal cooperation of local government. Solutions are limited to one-time application in single towns and cities of Denmark as a result of unclear and disconnected municipal interests. This undermines continued investment from the private sector.

- Research and skills: In many of Denmark's industries, (such as green energy, healthcare and lighting), there are citisens with specialised digital skills. To promote the creation of technologies and expertise in the field, universities have invested in research on smart cities. However, many businesses do not have access to the digital expertise and skills they require (about 25 percent of Danish digital companies) and do not have

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an adequate perspective of the related industry answers and mechanisms available in Denmark.

- Digital literacy and public acceptance: Denmark's top ranking in the EU Digital Scoreboard indicates that there is good availability and access to ICT infrastructure and education throughout the country. Still, public unease about data protection, cyber privacy and stability pertaining to smart city solutions, could potentially impede adoption. For instance, a third of Denmark's people do not feel safe when making use of public digital facilities.

- Data-sharing: The public availability of data in Denmark is common-place in each level of the public sector to promote political transparency and create economic opportunity. Open data repositories are common amongst most municipalities and similarly a network is being built in Copenhagen for data sharing between businesses and the local municipality. Yet inside public and private organisations, important city data remains bottled up where the case for its release has not been raised or addressed. Organisations are creating smart city networks that are not compatible or integrated with those used by other organisations, restricting cross-organisational innovation.

The four of the five requirements was included in the framework as follows: capable municipalities (Steps 1.2a to 1.2d and 1.4b), certainty for investments (Steps 1.8, 4.2 and 7.5), digital literacy and public acceptance and data sharing (Steps 4.3, 4.4 and 6.4). Although the learning, research and skills are motivated in the research, this will be added and highlighted in Stage 3.

The examples set by other governments to grow smart cities in their countries as an industry, can provide valuable insights:

- Certainty for investment: The private sector does not generally see the potential return on investment of smart cities projects and the related goods and services. There is a connotation of high risk involved with innovative projects, vast amounts of investment required, long time frames in achieving profitability and restricted potential for financial support from municipalities. Municipal digital governance, which is also related to that uncertainty, cannot be removed from the equation, as that would result in no significant customer for smart city solutions. Consequently, support for smart city programs, are primarily by means of innovation and research grants, stunting projects' wider implementation to other cities. For smart city initiatives, business models are needed that present a strong, enticing offer to the private sector and other stakeholders concerned, such as the public- and not-for-profit sectors and residents. Long-term dedication from government is also required

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to raise investor trust in order to secure financing, such as committed industrial policies and market analysis on smart city opportunities.

- Research and skills: It is important for researchers and experts involved in the development of smart city solutions, to have knowledge and skills across multiple fields of specialization in relation to urbanism and information and communication technology (ICT). In several nations, there is a scarcity of professionals that have adequate digital skills.

5.3 City transformation lessons

In the process of deriving the guidelines from various cases, twenty-five industry experts were also interviewed in Boorsma (2017). They are a diverse group comprising city council members, investors, government advisors, consultants and executive-level industry experts (i.e. CEOs, founders, technical and strategic directors) from the following domains:

- Local, regional and national government strategic and technical divisions of leading global cities in urban sustainability and technology.
- Global smart city technology departments of Microsoft, IBM, Frost & Sullivan, Cisco and IMEC.
- Academia, specialised firms, start-ups and organisations like the Smart Cities Council.

A comprehensive list of the interviewed experts and their affiliations is provided in Appendix B. From these case studies a checklist of twenty fundamental aspects for effective transitioning cities was articulated in Boorsma (2017) and is illustrated in Figure 5.2.

5.3.1 Case study analysis

Although the guide is full of detail and examples, for the purpose of this chapter, a short and concise description on each aspect is provided. A short summary was written to accompany each aspect, putting the guidelines and detail into context. For each aspect, the key requirements are identified and listed after the summary under 'reflections'. Here, reflection is done on how the framework embodies and addresses each requirement identified.

1. **Leadership:** 'Digitisation-ready' leadership entails the ability to respond to unexpected outcomes and disruptive innovations, among other things. Proper leadership in the smart city domain is not confined to effective 'control', but necessitates an overarching influence across a much greater ecosystem of stakeholders. Many smart city successes

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have originated from far-sighted leadership that managed to bring the community and its various stakeholders together and encouraged positive development. Frequently this leadership for successful smart city management often requires 'servant leadership'. This also applies to public-sector leaders. Private-sector leaders involved in smart community endeavours also need to reassess their roles and accept the roles and responsibilities associated with communal leadership.

Reflections:

a) *Far-sighted approach*: The SSUIT framework developed in this doctoral study embraces a far-sighted approach in various ways throughout the transition. The local and national development priorities, strategic goals and city challenges are taken into consideration from the first stage of the framework to formulate the vision and goals that play a central role throughout the entire transition. A long-term outlook is also strengthened by studying history and current state of the city, as well as data collection, simulation and scenario planning to form a better trajectory of the city's dynamics against possible future scenarios. Various assessments and evaluations are performed regarding, feasibility, sustainability, costs, risk and integration of various solutions with one another and within the six smart sustainable city dimensions. Implemented solutions and the overall outcome is also evaluated against the initial goals and requirements set for the transition and its initiatives.

b) *Ability to adapt, having flexibility*: In the framework there are

Figure 5.2: Twenty fundamental aspects for effective community digitalisation (Boorsma, 2017).

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various feedback loops that provide opportunity for re-adapting decisions or re-visiting previous processes. This provides adaptability in the event that unexpected change in circumstances occur; or project dynamics turn out differently than anticipated when earlier decisions were taken, necessitating revision and adjustment. In the last two stages of the transition framework, various components provide an aspect of adaptability and flexibility. In Stage 6, 'maintenance, evaluation and innovation', constant evaluation and awareness regarding various systems and activities in the city is advocated. This awareness relies on systems that are designed and implemented strategically in the previous stages, such as cyber-physical systems that incorporate city-sensing, real-time monitoring, big-data analytics, interactive user interfaces and remote control through IoT. In Step 6.1 and Step 6.2 short- and medium-term awareness of trends and changes in the city is managed. In Step 6.4 security threat monitoring, protocol, regulation and response plans are kept up to date. Step 6.5 encourages innovation and keeping track of technology development. Stage 7, 'new initiatives and upgrades' guides new considerations that have emerged through the proper evaluation process, reducing the likelihood of stagnation with current city solutions. The cross-cutting 'adaptive implementation and design' (AID) approach positioned between Stage 4 and Stage 5 also provides flexibility and adaptability regarding the design solutions and implementations in unique contexts, contributing to innovation.

c) *The leadership structure connects all stakeholders*: The transition coordinator and steering committee (team) appointed in Stage 1, manages the necessary interactions between the various stakeholders throughout the transition stages. In Step 1.3.a one of the responsibilities of the transition coordinator is open communication with all relevant parties of the transition. The steering committee and subordinate teams of various disciplines in Step 1.4.a, also have to be able to work cross-functionally with each other.

d) *Roles and responsibilities should be understood and accepted*: In Step 1.4.b, the steering committee, experts, key stakeholders including the relevant local and national governmental representatives, undergo orientation regarding their role relating to the smart sustainable city transition. Through the 'education and awareness' programme the citizens are also orientated regarding their place and contribution in the smart sustainable city. Opportunities are also provided where stakeholders are updated regarding progress and decisions, and have to indicate

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whether they are satisfied to continue, or request to review and adapt arrangements and decisions made earlier, as in the example of Step 1.2.c, 'reach consensus'.

2. **Governance:** Digitalisation is a horizontal endeavour and cannot become another silo. Community digitalisation initiatives must be implemented by means of a broad, well designed governance structure. These community digitisation governance structures must include the governance structure within a municipality, a state or provincial government, or the government of a national state, with the necessary extensions into an ecosystem of partners to incorporate companies, academics, residents, local neighbourhood initiatives and more to be sufficiently future-ready. Digitisation is not attributed to an IT-manager or a single team. It has an effect on the entire institution, community, municipality and ecosystem. Cross-vertical governance within the organisation is therefore important. Most of the successful smart city initiatives have originated with well empowered people and teams that were able to operate across silos and across departments.

   Reflections: Transition governance should have the following properties:

   a) *A broad governance structure that is well-designed with cross-vertical governance across silos with all stakeholders involved (government, private sector, academics and residents)*: The process of selecting the steering committee in Step 1.4.a is approached strategically, involving as many stakeholders as possible, and is focussed on including the appropriate combination of multidisciplinary skills and team dynamics. Multidisciplinary experts are also selected, which can also include stakeholders from academics, private sector, government and local residents.

   b) *Involves representatives from both local and national government*: Step 1.2.a and Step 1.2.b illustrate the involvement of local-level and national-level government, who are involved throughout the transition, in for example Steps 1.3.b, 1.4.b, 1.9, 3.4, 4.5 and 7.2.

   c) *Extends to all stakeholders:* observed in Step 1.4.a (multidisciplinary committee representing various stakeholders), Step 1.4.b and Step 1.5, for instance, during the orientation and identification of stakeholder requirements.

   d) *Capable to operate across silos and departments:* Part of the team selection criteria described under Step 1.4.a.

3. **Vision:** A good vision is rooted in a community's challenges and aspirations. A vision starts with an understanding of the community

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identity, and a sense of the ideal future worth endeavour and which can be embodied going forward. A well-formulated vision that is fully owned and supported by the community, requires an iterative and collaborative process of design and exchange amongst the community's stakeholders.

Reflections:

a) *Vision formation*: Visions are formed in Steps 1.6 and 7.3.

b) *Collaborative*: All inputs from stakeholder groups are obtained from Steps 1.3.b and 1.5, also involves inputs from multiple disciplines and entail sharing, communicating and forming the vision as a joint effort (also Steps 1.4.b and 1.6).

c) *Iterative*: The vision is not formed in one step, it starts early on during Stage 1, formed by various stakeholders' inputs, evaluated and reviewed against contextual information gathered for adaptations and refinement. Visions are reviewed again during the last stage in Steps 7.1 and 7.3 as part of the continuing urban development and transitioning process. Steps 1.6 and 7.3 can be reviewed via the return, 're-adapt' or 're-negotiate' arrows.

d) *Understand city's unique qualities, challenges and desired future*: Expectations are investigated in Step 1.1, 'drivers or pressures', Step 1.3.b 'project drivers and expectations', and the orientation with the government and team in 1.4.b. In Step 1.5 the other stakeholders inputs are gathered, data is reviewed to identify city characteristics, dynamics and possible issues.

4. **Needs, challenges and comparative advantages**: A thorough understanding of what the community wants and needs, their true challenges, together with insight concerning the area's strongest assets and selling points, constitute the right point of departure for a community digitalisation strategy. 'Solutionism' and 'technology outrageousness', can thus be prevented, with a prosperous smart community approach addressing real needs, while reinforcing social vitality and leveraging the comparative advantages.

   Reflections:

   a) *Start building strategy by knowing city challenges and advantages*: Before the visions, goals and strategic options are determined in Steps 1.6 and 1.7, information is gathered in Step 1.1 (drivers), and Step 1.5 (city appraisal) to identify and understand the needs, challenges and advantages in the city better.

5. **Assets**: A solid, comprehensive inventory assessment of existing assets of possible relevance to the smart city objectives, including

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conduits, fibre, municipal networks, light poles, street cabinets and so on that is presently accessible or that can effectively be leveraged may bring down costs and enhance ease of smart city project implementation.

Reflections:

a) *Inventory assessment*: The asset register is taken in Step 1.5; previous initiatives, current infrastructure state and readiness is evaluated in Step 2.4, and Step 6.3 ensures that asset documentation is kept up to date.

b) *Reduce cost and time by utilising existing assets and resources where appropriate*: Step 1.5 needs amendment to specify this during the city appraisal.

6. **Approach for connecting everything**: The key aspects of the art of connecting everything are: *First*, successful smart city initiatives need to run on architectures that are seamless and secure. *Second*, they need to be adequately open, in as much as differing hardware and software components need to be platform-independent and adhere to open industry standards, with the aim of not becoming compromised by the stumbling block of closed, proprietary solutions.
   Third, 'open' is not necessarily equivalent to 'open source'. The art of connecting everything is accomplished by sometimes obtaining value from what can be considered open source, by bringing these technologies together within a seamless and secure architecture, without arriving at a patchwork of well-intended software constructs which, together, may turn out less seamless or secure.
   Fourth, smart city architectures need to stay relevant for a future where much of the data gets processed hyper-locally for security and latency purposes, supplying intelligence capabilities where and when it is required. As a result, Fog (computing capabilities at the first points of hyper-local data aggregation) and Edge (intelligence at the edge of the network by means of computing capabilities in end devices) computing capabilities will be crucial.
   Fifth, multiple access technologies will have to be leveraged. Use cases define which access technology will fit best, and use cases differ significantly. Some use cases may run well on a mobile network connection, whilst others will run better on long-range, low-power network technologies such as LoRa.
   Sixth, optimal smart city architectures develop for connectivity, security, solutions and data getting controlled horizontally, across silos. It is counter-efficient to procure software in isolation for one vertical solution, if a horizontal platform can facilitate multiple verticals and solutions. Additionally, the present and future value of data depends on a city's

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capability to open up that data, and enabling it to be cross-referenced, as opposed to having it locked in silos.
Lastly, it is of paramount importance that sufficient future broadband infrastructure is available. Broadband infrastructure remains foundational to smart city initiatives.

Reflections:

a) *Seamless, secure, platform-independent (no vendor lock-in) and open industry standards*: These principles are found as ICT considerations in Step 4.3 for infrastructure design.
b) *Adequate computing capacity and sufficient bandwidth*: The functionality of the city end-devices are proportionate to these devices' available computing capabilities relative to what is required for its peak functioning. For this reason excess capacity of the system and its components is an important ICT consideration listed as an infrastructure design guideline in Step 4.3.
c) *Compatibility through use cases*: Every solution has other operational and compatibility dynamics. It is therefore important to understand the distinctive use cases of each technology and application. This will fast-track the experimentation phase for a particular theoretical solution up until implementation. This is a useful guideline to consider. Studying use cases to guide compatibility design can be referenced in the framework as supplementary information for interoperability in Step 4.3 under ICT considerations.
d) *Horizontal access across silos and value creation*: It is not efficient to create platforms that are horizontally restricted (only used vertically in silos). Data can be used to create value, and should be approached strategically. The framework places emphasis on value creation in the city, for instance to identify business models that can unlock value in Step 4.2, and the ICT consideration of interoperability listed in the 'design'-step, Step 4.3.
e) *Data and platform accessibility to ecosystems*: The ecosystem is an important aspect in the city for businesses to grow and thrive. Attempts to foster a healthy ecosystem are considered quite prominently during the design-stage, like business case design in Step 4.2; the ICT design considerations in Step 4.3; evaluating integration, policies and regulation for possible changes needed in Step 4.4; and regular communication with investors and business ecosystem stakeholders, in for instance Step 4.5.

7. **Standards:** Smart community initiatives, architectures and solutions should conform with open industry standards to the fullest extent

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possible, especially within the fast-developing, yet under standardised, environment of the internet-of-things. It is all-important to set the contractual requirements on interoperability (particularly if standards are lacking) and may in actual fact help to develop standards by the way smart city partners procure, deliver and scale.

Reflections:

a) *Smart city technology should comply with open industry standards*: A guideline supplied under ICT considerations in Step 4.3.

b) *Set contractual requirements for interoperability*: Step 4.3 under ICT considerations. Defining the interoperability agreements and standards to be implemented among contractors, service providers, ecosystem partners, and neighbouring cities can simultaneously accelerate the development of standardization protocol. Such coordination also contributes to answering the standardization challenges facing smart sustainable city implementation all over the world.

8. **Cyber security and digital resilience:** Cyber security is foundational in smart community initiatives and can never be an after-thought. Currently there are over 2.5 million cyber threats being monitored across networks around the world every second. We as a society and smart community must be orientated towards establishing a culture of resilience (that is both digital and non-digital in nature), along with the strategies and the means to support it. The community digitalisation strategist should commit to 'think security first'. Cyber-security should be architected into the network rather than on top of it. The society and smart community stakeholders must understand that no one can guarantee total cyber security. It is a given that hacks will occur and your digital assets will be endangered. Similar to the manner in which our immune systems respond to an infection, we have to take on an approach of resilience. Being proactive and prepared for the occurrence of a breach without knowing when it is going to happen.

Reflections:

a) *Cyber security as highest concern, security considerations built into design*: Cyber threats always have a probability of occurring and can have a high impact. This was considered in Step 4.3 under the 'design' considerations and Step 6.4, 'security'.

b) *Plan pro-actively for resilience on all levels*: Proactive efforts in the framework that improves resilience entail analytical and planning

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methods like modelling, scenario planning, risk analysis, updating documentation, monitoring, learning and adapting. Security is also placed as high priority, even during the design, Step 4.3, security aspects should be built into the design and are continually monitored and updated in Step 6.4.

c) *The community digitalisation strategist*: In Step 1.3.a the smart sustainable city strategist or project coordinator in the SSUIT framework is appointed. The coordinator is responsible to ensure security is incorporated in the designs in Step 4.3, and during hand-over in Step 5.5 sees that the necessary skills are procured to ensure that security roles are sufficiently resourced to continually monitor and improve the system.

9. **Big data and artificial intelligence:** The management of big data as well as the management of the opportunities and challenges associated with big data, are amongst the most pivotal considerations in a community digitalisation strategy. The essence of big data and big data analytics is the ability of finding new interrelationships to identify business trends, appreciate customer preferred choices, ward off diseases, combat crime, etcetera. For this reason, big data has become a crucial building block in the environment of scientists, corporate executives, medical practitioners, mobility directorates, retail dynamics, advertising and governments. In terms of data management, artificial intelligence resorts under big data in community digitalisation merely because of the role that current and foreseeable future artificial intelligence has in consuming and generating big data, algorithms, occurrence responses and for that matter, decisions within public spheres.

   Any community that needs to articulate its own strategy on digitalisation, must at the outset, formulate what the big data strategies should accomplish, what values these objectives should be benchmarked against and also needs to consider the compromises (such as, privacy versus public security). Next is the articulation of how the objectives are to be accomplished, as for how to advance from a state where raw data has been made available, to a sophisticated scenario that encompasses platform dynamics, data and platform governance and management. It requires an agile regulating framework to address matters such as, the way platforms will be leveraged, what state sector governed data will be made accessible for third party use, whether and how to monetize data, and the community requirements for demand-driven big data analytics.

   It has been shown that efficient smart city initiatives have typically articulated in a successful manner what value is to be derived from data, either public or private, what data should be open and transparent or not, how and what data should be stored or disposed. Good data

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management and governance is crucial, but remains one of the most important challenges of our time. Cyber security, privacy and trust are essential parts of digitalisation and should by design be built into a solution or network. Trust is a defining factor which should be addressed in considerations such as: who secures and guards the data, who or what defines the rules on data administration and who after all will guard the guardians?

Reflections:

a) *Cyber security, privacy and trust*: The following guidelines, regarding how to steer digitalisation ethically and responsibly agrees with the prioritisation of security in the framework. The following items are additional information for the framework related to Step 4.3, 'design':

- Formulate big data strategies.
- Define values to benchmark objectives against.
- Be aware of possible compromises that might be needed (privacy versus public security).
- Define data rights and permissions regarding who has accessibility and management rights and permissions.

10. **Smart regulations:** Change due to digitalisation occurs swiftly and exponentially, however our regulations are often stagnant and enshrined in old paradigms where the government is commonly in charge by means of central regulatory environments, although industry specific, self-regulating environments have proved effective and important. It is imperative that our regulatory frameworks involved with the governance of community digitalisation will have to be amended. On the one hand this translates into timely and incremental adjustments to existing rules and regulatory mechanisms providing the agility to deal with digital innovations landing on top of an old world. On the other hand, the more networked and distributed our community becomes, the less a requirement for central control remains. This also holds true for regulatory environments. Completely new rules and regulations have to be crafted to reflect the creation of completely new paradigms, business architectures and delivery models that merely did not exist in the past few years. It is pivotal to tackle this community digitalisation building block effectively to insure well organised self-regulating environments that will include community-specific entities as well as commons.

Reflections:

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a) *Adjusting and/or renewing policy and regulation for agile and appropriate handling of fast changing technology and systems*: Steps 6.5 and 4.4.

11. **Ecosystem:** Community digitalisation cannot be managed alone, it is enabled by means of ecosystems of different stakeholders - public sector, private sector, NGOs (non-profit organisations), academia, citizens and all these differing smart city stakeholders require to work in close cooperation. In this emerging industry the big companies need the small companies and vice versa. Comprehensive open, but nevertheless end to end architectures require rich and sophisticated ecosystems, while platform dynamics and digitalisation generally flourish by delivering on ecosystem value as opposed to 'just' customer value. Simply put, the various players can and usually should be part of an ecosystem but having it all merge together effectively is an art in itself. For instance, a traffic data platform only becomes relevant if it incorporates numerous automotive companies and road authorities. Similarly, a company providing an IoT (internet of things) platform for cities may have its technology paraphernalia in perfect order, even so, it will only succeed if it has structurally involved ecosystem partners to consolidate demand, solutions and data. The stakeholders that need to become involved include the following:

    - *Citizens* - In the end, a community digitalisation strategy can only succeed with some type of citizen involvement. Any response to a government-issued digitalisation-related request for information or request for a proposal, must amongst other things include a user experience and citizen experience.
    - *Large technology companies* - robust automation systems, scaling and establishing industry standards, and continually innovating.
    - *Telecommunications service providers* - technology and connectivity, complex architecture oversight, network solutions and services, etc.
    - *Utilities and urban service providers* - essential community services i.e., water, electricity and broadband networks.
    - *Small technology companies* - disruptive innovating, rethinking design, cater for uncharted realm of digitalisation.
    - *Vertical solutions vendors* - critical role acquiring certain expertise, data and solutions.
    - *Government* - open platform offered to different contributors, and set vision, rules, regulations, and standards.
    - *Investors* - various types remain important, such as venture capitalists and start-up investors.

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- *Regulators.*
- *Vertical-specific organisations in the domains of public interests* - hospitals, police and schools.
- *Academia* - innovate, invent, improve, survey, write and publish.

Ecosystem creation and management is assisted by the following:

- Establish and maintain a successful environment to make ready, manage and take decisions in.
- Apply public-private collaboration where possible which may take various forms and bring about a change in culture regarding the public-private relationship.
- By collaborating, these relationships are useful in developing regulatory frameworks.
- Having an expansive set of people representing private entities is useful.
- Utilise converging disciplines as a good basis to assist digitalisation which is technologically, politically, socially, economically and ethically desirable.

Reflections:

a) *A favourable environment needs to be developed for new ecosystems to flourish*: Steps 4.2, AID, 4.3, 4.4, and also Step 2.3, using city-sensing for value.

b) *Diversity and abundance within ecosystems of stakeholders needs to be fostered.* Diversity combined with interaction and collaboration among actors within the nested systems facilitates the emergence of greater value collectively than separately in silo. This correlates to complex adaptive systems dynamics in theory used as the analytical lens for the study. Step 1.4.a 'team selection and preparation', and Step 3.3 'SSC project integration'.

c) *Public-private and multi-disciplinary collaboration*: Steps 1.4.a-b.

12. **Public sector, connectivity and business architectures:** The public sector is the entity which pays either directly or indirectly. Government-derived broadband adoption initiatives have in the past lacked a sense of intricacy and refinement required for the successful use of business architecture implemented in the community digitalisation space. Four layers within energy and broadband markets can be identified:

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- Layer zero constitutes an important asset relating to ground, sewage conduits, subway tubes and physical cable carrier infrastructure.
- Energy and broadband infrastructure forms the second layer.
- The wholesale servicing of the network can be identified as the third layer, which includes fibre broadband deployment architectures for instance.
- Lastly, customer services as the fourth layer (provisioning, service, billing etc.).

Previous experiences in the history of modern connectivity carry value in what can be learned in contextual complex emerging digital markets, including connectivity, sensors, software, algorithms, data, etc. The latter aspects (data and algorithms) and platforms are emergent markets in the digitalisation space. A new digital deal or community digitalisation approach should acknowledge the following:

- There exists an increasingly narrow gap between producers and consumers situated in the digitalisation market context.
- The economy within the digitalisation sphere is shifting from a hardware to software driven market.
- Given the change, various societal role-players subsequently only utilise 'digital' in as far as it's required.
- An understanding of the way regulators function, information, platform and algorithm governance and an awareness of any unbundling occurrence relating to vertically integrated business architecture is necessary.
- More and more transactional players are appearing in the digitalisation economy.

Regarding business architecture, a few important matters can be highlighted with regards to planning community digitalisation:

- Discerning which choices will result in the best and most stable outcomes pertaining to free and fair market dynamics, innovation culture, service quality, etc.
- The ownership and governance of basic network technologies, how to reduce the negatives associated with two ideal choices, the choice of delivery models and identifying the cause for preparedness.
- Lastly, putting together and utilising the introduction of platform economics inside community digitalisation.

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Reflections:

a) *Learn from local and external cases of connectivity in history*: Step 2.4.

b) *The government requires sophisticated expertise regarding digitalisation, connectivity and complexities relating to business architecture*: Incorporated in Steps 1.4a and 1.2b.

c) *Solutions and initiatives should be evaluated and tested and improved regarding robustness, resilience and quality of service*: Various assessment mechanisms in the framework is present.

d) *Mitigation measures of negative knock-on effects should be investigated, delivery model selection criteria and trigger identification*: The framework makes use of systems thinking and has monitoring in Steps 5.5 and 6.1.

e) *Introducing platform economics in smart communities (economic and social activities through digital transactional platforms)*: Steps 4.2 and 4.3.

13. **Delivery models:** The next key component builds on the foundation of business architecture. Maturing technologies and economies in city endeavours, and new distribution and consumption models emerge. Smart city solutions can be obtained as 'products', and recently, it became possible to acquire various smart solutions as a particular service (CaaS). The concept of the city as a service may encompass numerous forms and is still in a developmental stage. Presently, community digitalisation strategies cannot be considered without balancing what is realistically possible and available. The transition into the city as a service is destined to occur and brings with it a seamless, stable and cost-efficient approach with regards to architectures, solutions and information management and consumption. Currently a lot of commercial conduct occurs within the digital space, and it has become a given, much like the widespread presence of electricity within homes and workspaces. The last stage of the smart city involves the way in which the city is utilised, maintained and experienced in a digital manner.

    Reflections:

    a) *Smart technology should not be incorporated into urban systems without first evaluating its feasibility according to available technology and expertise*: The cost-efficiency, interoperability and reliability is evaluated in Step 4.3.

14. **Geography:** The rapid demise of old industries and job types which become more apparent as days go by coupled with the various new

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jobs surfacing, present day economic development, new innovations and contemporary enterprises emerging, underscores the importance of planning and enabling what is referred to as the new 'geography of innovation'.

An increase in urban innovation hubs can be organically traced to the great economic and demographic forces affecting the way humans live and work. In order to fully enhance the required local geographies of innovation, any new digital deal for communities, should engage sufficiently with the topic, having knowledge of the local factors at work, and synthesise the included various stakeholders. These geographies are situated in environments that are open, and hybrid, essentially found in city centres, and modern work landscapes, creating domains fostering collaboration and cross fertilisation. Within the context of community digitalisation innovations, it can be observed how citizens become prosumers. 'Smart city' experimentation will be aided by establishing a decentralised city test platform granting innovators the permission to explore and fail.

The above mentioned initiative does not merely imply giving birth to a new 'smart valley' at the city fringes but truly understanding to manage and functionally merge various stakeholders at a specific location suited to the aim and utilising assets that are immediately accessible.

Thus effective geography of innovation operating within a community digitalisation strategy facilitates productively synthesize various sectors, fields, research establishments, finance, start-up, and advancements and citizens, inside communities that are of 'real', adaptable, and involved.

Reflections:

a) Establishing decentralised platforms that encourages experimentation, known as innovation labs, serve as test beds and incubators for urban innovations within local context. Framework to be adapted in Section 5.6 to include this.

b) *Accessibility to assets and the local eco-system actors and contributors*: These are important factors regarding geography of innovation. When choosing or adapting an area to develop into an innovation lab it is important to understand the urban dynamics that influence various stakeholders and the evolution of communities and spaces. The urban systems description framework (USDF) by Nel *et al.* (2018) is an example of how complex adaptive systems theory (CAS) can be used to understand urban change and dynamics within an area.

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15. **Culture of innovation:** Culture is something that requires enough time in order to develop, and change is most often observed only after ample time has passed. The question arising, is how the existing culture can be utilised in order to advance community digitalisation aims. The aversion towards risk found in many structured cultures is understandable, and innovation mainly involves disruption requiring organisations who manage digitalisation to have the readiness to adapt to change.

    Creating a plan for the goal regarding culture of innovation involves risk, and innovation culture is influenced by cultures, and values varying from communities to communities. Vision is the initial departure point in the process of community digitalisation. The importance of having a vision which inspires and is understood by a group of individuals cannot be overstated. The latter encourages the flourishing of talent in the process of fully engaging in a job, task or contending with an unknown idea. The following is an example of how an inclusive dream or goal can enhance a culture of innovation: Flourishing cultures of innovations are found in environments with a positive stance towards risk, entrepreneurship being inseparable from risk.

    Engaging with risk may entail running pilots that may not be effective, initiating ideas in an organisation without the promise of accomplishment. Alongside the culture of innovation, the culture of resilience is located, and although different, they strengthen one another. A culture of resilience understands that central control is not attainable, and rather adopting a resilient stance and being nimble will serve as the most useful approach. In aiming to achieve the above, it is useful to discern the nature of a specific network prototype for a given organisation. The following are mechanisms by which a culture of innovation may be facilitated:

    - Establish examples that inspire, which others can mirror, and make sure examples are given the importance they deserve.
    - Having virtual teams enables various talents to unite at any given time and allows different departments to communicate more.
    - Enable local investments regarding community and the organisation.
    - Be a practitioner regarding what you advocate. Plan events, establish streamlined communications, take part in the learning process.
    - Clearly define ‘innovation commitments’.
    - Define ‘anti-embarrassment clauses’ and integrate innovation unpredictability into policies, agreements etc.

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- The organisation, community, service providers etc. should not live in isolation from others and be open to interaction, international if need be.

Reflections:

a) *Innovation is advanced through exposure to disruption and a culture of handling change instead of avoiding change*: This approach is embodied by the framework in various ways, such as investigating previous initiatives which include; learning from failures; learning from each implementation (AID); and updated documentation such as contingency and emergency response plans in Step 6.3 and 6.4.

b) *In order to overcome community differences in culture and values*, a common vision that is understood and supported by all stakeholder groups is a key component of planning for digitalisation and managing the risks involved. This is addressed by the framework by involving all stakeholders in vision formation (Step 1.6 and Step 7.3), and through the education and awareness programme in Step 1.10.

c) *Innovation culture flourishes in contexts that embrace a positive outlook on risk*, as risk is a prominent aspect of entrepreneurship. Risks entail unsuccessful pilot projects, initiating ideas without any certainty of success. In the framework a balanced approach to risk is present such as testing before scaling to minimise losses and maximise results. Failures, although not ideal, are a valuable source of information and are leveraged in the framework as lessons learned and documented.

d) *Innovation through agility*: Resilience is a supporting capability, being aware that constant and total control is not achievable, and rather embracing agility.This is addressed in the AID step and through the whole Stage 6.

16. **Community communications:** The communication aspect is vital in guaranteeing that the community digitalisation practice is inclusive, and to see that each individual is informed, partaking and serving. It is interesting that communications regularly do not succeed at various levels. The way numerous projects are executed is in a closed-off manner, and lack inclusion with regards to significant stakeholders. A new digital deal comes with a conceptual social agreement, which is only possible by establishing a genuine exchange, discussions, and an experience of aims and prioritisation and genuine inclusion. Without a precise view of the aims and individual roles and responsibilities, community

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communications do not carry much weight. A few outcomes concerning community communications are listed below:

- Having political agendas, and leadership that is of a devoted, receptive, and amenable nature.
- Community leaders need to ensure that all members involved have a basic awareness regarding any community projects.
- The citizens of the community need to be involved in the transition into digitalisation.
- Garner interest from investors, entrepreneurs and structured drivers.
- Altering management environments require frequent internal communications.
- Build innovation culture into the organisation's structure of being.
- The latter methods of communication and aims may take various forms.

Reflections:

a) *Inclusive communication*: In Step 1.5 and 7.1, stakeholder requirements are identified through surveys, town hall meetings etc. and all potential stakeholders are identified in Step 1.2.b to know the variety of individuals that need to be involved.

b) *Awareness of community projects*: Addressed in education and awareness programme, Step 1.10, which includes announcing initiatives, information and achievements.

c) *Frequent internal communications*: Present at Steps 1.2.a, 1.2.c, 1.3.b, 1.4.b and 1.9.

d) *Investor interest*: In Step 1.8, funding options are investigated, not relying solely on government funding, but attracting other sources of investment from the private sector and potential business opportunities. Factors that influence investor confidence have also been addressed in the framework, such as appropriate and responsible policy adaptations; good communication and reporting; improved information availability, analytics and forecasting through strategic city sensing and monitoring; contractual aspects; progress tracking; project control measures and progress tracking.

17. **Good design:** Proven innovation involves great design throughout the process, yet numerous organisations do not regard the process of design with seriousness. Good design does not necessarily safeguard

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against digital divides. In the process, service design should precede engineering. Utilisation is dependant on the quality of design and relevance forms a requirement, which highlights the position of good design within the centre of governance structure. Uniform and stable architecture, effective structured efforts towards geography of innovation and the attainability of business architectures etc. are dependent on good design. Design thinking involves creative blueprints and is implemented to examine matters with the aim to resolve. Design thinking distinguishes itself from engineering work in that it operates with the final aim in view, and functions well in complex situations.

Reflections:

a) *Service design*: focuses on solution functionality towards the main purpose, even within complex contexts. The framework strives for resolve of solution suitability through the adaptive design process, most dominantly featured at Stage 4 and 5, Design and Implementation. The designs and implementations are first tested on a small area of the city, it is adapted until suitable, lessons learned are passed on for the next implementation areas or zones, and similar zones are grouped regarding the adapted designs and methods to assist scaling, reduce time spent on adaptations, and reduces inefficiencies due to sub-optimal design for the location and its cascading effects.

18. **Skills:** The following trends and data directly affect skills and executive requirements regarding digitalisation:

    - Impactful and increasingly complex network technologies need to be understood and form the foundation for digitalisation.
    - Algorithms and large-scale information-based software will hugely disrupt many single-skillset jobs in many industries birthing new labour opportunities.
    - Media ecology is here and expanding rapidly and a data-centred world brings with it a magnitude of information, including access to patterns and design structures.
    - Our work process, learning and methods of execution are significantly affected by network paradigms.
    - New business architectures have emerged as a result of digitalisation.
    - Ethics become a matter of collective concern with digitalisation, AI and new platforms.

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In order to flourish in the age of digitalisation, the ensuing skillsets are a requirement:

- a fundamental grasp of technology and data analytics;
- social and emotional competence needed to bloom in environments requiring collaboration;
- a capacity to integrate various skills; adeptness regarding media; and
- design thinking, unified skills and resilience.

Smart city development requires establishing teams with combined skills pertaining to digitalisation and forging continuous learning strategies.

Reflections:

a) *Skills*: Step 1.10, 'education and awareness programme', entails planning and establishing the adequate skill development programmes according to the appraisal findings from Step 1.5, such as current citizen literacy, skills and technology access, as well as discerning what is viable and required for the smart sustainable city transitioning. The available knowledge and skills within the city is also evaluated in Step 1.5, and at the end of Stage 3 it is addressed by a broad-based SSC education programme targeted at citizens, schools, tertiary institutions and training opportunities.

19. **Proof of value:** The needs being served, the drive behind innovation, measuring the effectiveness of solutions or services etc. are all to be considered, and often the reason smart city efforts do not work involves failure to ask the right questions. Innovation and digitalisation are part and parcel with regards to businesses, verticals, society and the public sector. Asking whether the outcome of a resolve or service serves the aims, service and requirements and provides the projected results will assist smart city efforts tremendously. Various learning endeavours can be identified:

    - *Proof of concept* - requires showing how either the technology or solution proved effective.
    - *Demonstrator* - showcasing a certain service, result or type of technology to a crowd, and being effective instruments in community communications plans.
    - *Pilots* - define learning aims past technology and assist in initial validation of production, value, repeatability and scale of the finding or service.

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- *Phase-one delivery projects* - projects or service outputs where stakeholders learn and test, but which contain potential for larger scale or repetition.

Smart city initiatives need to factor in proof of value in order to scale and succeed. The latter requires merging ethical dynamics to solutions or services.

Reflections:

a) *Relevant criteria for performance, suitability*: In the framework propositions are assessed according to value for money studies, testing, modelling and learning endeavours, KPIs and CSFs, scenario planning, adaptive implementation and design, project evaluation, tracking performance, improving, reporting and knowledge transfer.

b) *Testing and learning endeavours*: Universities, innovation hubs, private sector, living labs and pilot projects for example, should be utilised to test, demonstrate, model, simulate and refine innovations and solutions with the aim of achieving scalability. These endeavours are very valuable for urban solution design and development. The framework will be adapted to include this feature.

20. **Proof of values:** Ethical aspects surrounding digitalisation can attract lavish discussion from a public stance, yet they are seldom integrated into the design of community digitalisation endeavours. The effectiveness of digitalisation cannot be removed from proof of values and the respective ethics involved. Proof of values should accompany each stage of a community digitalisation project, either as evaluations or stability giving form to a project until it matures.

Reflections:

a) *Applying proof of values throughout*: Measures are built in throughout the framework design to shape and guide the development of initiatives, projects and solutions. The values upheld in the framework entail the vision and goals, policy adaption, innovation, integration, interoperability, value creation, security, long-term focus and the six dimensions of smart sustainable cities. These values are enforced throughout the stages by requirement specifications; project evaluation and selection; testing and adapting; contractual design; project control measures; monitoring; reporting and re-iteration.

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The findings from the city transformation lessons evaluation are summarised and provided in Table 5.2:

Table 5.2: Steps of the SSUIT framework correlating with the aspects from the 20 urban transition lessons.

(a) Steps 1-10 of 20.

Principle	SSUIT steps and stages
1. Leadership	
1a) Far-sighted approach:	All stages
b) Ability to adapt, having flexibility:	6.1, 6.2, 6.4, 6.5, stages 4-7
c) The leadership structure connects all stakeholders:	1.3.a, 1.4.a, stage 1 in general
d) Roles and responsibilities should be understood and accepted :	1.2.c, 1.4.b
2. Governance	
a) A broad governance structure that is well-designed with crossvertical governance across silos with all stakeholders involved (government, private sector, academics and residents):	1.4.a
b) Involves representatives from both local and national government:	1.2.a, 1.2.b, 1.3.b, 1.4.b, 1.9, 3.4, 4.5, 7.2
c) Extends to all stakeholders:	1.4.a, 1.4.b, 1.5
d) Capable to operate across silos and departments:	1.4.a
3. Vision:	
a) Vision formation:	1.6, 7.3.
b) Collaborative:	1.3.b, 1.5, 1.4.b, 1.6
c) Iterative:	1.6, 7.1, 7.3 (stages 1 & 7)
d) Understand city's unique qualities, challenges and desired future	1.1, 1.3.b, 1.4.b, 1.5
4. Needs, challenges and comparative advantages:	
a) Start building strategy by knowing city challenges and advantages:	1.1, 1.6, 1.5, 1.7
5. Assets:	
a) Inventory assessment:	1.5, 2.4, 6.3
b) Reduce cost & time by utilising existing assets & resources appropriately	1.5
6. Approach for connecting everything:	
a) Seamless, secure, platform-independent (no vendor lock-in) & open industry	4.3
b) Adequate computing capacity and sufficient bandwidth:	4.3
c) Compatibility through use cases:	4.3
d) Horizontal access across silos and value creation:	4.2, 4.3
e) Data and platform accessibility to ecosystems:	4.2, 4.3, 4.4, 4.5
7. Standards:	
a) Smart city technology should comply with open industry standards:	4.3
b) Set contractual requirements for interoperability:	4.3
8. Cyber security and digital resilience:	
a) Cyber security as highest concern, security considerations built into design:	4.3, 6.4
b) Plan pro-actively for resilience on all levels:	4.3, 6.4
c) The community digitalisation strategist:	1.3.a, 4.3, 5.5
9. Big data and artificial intelligence:	
a) Cyber security, privacy and trust:	4.3
10. Smart regulations:	
a) Adjusting and/or renewing policy and regulation for agile and appropriate handling of fast changing technology and systems:	4.4, 6.5

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(b) Steps 11-20 of 20.

Principle	SSUIT steps and stages
11. Ecosystem:	
a) A favourable environment needs to be developed for new ecosystems to	2.3, 4.2 - 4.4
b) Diversity and abundance within ecosystems of stakeholders needs to be	1.4.a, 3.3
c) Public-private and multi-disciplinary collaboration:	1.4.a-b.
12. Public sector, connectivity and business architectures:	
a) Learn from local and external cases of connectivity in history:	2.4
b) The government requires sophisticated expertise regarding digitalisation, connectivity and complexities relating to business architecture:	1.4.a, 1.2.b
c) Solutions and initiatives should be evaluated and tested and improved	3.2, 4.3, 4.4, AID, 5.2, 6.2, 7.1
d) Mitigation measures of negative knock-on effects should be investigated,	5.5, 6.1
e) Introducing platform economics in smart communities (economic and social	4.2, 4.3
13. Delivery models:	
a) Smart technology should not be incorporated into urban systems without first evaluating its feasibility according to available technology and expertise:	4.3
14. Geography:	
a) Establishing decentralised platforms that encourages experimentation, known as innovation labs, serve as test beds and incubators for urban innovations within local context.	5.4
b) Accessibility to assets and the local eco-system actors and contributors:	4.3
15. Culture of innovation:	
a) Innovation is advanced through exposure to disruption and a culture of	6.3-6.4
b) In order to overcome community differences in culture and values	1.6, 1.10, 7.3
c) Innovation culture flourishes with positive risk outlook	6.5
d) Innovation through agility:	AID step, stage 6
16. Community communications:	
a) Inclusive communication:	1.2.b, 1.5, 7.1
b) Awareness of community projects:	1.1
c) Frequent internal communications:	1.2.a, 1.2.c, 1.3.b, 1.4.b, 1.9.
d) Investor interest:	1.8
17. Good design:	
a) Service design:	Stages 4 & 5
18. Skills:	
a) Skills:	1.5, 1.10, stage 3
19. Proof of value:	
a) Relevant criteria for performance, suitability:	5.2, 5.3
b) Testing and learning endeavours:	AID, 5.5
20. Proof of values:	
a) Applying proof of values throughout:	4.4, 5.5

5.4 CAP4CITY projects

Eleven key aspects were extracted from Pereira and De Azambuja (2022), with each aspect further supported by subcomponents narrowed and listed after reviewing the research on the CAP4CITY projects. These were then tested against the SSUIT framework and tabulated in Table 5.3.

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Table 5.3: Steps of the SSUIT framework correlating with the aspects from the CAP4CITY cases.

Description	SSUIT steps
1. Current State	1.10, 2.3
1.1 define stakeholders,	1.2c
1.2 understand the context,	1.2b
1.3 needs assessment and	1.5
1.4 risk assessment and management.	3.2, 5.2
2. Strategic Planning	
2.1 develop a vision for smart sustainable city development,	1.6, 1.7, 1.10, 7.3, 7.4
2.2 plan human resources capacities	1.4.a, 2.1
2.3 plan infrastructure	3.1
2.4 define a financial plan	1.2c
2.5 plan partnerships, and	1.2c, 1.4.a, 1.8
2.6 seek for approval and commitment	1.2d, 1.4.b, 3.4
3. Evaluation Criteria	
3.1 define key performance indicators (KPIs) (what will be checked),	2.4
3.2 define assessment tools (how the KPIs will be checked), and	6.2
3.3 define performance evaluation plan (who will check the KPIs and when).	
4. Policy Management	
4.1 identify existing policies and	1.5
4.2 review, update, create, integrate, and evaluate policies.	1.2c, 4.4
5. Defining Management and Governance Arrangements	
5.1 establish a governance model and	5.1
5.2 manage capacities.	AID
6. Engaging with Stakeholders	
6.1 engaging citizens	1.4.b
6.2 engaging internal stakeholders and	1.2d, 1.4.b
6.3 engaging external stakeholders.	1.2d, 1.4.b
7. Govern & Manage Data	
7.1 ensure appropriate data management	1.5, 2.3, 7.1
7.2 establish data governance strategy and	6.4
7.3 define security and data privacy policies	6.4
8. Infrastructure Setup & Integration	
8.1 Implementation of device & systems infrastructure	2.3, 4.3, 5.4
8.2 Systems integration & interoperability	3.3
9. Initiative Delivery & Dissemination	
9.1 Good internal & external communication.	4.5, 5.4, 7.2
10. Education & Users' Training Management	
10.1 manage education programs	1.4.b
10.2 provide training for users.	1.4.b
11. Monitoring & Assessing Initiatives for Continuous Improvement	
11.1 performance assessment and	2.4, 6.2
11.2 feedback analysis and knowledge creation.	AID, 5.5, 7.6

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5.5 Findings

A summary of the three case studies used is provided in Table 5.4:

Table 5.4: Correlation of the three case studies with the SSUIT framework.

(a) Stages 1-3 of 7.

SSUIT framework		Transformation lessons	CAP4CITY projects	Copenhagen case
Step	**Description**	**20 Aspects index**	**11 Aspects index**	**Confirm**
Stage 1	Pre-project preparation	1c, 1a, 3c		
1.1	Drivers	3d, 4a, 16b		x
1.2a	National gov	2b, 16c		x
1.2b	Local gov / municipality	2b, 12b, 16a	1.2	x
1.2c	Feasability	1d, 2b, 3d, 16c	1.1, 2.4, 2.5, 4.2	x
1.2d	Consensus		2.6, 6.2, 6.3	x
1.3a	Coordinator	1c, 8c		x
1.3b	Project drivers and expectations	2b, 3b, 3d,16c		x
1.4.a	Team selection & preparation	1c, 2a, 2c, 2d, 11b, 11c, 12b	2.2, 2.5	x
1.4.b	Educate	1d, 2b, 2c, 3b, 3d, 11c, 16c	2.6, 6.1, 6.2, 6.3, 10.1, 10.2	x
1.5	Appraise the situation	2c, 3b, 3d, 4a, 5a, 5b, 16a, 18a	1.3, 4.1, 7.1	x
1.6	Vision(s) & goal(s)	3a, 3b, 3c, 4a,15b	2.1,	x
1.7	Strategic options to realise vision(s) & goal(s)	4a	2.1	x
1.8	Investment companies, other opportunities	16d	2.5	x
1.9	Continue /abort /re-negotiate	2b, 16c		x
1.1O	Education & awareness	15b, 18a	1, 2.1	x
Stage 2	Teams, city state, readiness and assessment	1a, 3c		
2.1	Team preparation		2.2	x
2.2	Draft charter			
2.3	City state & readiness	11a	1, 7.1, 8.1	x
2.4	City assessment	5a,12a	3.1, 11.1	x
Stage 3	Project(s) identification and selection	1a, 3c, 18a	2	
3.1	Project identification		2.3	x
3.2	Project evaluation and selection		1.4	x
3.3	SSC project integration	11b	8.2	x
3.4	Communicate with government and project investors	2b	2.6	x

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(b) Stages 4-7 of 7.

SSUIT framework		Transformation lessons	CAP4CITY projects	Copenhagen case
Step	**Description**	**20 Aspects index**	**11 Aspects index**	**Confirm**
Stage 4	Design	1b, 1a, 3c, 17a		
4.1	Resources			x
4.2	Business case design	6d, 6e,11a, 12e		x
4.3	Design	6b, 6c, 6d, 6e, 7a, 7b, 8a, 8b, 8c, 9a,11a, 12e, 13a	8.2	x
4.4	Evaluate	6e,10a, 11a	4.2	x
4.5	Communicate with government and project investors	2b, 6e	9.1	x
AID	Adaptive implementation & design	15d	5.2, 11.2	x
Stage 5	Implementation	1b, 1a, 3c, 17a		
5.1	Management office		5.1	x
5.2	Develop project definition packages		1.4	x
5.3	Resources		1.3	x
5.4	Implement & monitor	14a	8.1, 9.1	x
5.5	Review: re-adapt or handover	8c, 12d	11.2	x
Stage 6	Maintenance, evaluation and innovation	1b, 1a, 3c, 15d		
6.1	Monitor, manage and respond	1b,12d		x
6.2	City assessment	1b	3.2, 11.1	x
6.3	Infrastructural maintenance	5a,15a		x
6.4	Security	1b, 8a, 8b,15a	7.2, 7.3	x
6.5	Innovation	1b, 10a		x
Stage 7	New initiatives and upgrades	1b, 1a, 3c,		
7.1	Appraise the situation	3c,16a	7.1	x
7.2	Communicate with government and project investors	2b	9.1	x
7.3	Vision(s) & goal(s)	3a, 3c, 15b	2.1	x
7.4	Strategic options to realise vision(s) & goal(s)		2.1	x
7.5	Project feasibility study			x
7.6	Investment companies, other opportunities		11.2	x
7.7	Pursue / re-negotiate / business-as-usual			x

5.6 Adaptations and verified framework

Stage 1: From requirements identified from the fifth case study aspect 'assets', adaptation is required to Step 1.5 by adding identifying the city's unique qualities and available resources, to the subtext of the step. The updated Stage 1 is provided in Figure 5.3 (short version) and with more detail in the expanded diagram, Figure C.6, from Section C.2, Appendix C.

Stage 2 and 3: Requirements 14.a and 19.b, entailing testing and learning endeavours, under the 'proof of value' aspect. Incorporate diverse ecosystem

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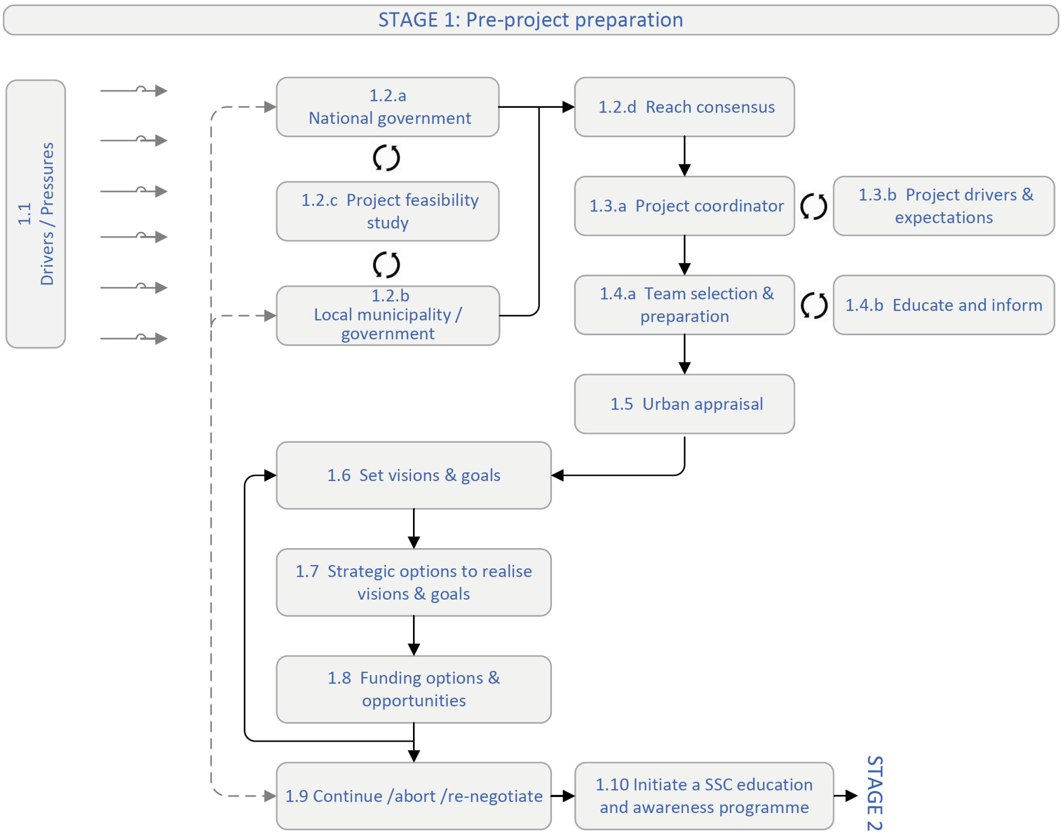

Figure 5.3: Verified pre-project preparation as Stage 1 of the framework.

partners (universities, private sector, living labs, etc.) as part of testing and learning endeavours. Adding the learning, research and skills to Stage 3 is also a recommended from the Copenhagen case study. The framework is adapted so that these testing and learning endeavours is inserted as a process that continues while various activities are executed, supporting, advising or even forming part of them. Therefore, the testing and learning endeavours feature alongside the steps in Stage 3 instead of inside each one. The updated Stage 3 is provided in Figure 5.4 (short version) and with more detail in the expanded diagram, Figure C.7, from Section C.2, Appendix C.

Stage 4 and 5: The sixth aspect 'approach for connecting everything', requirement 6.c entails utilising use cases to understand suitability and compatibility of technologies. This applies to Step 4.3 and forms part of the interoperability aspect as supplementary information. Although the diagrams will remain unchanged, it form part of the additional information supplied with the framework.

Stage 6 and 7: From the discussions and reflections presented in this chapter on the twenty perspectives of effective community digitization, it

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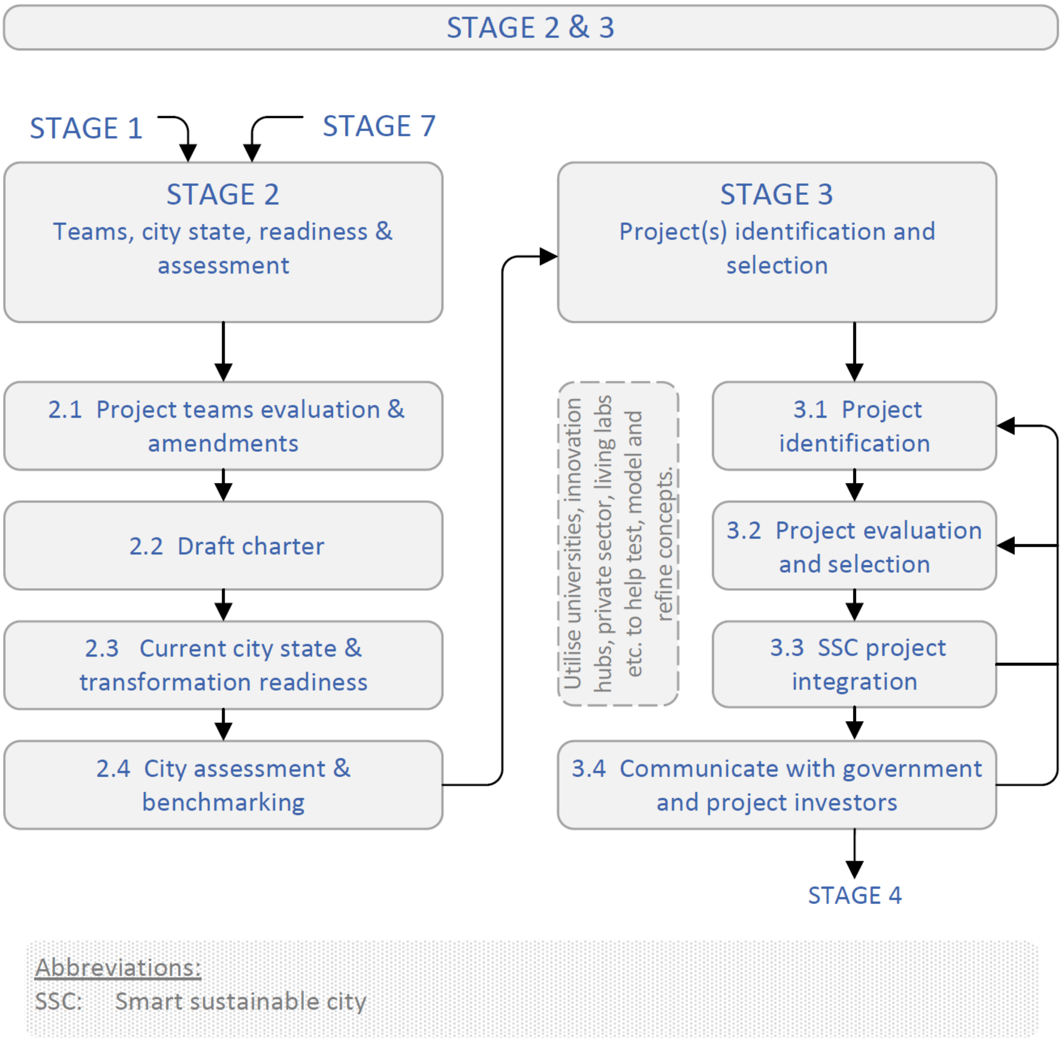

Figure 5.4: Verified Stages 2 and 3 of the developed framework.

became more apparent that Steps 6.1-6.4 are not necessarily in a linear process. For instance, Step 6.4 'Security' will always be active and might require immediate innovations in a response to a threat. By changing the flow structure between Steps 6.1 to 6.4, Stage 6 will offer better responsiveness and adaptability. This speaks directly to reflection 1.b, 10.a, 12.e, and 15.d. The updated Stage 6 and 7 is provided in Figure 5.5 (short version) and with more detail in the expanded diagram, Figure C.9, from Section C.2, Appendix C.

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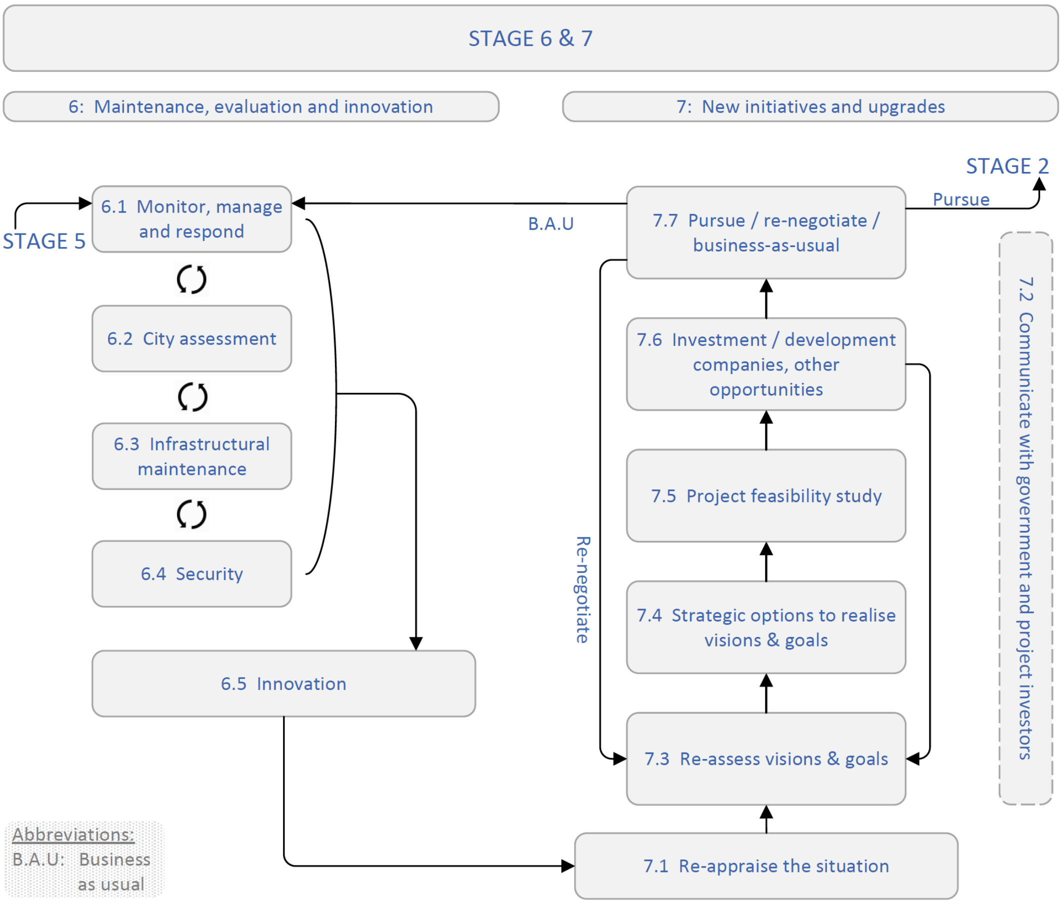

Figure 5.5: Verified Stages 6 and 7 of the developed framework.

5.7 Conclusion

The smart sustainable urban infrastructure transition (SSUIT) framework in Chapter 4 was developed from existing knowledge and approaches following a systematic and conceptual review of the relevant literature available in preceding chapters. In this chapter the theoretical framework is verified through a collective case study analysis.

Three case studies were selected as the focus of the verification:

- City of Copenhagen - discussion of city context, drivers, goals, initiatives and lessons from a sustainable city and smart city perspective with linkages to the framework.
- City transformation lessons: The discussion of the lessons and a reflection on the framework's suitability was presented in order to explain interlinking and complex facets.
- CAP4CITY projects: important requirements for SSC projects derived from 12 successful city cases from the CAP4CITY projects.

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Results were presented in tables showing the correlation between each of the case studies with the SSUIT framework, and a combined table of all the SSUIT framework steps and stages against the respective case studies.

Adaptations were made to the framework where gaps were identified from the evaluations.

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Chapter 6

Validation and Adaptations

The smart sustainable city transformation framework was developed from the conceptual literature in Chapter 4, verified and adapted in Chapter 5 and is further validated and adapted in this chapter. The validation of the framework forms part of phase 3, sub-objective 3 of the main objective as illustrated in Figure 6.1.

A frequently applied method for validating a conceptual framework is to ask the opinions of experts, who understand and have experience on relating subject matters, to then verify the correctness and accuracy of the framework components (Banks, 1998; Sargent, 1996; Robinson, 1997). This method has been used to validate research in smart cities (Gongora and Bernal, 2016) and in smart sustainable cities (Ibrahim, 2019). The validation of the framework will help to discover possibilities for improvement and potential knowledge gaps (Beceiro *et al.*, 2020).

The aim of the validation is to ascertain the validity of the conceptual framework and to ensure that its representation (e.g., its components) is logical

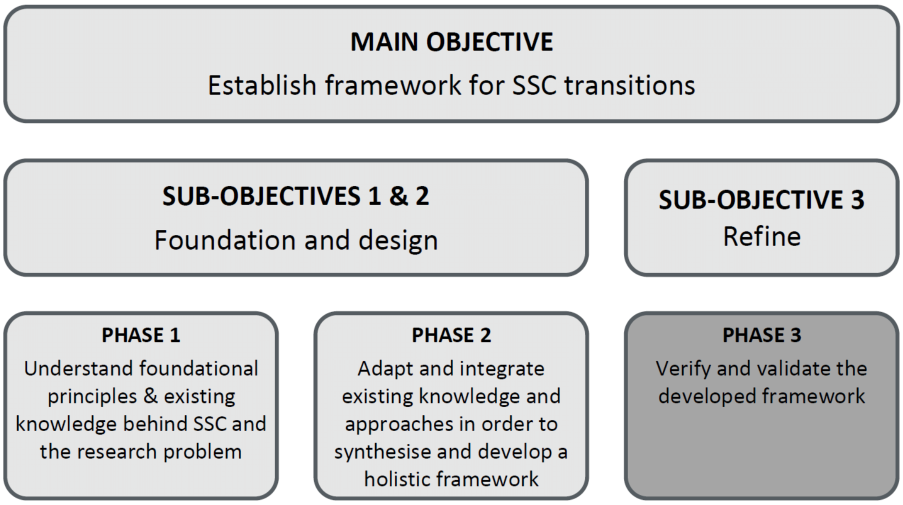

Figure 6.1: Approach followed during the research.

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for its intended purpose (Sargent, 1996; Balci and Sargent, 1981; Robinson, 1997; Kleijnen, 1994). The input provided by the experts will be utilised to adapt and update the framework as necessary, by modifying the existing components or adding missing components (Ibrahim, 2019). This contributes to the framework's credibility when applied to real-world systems and instances (Beceiro *et al.*, 2020).

6.1 Participant selection

A group of five multi-disciplinary experts were asked to participate in the validation process for the proposed novel framework. Experts were chosen according to their experience in practice and their availability to participate in the validation. An overview of each of the participating experts follows.

6.1.1 Participant 1

Participant 1 has 39 years of experience in civil engineering works, specifically bridge construction, railways, housing projects and large sheds. During this time the participant was often in charge of groups of people and has experience working with the government on projects. In Figure 6.2, participant 1 indicated his level of expertise according to a Likert-scale. It can be observed in Figure 6.2 that participant 1's expertise is focused towards project management, infrastructure, construction, engineering, management and business.

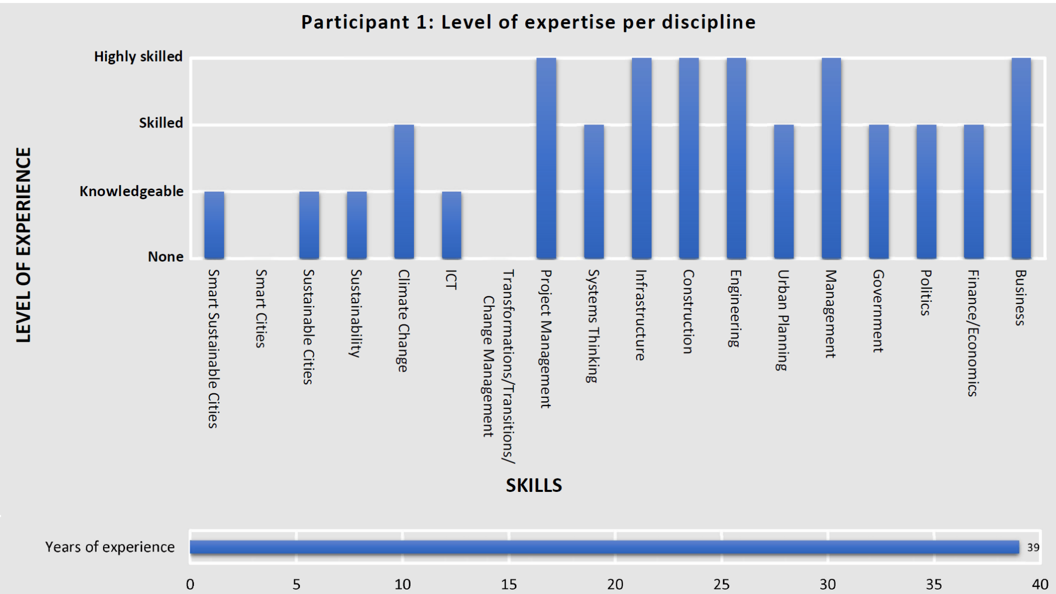

Figure 6.2: Level of expertise per discipline for participant 1.

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6.1.2 Participant 2

Participant 2 has experience in most aspects of business management, specifically managing resources of large construction projects. The participant has also collaborated with local and international clients. The skills indicated by the participant in Figure 6.3 shows a more general distribution and the participant is knowledgeable on all eighteen domains. Participant 2 has a total of fifteen years of experience in practice.

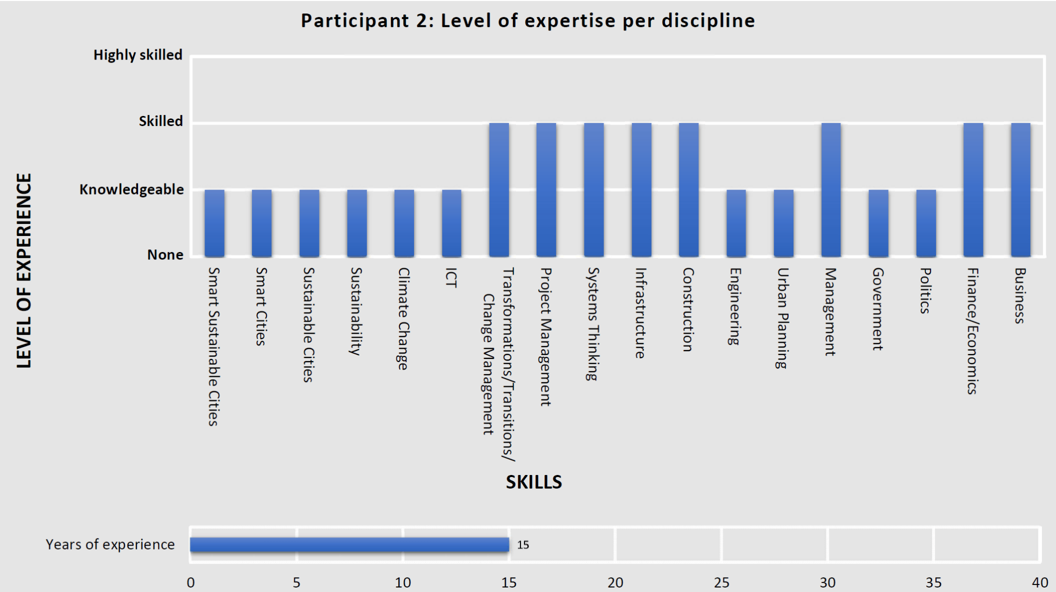

Figure 6.3: Level of expertise per discipline for participant 2.

6.1.3 Participant 3

Participant 3 holds a doctoral degree in Geoinformatics, has 20 years of experience in geographic information systems, remote sensing, environmental science and military science. As indicated in Figure 6.4, the participant has knowledgeable experience on all domains and is highly skilled in the sustainability, climate change, ICT, systems thinking, management and governmental domains.

6.1.4 Participant 4

Participant 4 is a chartered accountant that is part of the power and infrastructure team at a global investment bank. His role as senior transactor entails meeting directly with local and international clients, travelling to project sites and working with multi-disciplinary consultants on infrastructure. In Figure 6.5 it is shown that the participant has 7 years of experience and is

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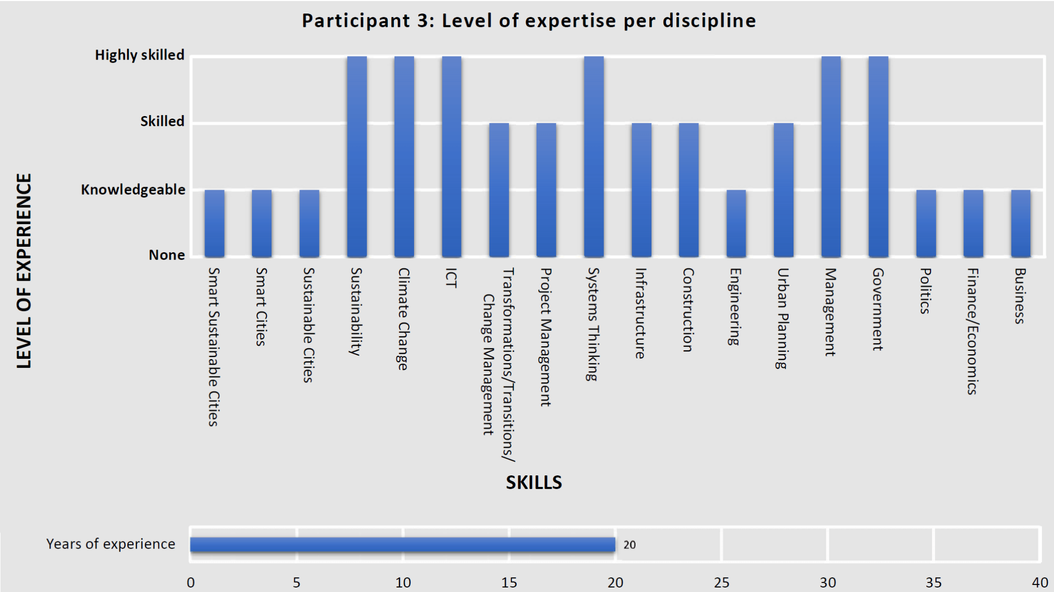

Figure 6.4: Level of expertise per discipline for participant 3.

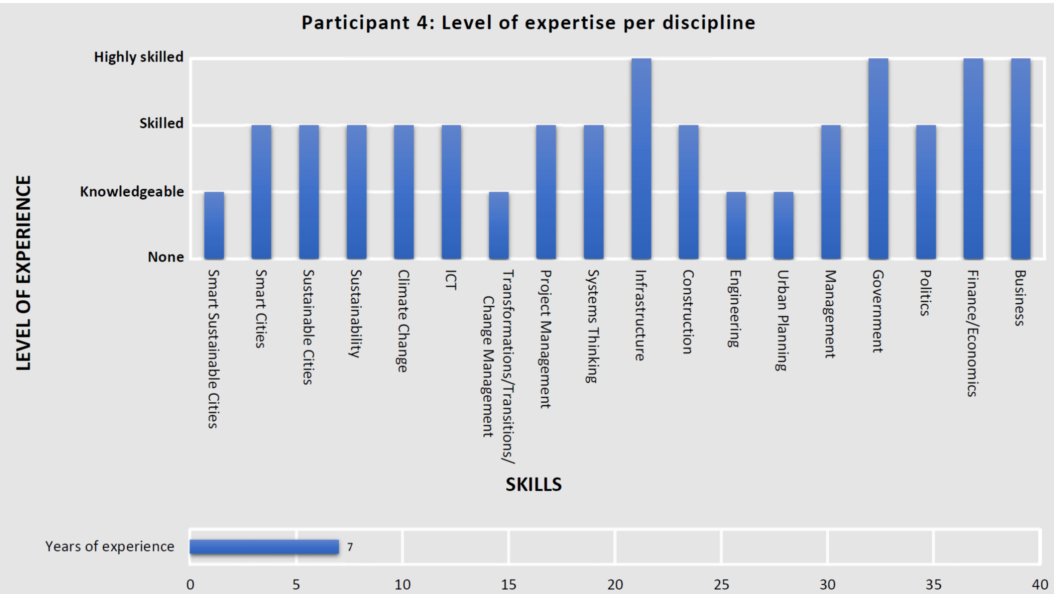

Figure 6.5: Level of expertise per discipline for participant 4.

knowledgeable on all domains and highly skilled in infrastructure, government, finance and business aspects. In addition to the participant's career in infrastructure financing, the participant also obtained a master's degree with distinction in taxation and received a national award for the research.

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6.1.5 Participant 5

The participant is a senior engineer with experience in systems engineering, infrastructure development, project management, product development and financing of infrastructure with 38 years of total experience. The participant has 4 years of experience in systems engineering, 7 years of experience in renewable energy, was a project director for 9 years at a company that specialises in nuclear infrastructure and engineering, and worked for 8 years in business development. Due to his extensive experience in practice, the participant has been contracted for the past 6 years as an infrastructure project investment consultant at a global investment bank. As depicted in Figure 6.6 the participant is generally skilled on almost all domains and highly skilled on systems thinking and infrastructure projects.

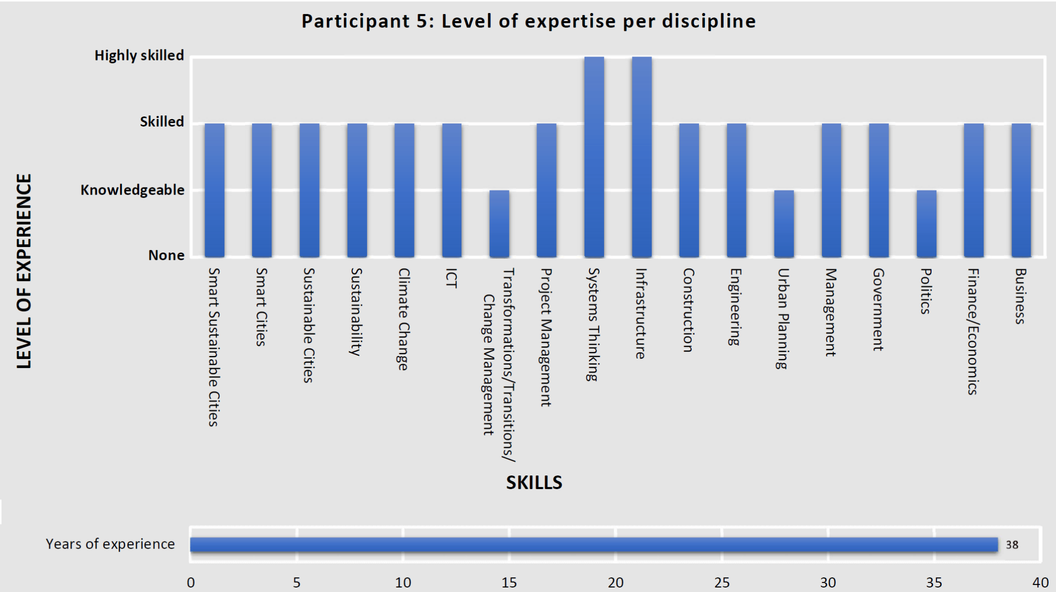

Figure 6.6: Level of expertise per discipline for participant 5.

6.1.6 Holistic distribution of participant skills

Each of the skill distributions from Figures 6.2 to Figures 6.6 is relative to the opinions of participants. However, if the highest skill levels of each participant in the group were represented by a single figure to possibly indicate the holistic skill distribution in the group, it would be found that all of the eighteen domains were at least represented by the "skilled," or second highest level of experience.

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6.2 Rated level of importance of stages and steps

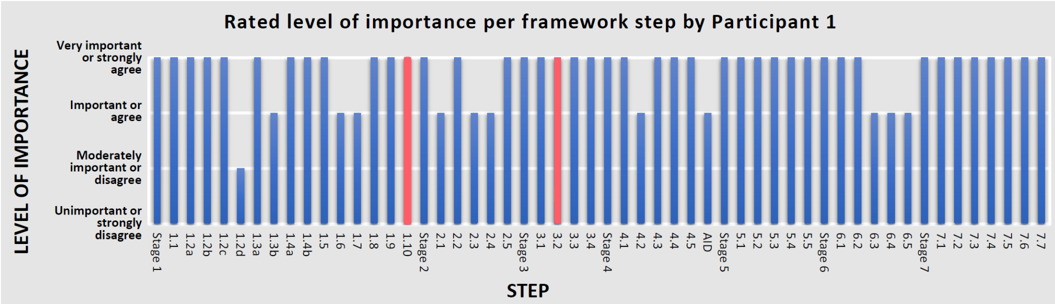
During the first round of review, each participant had the opportunity to express his or her opinion on the framework through both closed-ended and open-ended questions. The closed-ended questions were used to gain information on what the perceived level of importance is of each stage and step in the framework. The focus of determining rated level of importance for the stages was to see whether any of the steps might be deemed unfit or perhaps very important. A 5-point Likert scale has the advantage of offering a neutral choice to respondents, but a 4-point was chosen as it was chosen to prevent respondents clustering responses towards a middle or neutral category (McMillan and Schumacher, 2014). The participants were required to rate every step and stage according to the following 4-point Likert scale options:

- 1 = 'Unimportant or strongly disagree',
- 2 = 'Moderately important or disagree',
- 3 = 'Important or agree', and
- 4 = 'Very important or strongly agree'.

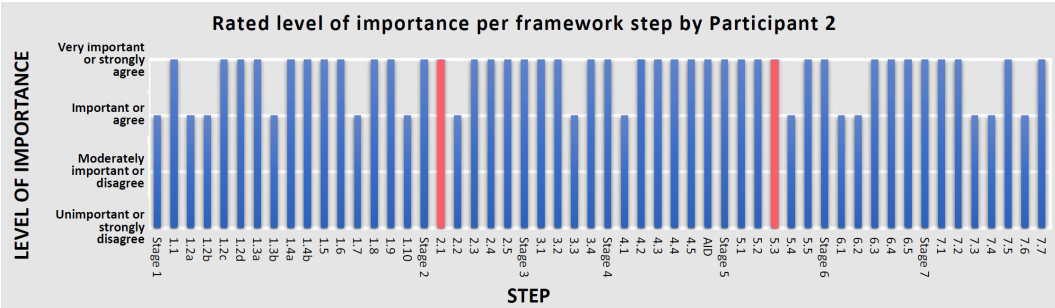
When inspecting the results for the perceived step and stage importance provided in Figures 6.7a to 6.7e, no commonality could be found that indicates a commonly agreed on framework aspect to be of less importance or irrelevance. This was also confirmed through the open-ended questions later on. For instance, in Figure 6.7c, Participant 3 indicated that every stage and step is to be regarded equally and highly important to the framework. When later asked about this choice, the participant indicated that each stage and step plays a vital role in the system and has a unique goal to achieve for the system to function. If any of the stages or steps should be left out, the system might suffer and become unsuccessful.

With regards to Step 1.2d, Participant 1 indicated the 'reach consensus' step to be moderately important, the participant felt that there will still be some uncertainties and unknowns within the governmental structures. Concern was raised whether government might at this stage be 'informed' or 'educated' enough on the matters of smart sustainable cities.

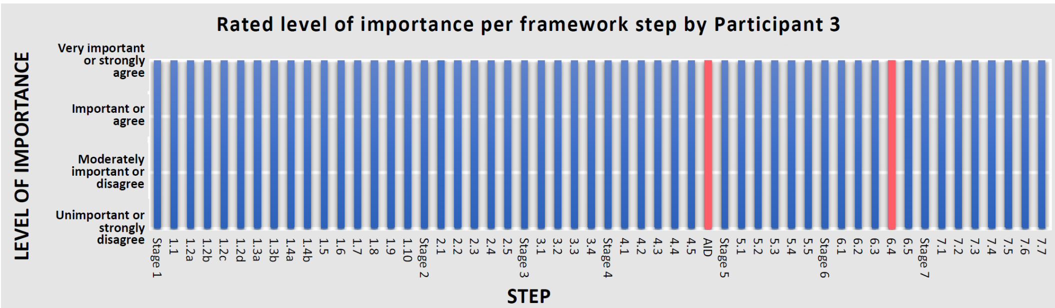
Participant 4 indicated moderate importance on Step 1.7 'strategic options to realise visions and goals' and 1.10 'SSC education and awareness programme for citizens'. Although the participant later noted that both these steps cannot be ignored as it might have repercussions in the long term, it was reasoned that these steps are not as critical to the success of planning the transition. On the contrary, Participant 1 expressed great importance for Step 1.10, that educating citizens and creating awareness can help to excel the adoption of



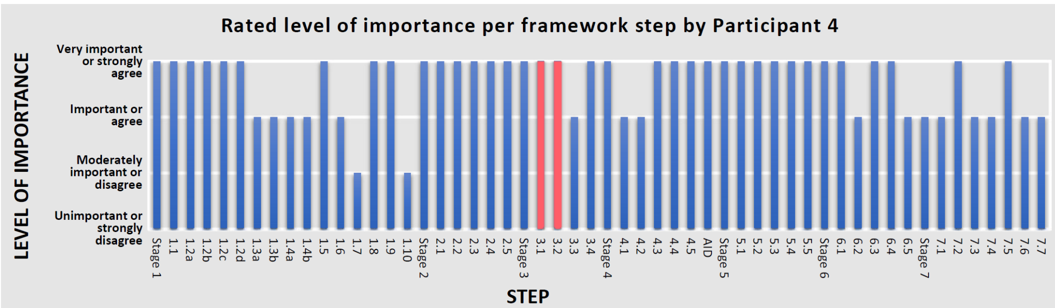
(a) Participant 1



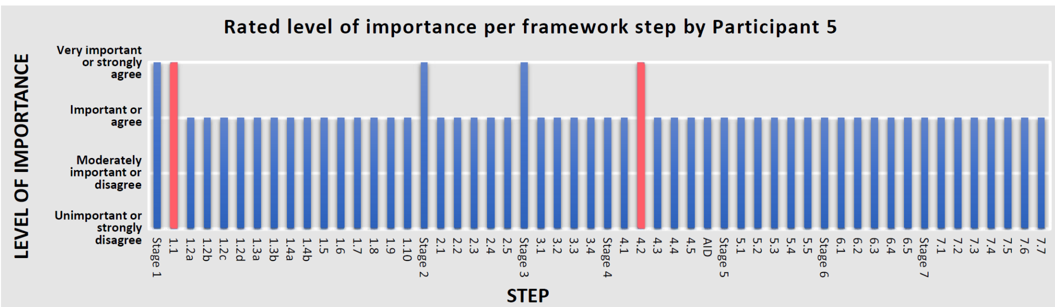
(b) Participant 2



(c) Participant 3



(d) Participant 4



(e) Participant 5

Figure 6.7: Rated level of importance per framework step and participant.

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the city's smart functions among citizens. The same applied to Participant 3 who also found Step 1.10 to be of importance. And so it was also indicated that Step 1.7 has a shared importance among Participants 1, 2, 3 and 5.

For the most part Stages 1-7 received a 'very important or strongly agree' rating, except for Stage 1 with Participant 2, Stage 7 with Participant 4 and Stage 4, 5, 6 and 7 with Participant 5 who all scored the second highest rating 'important or agree'. It was later added by Participant 5 that Stage 1 serves an important role in large projects like a smart sustainable city transition, as it lays the foundation for the projects.

After providing importance ratings, each of the participants had a chance to provide or highlight, according to their opinion, two steps they regard most critical to the smart sustainable city transition. These are, for each of the participants, indicated in red bars in Figures 6.7a to 6.7e and will be elaborated.

In Figure 6.7a, Participant 1 selected Steps 1.10 and 3.2 as most critical, which represents 'SSC education and awareness programme for citizens' and 'project evaluation and selection' respectively. Participant 2 in Figure 6.7b described Step 2.1 'team preparation' and Step 5.3 'resources' to be key steps in the transition. Participant 3 in Figure 6.7c selected AID 'adaptive implementation and design' and Step 6.4 'security' as significant steps to maintain a successful smart sustainable city transition. Participant 4 in Figure 6.7d singled out Step 3.1 and Step 3.2 which constitute 'project identification' and 'project evaluation and selection' respectively. Step 3.2 is the only step that was selected more than once by the participants. Finally, in Figure 6.7, Participant 5 called attention to understanding the drivers that initiated the transition, Step 1.1, and building a business case design, Step 4.2, as the most important. In closing, it is shown that, by and large, the panel places emphasis on different aspects of the framework, and could be a positive indicator for the multi-disciplinary nature of the panel and the value that can be gained from the different points of view in the group of experts.

6.3 First round of validation and adaptations

The open-ended responses in Round 1 build or extend on some of the responses provided in the previous Section 6.2. Going over Stage 1 in Round 1, Participant 1 called attention to Step 1.2.a 'national government' and 1.2.b 'local municipality'. It might be necessary to assist governmental officials during these steps according to the participant, as they might not have enough information regarding smart sustainable cities and city transformations. This might help officials to better understand and interpret the project early on. Step 1.a and 1.2.b, according to Participant 3, can possibly be reduced to a single step, as not all governments share the same structure. Participant 1 elaborated on the importance of Step 1.10 'SSC education and awareness

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programme' as this step will help to inform and enable city occupants to make use of SSC functions. High importance was assigned by Participant 5 to Stage 1.1 'drivers or pressures' as it was maintained that understanding the circumstances under which the transformation project initiated is key. Stage 1 was also a fundamental stage to Participant 4 as it is important to obtain governmental 'buy-in' before entering the next stages and progressing too far into projects. Likewise, it was advised by Participant 2 to identify potential signs of 'buy-in' early on through the project development from the 'involved parties (internal - the team) and (external - government or investors).'

Following the advice from the experts, adaptations were made to the verified Stage 1 framework. An adapted Stage 1 is presented in Figure 6.8 (and an expanded version in Figure C.10, Section C.2, Appendix C). The adapted Stage 1 will undergo further validation when presented to the experts in Round 2. The adaptions that were made to Stage 1 include merging Step 1.2.a 'national government' and 1.2.b 'local municipality' into one step, now Step 1.2.a 'governmental structure'. This was done based on the advice received from Participant 3. The step can still be representative of both national government and local municipalities, but will now be able to also serve for a broader spectrum of governance structures. Step 1.2.c was added to Stage 1 in Figure 6.8 as suggested by Participant 1. This step appoints a

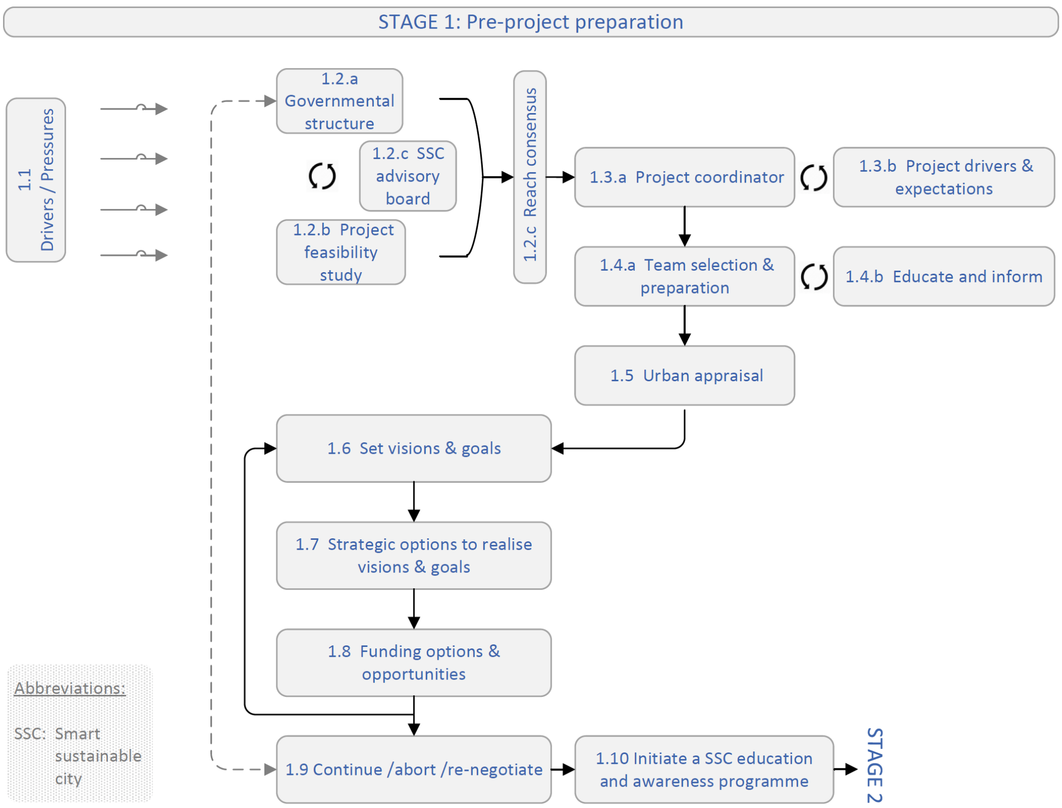

Figure 6.8: Adaptations made to Stage 1 for Round 2 of the framework validation.

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multi-disciplinary SSC advisory board to provide guidance on the workings of a SSC to the governmental structure (Step 1.2.a).

During Stage 2 and 3 feedback, Participant 2 regarded Step 2.1 'team preparation' as one of the fundamental steps in Stage 2, as the 'team' plays a primal role through the transition and without the proper skillsets and alignment it directly influences the success of the transition. The same participant added that Step 3.2 in Stage 3, which consists of communicating with investors and government, is of priority and that it is necessary to always keep an open channel with these representatives. As previously mentioned in Section 6.2 (indicated in Figure 6.7a and 6.7d), Participant 1 and 4 places significant value on Step 3.2 and Participant 4 on Step 3.1 as role players in the overall success of the transition. Participant 2 expressed that he/she is pleased with the overall layout of Stage 2 and 3 and that it should work in practice. The same opinion was expressed by Participants 1, 3, 4 and 5 who were pleased with Stages 2 and 3 and requested no changes.

Regarding Stage 4 and 5, Participant 4 suggested that the design and construction tendering processes could also be indicated along the borders of Stage 4 (Step 4.1 to 4.3) and Stage 5 (Step 5.3 to 5.4). Participant 4 was generally satisfied with the two stages and the way that they are structured and interlinked. To review findings in Section 6.2, the steps in Stage 4 and 5 regarded as crucial to the transition success are Step 4.2 (Participant 5), AID (Participant 3) and Step 5.3 (Participant 2). These steps are labelled as 'business case design', 'adaptive implementation and design' and 'resources' respectively. Participant 2 added on Step 4.2 'business case design' that the step is exceedingly important, as a city should be equally sustainable financially as it is environmentally and socially sustainable. The participant also deemed Steps 5.1 'management office' and 5.3 'resources' to be very important. In this participant's own words and based on experience with similar activities to Step 5.3 (resources), "sometimes a project can get by with an okay or good enough design team, but an excellent execution team when it comes to the construction of the hard infrastructure can in many cases detect design mistakes early on, and correct them where possible as the project progresses." Participant 3 concurs that in Step 4.3, the 'designing' of security for ICT devices should be included in the integration of the fundamental design of the infrastructure.

Taking the suggestions made by Participant 4 into consideration, alterations were made to Stage 4 and 5 of the framework. The adapted Stage 4 and 5 were included in Figure 6.9, and an expanded version of the two stages is provided in Figure C.13, Section C.2 of Appendix C.

Finally, Stage 6 (maintenance, evaluation and innovation) and 7 (new initiatives and upgrades) were reviewed. It was found that all participants were pleased with these two stages. Participant 5 was very pleased with the way Stage 6 and 7 was structured and also believes the stages will work when applied in practice. In Step 6.3 'infrastructure maintenance', Participant 1

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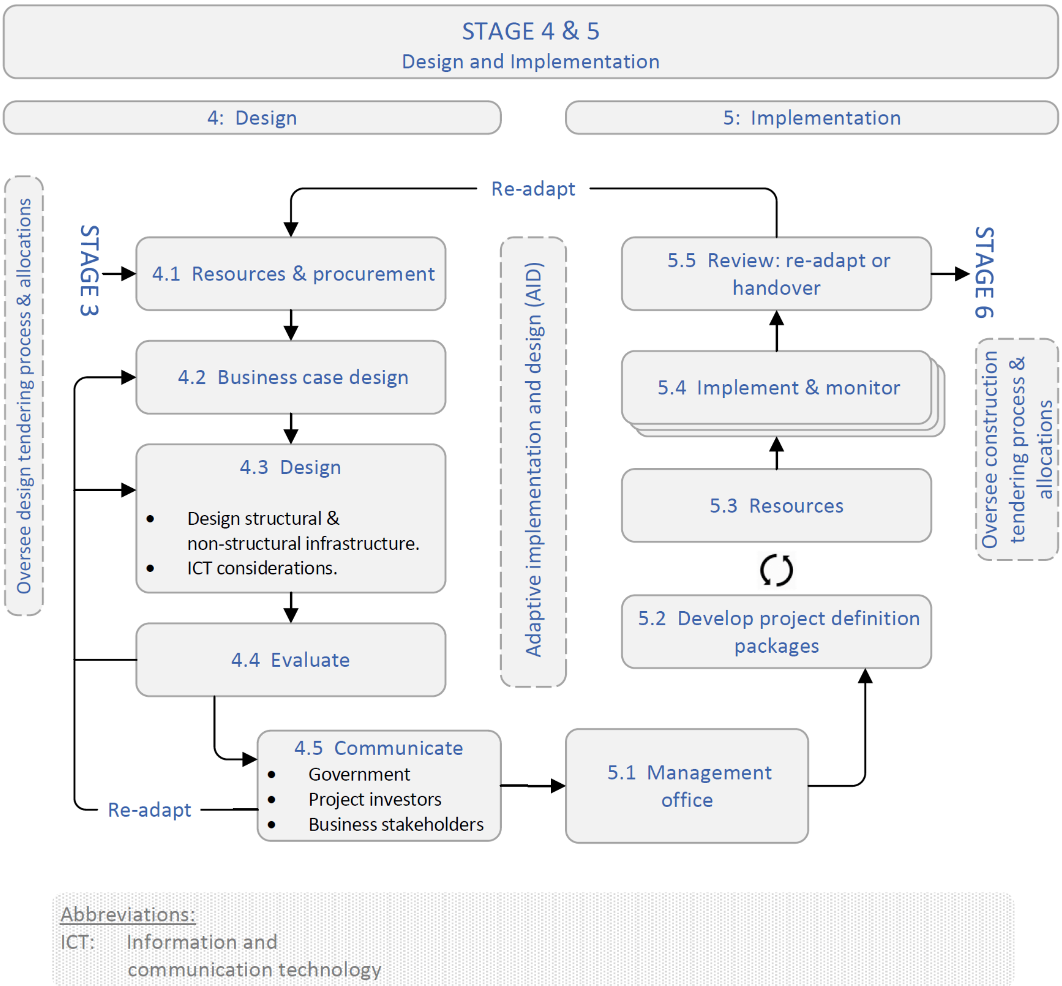

Figure 6.9: Validated Stages 4 and 5 of the developed framework.

added from his/her experience that keeping the maintenance management plan and documents up to date are often neglected, especially in government projects. Participant 2 also elaborated on Step 6.3 and added that keeping good documentation plays an essential role, as this means that knowledge is passed on and retained in the system in order to sustain it correctly. If an event should occur involving key personnel, the documentation would facilitate the emergency handover and serve as a fall back.

6.4 Second round of validation and adaptations

During Round 2 of the validation, the updated framework with Stage 1 presented in Stage 1 (Figure 6.8), 4 and 5 (Figure 6.9), and Stage 4 and 5 presented in Figure 6.9 were reviewed. As each of the adaptations made could potentially influence other areas of the framework, participants were allowed to add to framework stages that had not been amended during Round 1 of

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the validation. Also, this was allowed as participants might have developed new insights since the previous round. It can also be noted that during this validation, all of the participants who took part in Round 1, was also actively involved in Round 2 and 3 of the validation.

The amended Stage 1 in Figure 6.8 was presented to the participants. Participant 1 was contented and happy with the changes made when including a SSC advisory board in Step 1.2.c of Figure 6.8 in helping to advise and inform government in advance on the workings of a SSC. The same can be said with Participant 3 who was at ease with the changes made when merging 'national government' and 'local municipality/government' steps into a single unified Step 1.2.a 'governmental structure' in Figure 6.8 that now caters for a broader spectrum of governance. Participant 2 and 4 did not have any changes requested for the new Stage 1.

Upon presenting Stage 1 to Participant 5, it was made known that there is currently nothing specific in Stage 1 that he/she disapproves of or finds unimportant. The participant feels that after having time to think about Stage 1, the stage might not hold up in practice. The participant mentioned that Stage 1 as it currently stands, should be fine in theory, but that he/she would like to see this framework succeed in practice and judging by his/her experience, the current Stage 1 will determine the success of transition. In practice this participant is largely involved with determining feasibility of large infrastructure projects, judging new proposals and critiquing not only if a project concept is a good idea, but if it will work in practice and be investable. This role carries substantial responsibility as other stakeholders depend on his/her opinion.

This being said, Participant 5's recommendation was interpreted as necessary and further questions were posed on what could potentially work better for Stage 1. The participant did not necessarily have a clear answer or idea, but set out some guidelines to follow when re-designing Stage 1. It can be beneficial for Stage 1 to:

1. be made shorter and simpler;
2. place focus on what needs to be achieved;
3. develop awareness of existing global initiatives/projects that can be considered examples of what is possible and how to achieve it;
4. bring together relevant stakeholders around the initiatives they have mutual interests in; and
5. narrow the focus from the start to the respective functional infrastructure divisions, as the SSC focus is currently very broad: can make use of workshops aimed at specific work-groups (i.e. transport, energy, waste, etc.).

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Feedback on the amendments made on Stage 4 and 5 was well received by all participants. Further changes was not required by the participants for Stages 4 , 5, 6 and 7, but Participant 4 suggested adding two extra steps with which he/she believes Stage 3 can potentially be improved. The participant suggested adding an additional 'business case' and 'project selection' step in between the current Step 3.3 'SSC project integration', and Step 3.4 'Communicate project with government and investors'. The business case step will help with reviewing financing particulars and reaching concensus with all major role-players. The project selection will add to the Stage as a final selection of projects will be required after determining the project integration in Step 3.3 and further business case particulars have been looked at before communicating with government and investors.

6.4.1 Adaptations

After carefully deliberating on the guidelines provided by Participant 5 during Round 2 of the validations, an approach from the doctoral study in Fouché and Brent (2020) was identified as a suitable alternative that can be adapted and incorporated in Stage 1. The research in Fouché and Brent (2020) will be elaborated on before applying the adaptions to Stage 1. As significant changes to Stage 1 might impact other stages, including Stage 2 and 3, the adaptions suggested by Participant 4 in Round 2 will only be included once Stage 1 has been adapted in this round.

6.4.1.1 EDAS

The work by Fouché and Brent (2020) presents a novel participatory planning approach named EDAS, which stands for Explore, Design and Act for Sustainability. The approach involves stakeholders and enables the integration of local and scientific knowledge. Methods to determine possible paths could be, for example, scenario planning, PESTLE analysis or similar techniques as recommended by Fouché and Brent (2020) as part of their EDAS approach for sustainability planning. It was used to perform sustainable energy planning for a municipality in the Western Cape Province of South Africa as a case study. The acronym PESTLE refers to external factors that can impact a specific system such as political, economic, socio-cultural, technological, legal and environmental aspects (Basu, 2013). Fouché and Brent (2020) advise that multi-disciplinary expert knowledge, relevant to the city aspect considered for transformation, be involved in the PESTLE analysis to identify and understand the factors, dynamics and components that may have an influence on the future context. These factors can be used to develop possible future scenarios treated as a set of backdrops, against which, various strategies can be evaluated (Fouché and Brent, 2020). This is known as scenario planning, where various possible future scenarios, such as positive, negative and most

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probable outcomes, based upon factors outside the control of the stakeholders, is used to determine the overall most suitable paths to realise a specific goal. The risks within the possible futures should also be taken into consideration for each strategy to determine the most desirable path(s) (Fouché and Brent, 2020).

In South Africa, local governments are grappling with several difficult issues, such as local economic development, energy security, poverty, climate change and so forth. Stakeholder engagement is critical in dealing with these complicated issues at the local government level (Fouché and Brent, 2020). Stakeholder participation should be guided by equality, a philosophy of empowerment, learning and trust. The EDAS method was originally created for energy sustainability, but it may be applied to any sustainability issue. Although public involvement is a democratic right of all South African people, and expressed in the South African Constitution, finite evidence in literature indicates the way public engagement is enabled as well as its efficacy (Fouché and Brent, 2020).

The Explore, Design, and Act for Sustainability (EDAS) methodology is a participatory planning method created in the area of soft operational research, originally designed for energy sustainability, yet with the option to be adapted to any given sustainability issue (Fouché and Brent, 2020). To offer a complete understanding of complex and socio-ecological systems and processes, EDAS engages stakeholders and combines local and scientific information. The EDAS method, for example is utilised in addressing problems concerning sustainability, such as the United Nations Sustainable Development Goals. EDAS organises conversations and debates with the purpose to investigate and imagine the future; to discover sustainable alternatives, variabilities, barriers, and difficulties; to develop sustainable strategies; to identify the imagined system; and to assess the strategies regarding potential futures. The EDAS method is collaborative, comprehensive, straightforward, inclusive, dynamic, and transparent. The EDAS approach's primary outcomes are a realistic action plan and the creation of continuous stakeholder engagement (Fouché and Brent, 2020).

The requirements for creating the EDAS participatory Planning Approach for Local Energy Sustainability was listed by Fouché and Brent (2020) as follows:

1. The approach must be participatory and inclusive.
2. The approach must be all-encompassing.
3. The approach must be straightforward and transparent.
4. The approach must include the discernment and evaluation of risks, during the deliberation process.

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5. A realistic action plan must be developed, at the end of a two-day workshop.

6. The approach must be dynamic.

7. The approach must be formalised through specific institutional arrangements.

The three components of the EDAS method, namely Explore, Design, and Act, create a continuous cycle that reflects an active adaptive process of constantly gaining information and then acting on that knowledge, as presented in Figure 6.10 (Fouché and Brent, 2020).

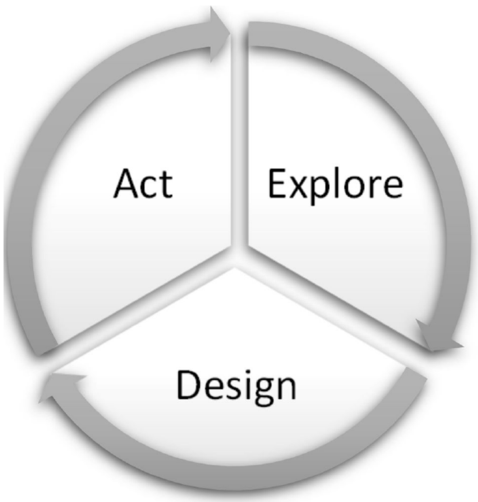

Figure 6.10: EDAS Cycle (Fouché and Brent, 2020).

The following three aspects make up the EDAS approach: 1. Explore to establish sustainable alternatives and projected circumstances, 2. Design beneficial strategies, and 3. Act for sustainability.

Explore to determine sustainable options and future conditions
The initial segment of the EDAS approach, Explore, seeks to identify feasible sustainable alternatives within a particular environment (Fouché and Brent, 2020). The Explore section is divided into three steps: a) envisioning the future, b) determining sustainable alternatives, and c) identifying future circumstances. During a stakeholder workshop, these three stages are carried out. Three questions are posed to the participants, who are divided into groups. An examination of possible future circumstances is also carried out (Fouché and Brent, 2020).

- Envisioning the future: The stakeholder workshop provides an opportunity to expand participants' ideas by displaying, presenting, and debating current developments in sustainability.

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- Determine sustainability options: The next stage in the Explore section serves as a means to identify sustainable alternatives. As a starting point, the visualised strategy and/or future statements may be utilised. The participants are asked two questions pertaining to which sustainable option to consider contextually and the constraints towards implementation.

- Identify future conditions: The third phase in the Explore segment's goal is to discover, via a subjective process, a collection of futures indicative of potential system settings that are not within the stakeholders' control. To keep things simple, there are three potential future circumstances to consider: 1) an optimistic outlook, 2) a negative outlook, and 3) the most probable outlook.

The variables used to identify these future circumstances should be agreed upon in advance with subject matter experts and may include those listed in the PESTLE analysis (Fouché and Brent, 2020).

Design desirable sustainable strategies

A systems approach is employed in the design section, in which we perceive everything as linked. The first step in the Design segment is to create a root definition to identify what the system should strive to accomplish. Before creating the system's root definition, it is critical that participants grasp the idea of systems thinking (Fouché and Brent, 2020).

More information may be added to the root definition's basic structure, however for the purposes of EDAS, the basic structure is sufficient. Specific sustainability strategies may be created after the system has been identified (Fouché and Brent, 2020).

The goal is to be mindful of the system description and create no more than five to nine feasible solutions (Fouché and Brent, 2020). The selected sustainability solutions are then compared to potential futures to decide which strategies are acceptable and which are undesirable. The assessment is based on the perceived risks associated with each approach within the specified futures. The methods with the lowest perceived risks are the most appealing. The number of suitable solutions will be determined by a discussion of how much risk the stakeholders are prepared to accept. These ideal strategies will subsequently then be utilised to identify the appropriate action stages and next actions to make the desired plan a reality (Fouché and Brent, 2020).

Act for sustainability

The end state of EDAS is achieved when all stakeholders have reached an agreement on how to proceed. The Act segment focuses on the creation of an action plan, which includes a description of the particular activities or changes that must take place, agreement on the champions who will push the

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action points, and a commitment to when the action steps will be accomplished (Fouché and Brent, 2020).

The EDAS method is adaptable and should be tailored to the facilitator's expertise and awareness of the particular situation. After the initial workshop, it is critical that the results and discussions are summarised and feedback is provided to all participants (Fouché and Brent, 2020).

6.4.1.2 Adaptations to Stage 1

After thoroughly exploring the guidelines in Section 6.4 put forth by Participant 5 for the redesigning of Stage 1, and drawing from previous knowledge learned, it was decided to incorporate and adapt the EDAS method in Fouché and Brent (2020) (illustrated in Figure 6.10) into Stage 1 as EDASS, which stands for Explore, Design and Act for Smart Sustainability.

A re-designed Stage 1, is presented in Figure 6.11, with an expanded version also provided in Figure C.11, Section C.3 of Appendix C.

In Figure 6.11, Stage 1 (now renamed to SSC 'Initiation') starts with establishing a facilitator and expert team. Having a capable and multi-disciplinary team who has an understanding of smart sustainable cities is recommended (Ibrahim, 2019; Boyko *et al.*, 2005; Gil-García and Pardo, 2005). The role of each team member should also be clearly defined (Leger *et al.*, 2013; Chourabi *et al.*, 2012). After the facilitators and expert team was established, determining the infrastructure layout or hierarchy of the city as well as finding examples of benchmark or successful smart or sustainable projects will commence. Determining the city's infrastructure layout or hierarchy consist of developing a network representation thereof, identifying the major role players at each level of the branch or node and determining dependencies on another. During the 'benchmark projects' step, information should be drawn from successful real-world smart or sustainable projects around the world, and the information should be categorised under each of the infrastructure decisions applicable to the city. This step was designed according to Participant 5's recommendations.

The city background and transition drivers group addresses two aspects of the city. The background of the city will be beneficial in better understanding the political, social and historical context when designing and executing workshops later in Stage 1. Transition drivers, highly regarded by Participant 5, will help with understanding the motivations for the smart sustainable city transition.

Workshops will be designed and executed during the next step for each of the major infrastructure functional divisions (nodes) according to the EDASS method. Each workshop will require major stakeholders of the associated functional divisions to be included. The workshop will commence with an orientation on SSC's, how the specific functional division slots into a SSC, and examples of successful global benchmark projects relevant to the

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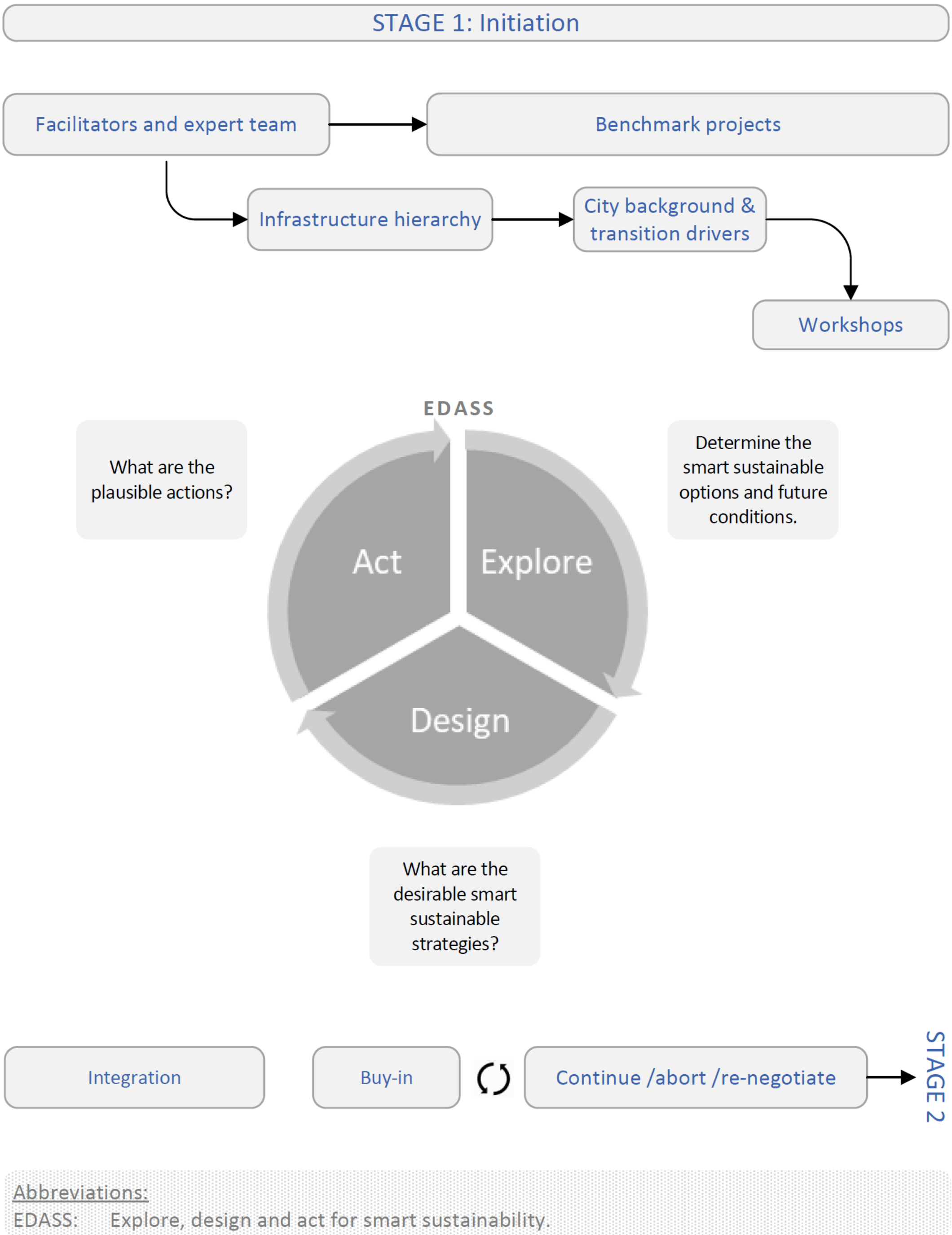

Figure 6.11: Validated pre-project preparation as Stage 1 of the framework.

division. Thereafter each of the workshops will begin with executing the three components of the EDASS method, which are: Explore, Design and Act. The three components will be executed in a continuous cycle as the goal of this exercise is continually acquiring information and acting on that knowledge (Fouché and Brent, 2020).

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The *Explore* component, like in Fouché and Brent (2020), strives to develop viable, smart sustainable city options within the given infrastructure's context. Three steps will be executed after assigning workshop participants into groups. The three steps for the Explore section is; envisage the future, smart sustainable options, and future conditions. Envisage the future asks how the particular infrastructure can be pictured in 30 years time. It gives participants a chance to broaden perspectives on smart sustainability by showcasing, discussing, and debating contemporary smart sustainability advancements. Determining the smart sustainable options asks which of the smart sustainable possibilities are perceived as plausible given the context and envisaged future. This functions as a means for identifying smart sustainable alternatives. Regarding Future conditions, the third step of the Explore segment, the aim is towards finding a collection of possible futures suggestive of non-controllable future circumstances. An optimistic, negative, and most probable outlook can be used. A PESTLE which stands for political, economic, social, technological, legal and environmental factors analysis in Basu (2013) can also be used.

The *Design* component is based on Fouché and Brent (2020) and uses a systems approach. Before commencing it is vital that participants comprehend the concept of systems thinking. The first step in the Design segment is to develop a root definition for the system's objectives. After identifying the system, specific smart sustainability strategies may be developed. The objective is to keep the system description in mind and to generate no more than five to nine suitable solutions. The chosen smart sustainability solutions are then compared to possible futures in order to determine which strategies are desirable and which are not. The perceived risks associated with each of the futures mentioned will be used as part of the assessment, with the lowest risks being most appealing. The level of risk stakeholders are willing to take will affect the number of viable options. These ideal techniques will then be used to determine the proper action stages and following activities necessary to turn the desired plan into a reality.

The *Act* component is the last component of the EDASS method based on Fouché and Brent (2020). This component is attained when all of the stakeholders agree on a course of action and focus on the development of an action plan. It includes a description of the specific actions or changes that must occur, agreement on the champions who will advocate for the action points, and a commitment to when the action points will be completed.

After the first round of workshops have been completed, the facilitators and expert teams will have to confer to work out an integration of all functional division's options gained during the workshops into a holistic plan. It is vital that after completing the holistic plan for the first workshops, the outcomes and discussions are summarised and all participants get feedback. More workshops will follow as this is an iterative process. After the first round the second workshops will still continue at the same functional division level

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until the integration of options provided by these divisions starts to converge. Thereafter workshops will be integrated on a holistic scale where joint planning efforts of the appropriate representatives from each of the divisions will sit together during new EDASS iterations. Once sufficient consensus is reached among various division representatives, the EDASS iterations is concluded.

The 'buy-in' step determines the governmental and investor interest or 'buy-in' within the options concluded from the EDASS rounds. The potential buy-in is a determining factor for whether the smart sustainable city will be able to continue to Stage 2.

6.4.1.3 Adaptations to Stage 2 and 3

The adaptations to Stage 2 and 3 are based on the feedback from validation Round 2 and the redesigning of Stage 1 of the framework. Feedback from Participant 2 in Section 6.4 consisted of adding two extra steps in Stage 3: 'business case' and 'project selection'. The steps should be incorporated between the 'SSC project integration' and 'communicate project with government and investors' steps. According to Participant 4 these steps will improve the overall stage and add to the transformation. Presented in Figure 6.12, Step 3.4 and 3.5 was added as requested by the participant. Step 3.4 'business case' adds to Stage 3 by reviewing and refining the financing particulars of projects, as well as reaching consensus will all major role-players. Step 3.5 'project selection' helps with the objective selection of projects and can use a weighting criteria or scorecard approach.

During the redesigning of Stage 1 and the feedback received from Participant 5 during Round 2 of the validation, studying successful smart and/or sustainable infrastructure projects available could hold value to the smart sustainable city transition. This suggestion was incorporated under the step 'benchmark projects' in Stage 1. It was thought that revisiting these benchmark projects during the 'projects teams evaluation and amendments' Stage 2.1 and 'draft charter' Step 2.2 could be worthwhile. This is because successful example projects can hold information on the skills required, best practices and additional items needed in the draft charter.

Finally, in the previous Stage 1, Participant 1 expressed the 'initiate a SSC education and awareness programme' step to be essential. This step was therefore moved to the end of Stage 3 after Step 3.6 'government and project investors.' By this more information on the SSC transition will be available and could help to shape the awareness programme suggested in this step.

6.5 Final round of validation

During the final round of validation, participants were presented with the re-designed Stage 1 as depicted in Figure 6.11 and the changes made to

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Stages 2 and 3 in Figure 6.12. Participants were asked whether they approve of these changes; if the re-designed Stage 1 fits in within the rest of the framework stages; whether they have any changes they still feel need to be made within all stages; and finally, if they feel the stages will hold up in practice.

When introduced to the re-designed Stage 1, all of the participants agreed that it was an improvement and that they welcomed the change. Participant 5 was especially pleased when shown how his feedback was addressed. Participant 4 thought the 'benchmark projects' step in Stage 1 and 'revisit benchmark projects' step in Stage 2 was an excellent addition to the transition's success. Participant 1 was also pleased with the 'business case' Step 3.4 and 'project selection' Step 3.5 which was added according to his/her recommendations. This approval of adding Step 3.4 and 3.5 was also reflected by the other participants. Participant 1 was satisfied with the moving of the 'SSC education and awareness programme' step in the old Stage 1 to the end of Stage 3 in Figure 6.12 and believes the step will still function effectively at the new placement.

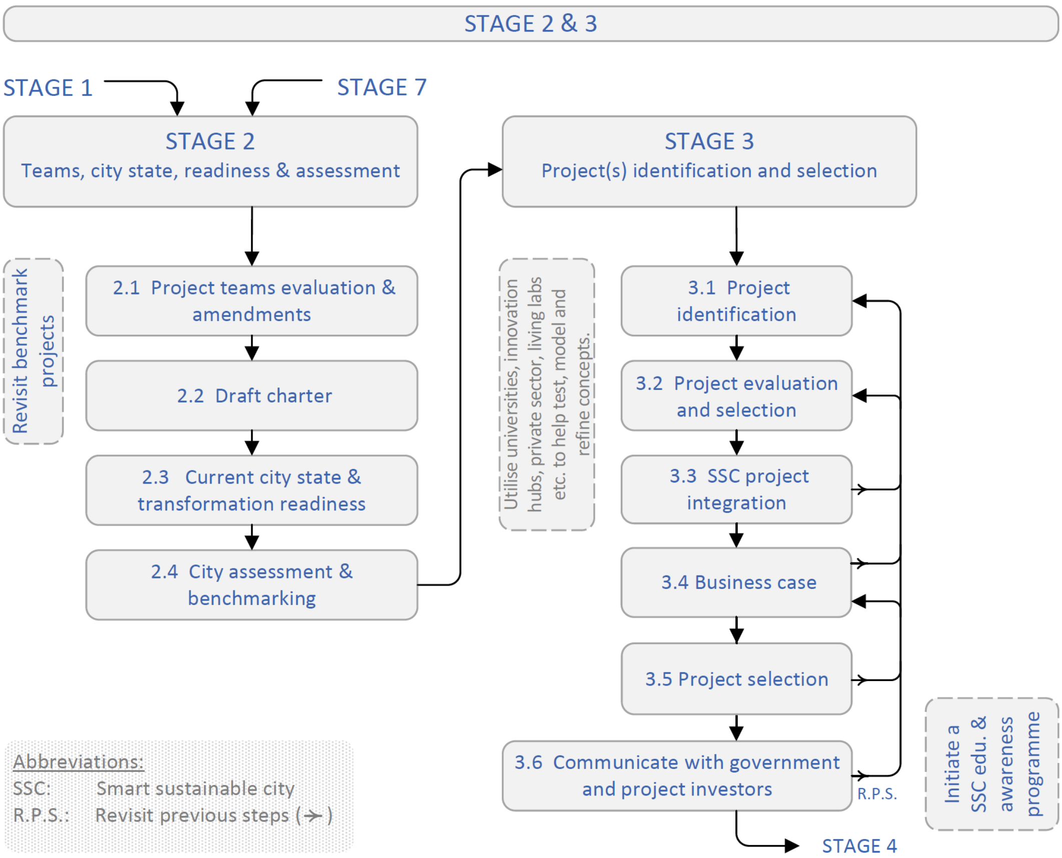

Figure 6.12: Validated Stages 2 and 3 of the developed framework.

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6.6 Findings

The selection of experts contributed valuable insight and experience to the study due to their unique record and involvement that is typically lacking in traditional municipal planning processes, due to current vertical and horizontal silo phenomena being a known hamper to transition success. This is one of the key barriers uncovered in the literature and verification. Their overall backgrounds contributed in the following manner:

Investment banking - expertise refined from evaluating long-term project feasibility and risk before approving funding and project commencement. Monitoring performance of assets invested in, to ensure debt will be cleared and financial return on investment. This leads to refined approaches of investigating current critical impact factors and forecasting and managing future dynamics and risks.

Construction and implementation - some complications that arise during implementation overlap with other construction projects, which has a direct effect on implementation costs, and future success of the intended intervention. Experts with experience in construction management over a whole career span, can see various project complications, impact, mitigation and long-term future roll-on effects which sometimes are not able to be undone. These cases observed and lessons learned are valuable to inform early project planning, implementation and hand-over aspects in the framework that can have a high impact on the transformation.

Human resource management on multi-projects - teams are of high importance as proved from the verification activities. Contributions from industrial psychology are important to manage social challenges that often complicate or stall projects.

GeoICT - the expert chosen has experience with environmental studies, urban crime management, defence applications, applications of satellites in urban areas, urban surveillance technologies and mapping, and municipal development planning. GeoICT in addition plays an important role as it concerns the use of data to make interpretations linking social, economic, environmental and technological dynamics to the spatial plane in order to provide invaluable insights to urban development.

Engineering management - advisory services valuable to the banking and infrastructure sector, and also experience in managing project firms and teams, risk profiling and judging new initiative propositions, business cases and project tenders. This requires sound knowledge in engineering, management, business and practical experience.

During the first round of validation and adaptions minor changes was made to Stage 1, where the 'national government' step and 'local municipality' step were merged to a single 'governmental structures' step. The combined step can still represent both 'national government' and 'local municipality', but can now cater for a larger group of governance structure types. A step for

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setting up a multi-disciplinary 'smart sustainable city advisory board' was also added to provide guidance on the workings of a smart sustainable city to the governmental structure. Overseeing the design and construction tendering process and allocations was also indicated on the border of Stage 4 and 5 as recommended by one of the participants.

The second round of validation required larger modifications than the first round. This could possibly be due to the experts being more familiar with the framework and because they had time to think it over. One of the participants indicated that after careful consideration, they suggested that Stage 1 of the framework be redesigned. It was felt that although the information contained in Stage 1 was correct, the specific stage might struggle to hold up in practice. Stage 1 was redesigned with work incorporated from research done in Fouché and Brent (2020) which resulted in a much more efficient Stage 1 and a refined overall framework.

Other smaller changes suggested during the second round of validation was to add 'business case' and 'project selection' to Stage 3. Identifying projects that are similar to potential projects suggested for the urban transformation was another added suggestion which was included in the designing of the new Stage 1 as 'Benchmark projects' and added to Stage 2 as 'Revisit benchmark projects'.

During the final round of validation, the latest version of the framework was well received by all of the participants and they felt it was no longer required that any changes be made to any of the stages or steps in the framework. The final version of the SSUIT framework is presented in Appendix D. Finally, when asking the participants' opinion whether they feel the framework will hold up in practice, all of the participants were sure that it would hold up.

In Conclusion, the overall flow of the framework is presented in Figure 4.2 in Chapter 4. Stage 1, the SSC initiation, final version is presented in Figure 6.11. Stage 2 and 3 in Figure 6.12. The final version of Stage 4 and 5 is presented in Figure 6.9 and the final Stage 6 and 7 is presented in Figure 5.5 of Chapter 5. Additionally, the full detailed version of the framework can be viewed in Appendix D in a chronological order.

6.7 Conclusion

Chapter 5 entailed the verification by case study and resulting adaptations to the smart sustainable urban infrastructure transition (SSUIT) framework developed from literature. This was done to test and refine the framework's content and design for its intended purpose. In this chapter the framework is validated by industry experts through the Delphi technique.

The review by the experts was used to test the academic data collected and synthesised whether it was feasible and aligns with reality of these projects. The results obtained and the response to the framework from

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different perspectives turned out to be mostly agreeable with each other, with critique, adaptations and additions being helpful to address vague, weak, impractical or vulnerable aspects in the framework as pointed out by the experts. Fortunately, the number of discrepancies was not very high, which might indicate that the frameworks and qualitative data used from the academic literature provided insights that were true and useful regarding real world challenges and success factors, as well as the structures used in synthesising an appropriate approach.

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Chapter 7

Discussion and Conclusion

The purpose of this chapter is to summarise the main findings in relation to the research aim and sub-objectives. The unique contribution and significance of the research is also discussed. Thereafter limitations of the study and suggestions for future work are provided. In Figure 7.1 the main research objective and its underpinning sub-objectives are distributed across three phases.

7.1 Research aims and findings

Smart sustainable cities are a new area addressing present and future urban concerns. This necessitates a socio-technical shift of infrastructure.

A systematic literature review is presented in Section 3.1 (Chapter 3) to establish what research is accessible, what has been done, and where the knowledge gap is. The present research does not offer a framework to guide large-scale infrastructure transition projects or long-term intervention

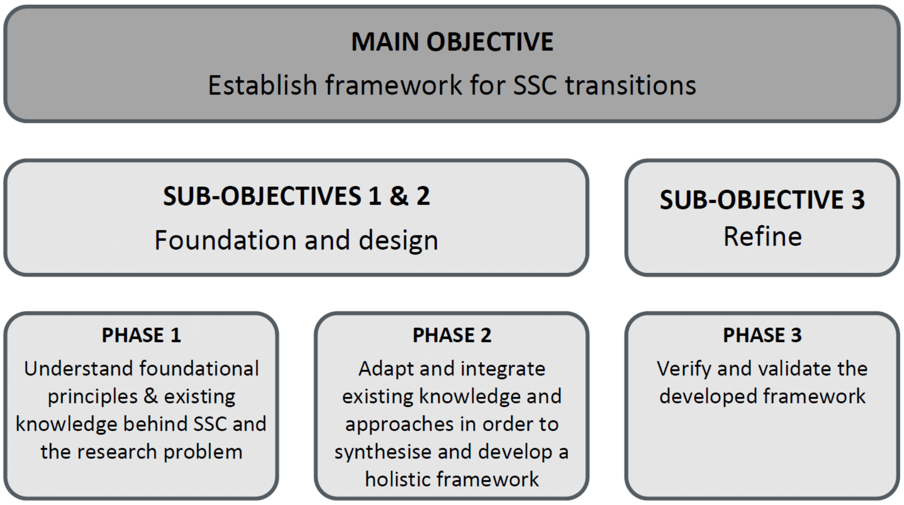

Figure 7.1: Approach followed during the research.

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programs to transform existing cities into smart sustainable cities. The objective of the research was then to develop such a conceptual framework for smart sustainable city transitions. An important point of intervention for transforming urban systems is infrastructure. The literature examined suggested that a systems-of-systems viewpoint is particularly appropriate for city contexts, infrastructure transformation and urban planning. In work by Ibrahim *et al.* (2018) a high-level transformation readiness roadmap for smart sustainable cities is featured, which highlights the essential stages. The results in Ibrahim *et al.* (2018) urge future research to build on the roadmap by establishing a transition framework for smart sustainable cities. Future research suggestions in Pereira and De Azambuja (2022) indicated that a more comprehensive and detailed guide or framework that is based on existing smart sustainable city roadmaps should be developed for the transitioning towards a smart sustainable city.

The conceptual literature study, which starts at Section 3.6 of Chapter 3, addresses sub-objectives one and two on foundation and design. This chapter covers several topics, some directly related to smart cities, sustainable cities, smart sustainable cities, and others indirectly related to these primary themes. These themes are meant to offer context for a city transition's nature and dynamics. This chapter provided a conceptual overview of relevant literature to the study challenge of transforming current cities into smart sustainable cities. To comprehend the study topic, multiple ideas, methodologies, and viewpoints must be researched and compared. The characteristics, technologies, distinctions, and flaws of the two urban development paradigms, smart cities and sustainable cities, were also separately investigated.

The methodology used throughout the study is described in Chapter 2. Sub-objective one and two include the framework's basis and design in two phases. Phase one includes understanding the research challenge and the underlying concepts of smart sustainable cities. In phase two, existing information and methodologies are adapted and integrated to create a complete framework. Phase three concerns the verification and validation of the established framework. This chapter described the research methodology used develop the framework from literature and existing frameworks; verification by descriptive analysis of a collective case study; and validation by expert review using the Delphi technique.

In Chapter 4 the framework is developed based on synthesising existing information, methodologies, concepts, and insights. The holistic framework based on literature focuses on infrastructure. The framework allows urban planners and local governments to plan and implement a holistic transition to a smart sustainable city. In the framework, there are seven stages: namely: 1.) pre-project preparation, 2.) teams, city state, readiness and assessment, 3.) project(s) identification and selection, 4.) design, 5.) implementation 6.) maintenance, evaluation, and innovation; and 7.) new initiatives and upgrades.

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The framework is then tested against a collective case study based on urban initiatives from nineteen smart and sustainable cities internationally, and the opinions of twenty-five international urban digitalisation experts from industry with diverse experience in city transformations. This is done to enhance the components and design of the framework, and adjust as necessary. From the case study analysis, in Chapter 5 twenty fundamental aspects for effective city transformation planning derived from the cases, were studied to extract the underlying requirements supporting the aspects. These requirements were compared to the framework, and by means of reflections, the manner in which the framework adheres to each requirement is described. This is to verify whether the framework is fit for its intended purpose. Adaptations were made where there were components lacking in the framework. The resulting verified framework satisfies the requirements and addresses the twenty fundamental aspects.

Validation of the framework is conducted in Chapter 6 to determine whether the framework is suitable for its application in practise. Using the Delphi technique, multidisciplinary industry experts examine and critique the framework. The feedback is used to modify the framework until the experts are satisfied with the final version.

It was made evident in the expert reviews that Stage 1 of the SSUIT framework had to be changed to better suit practice. A participatory sustainability planning approach, developed in the doctoral research of Fouché and Brent (2020), was found to be a suitable guide for the re-design of the pre-project planning stage, according to requirements determined from participant feedback during the expert review. The final feedback indicates that the experts are satisfied with the new Stage 1 design, and feel that the framework will be effective when applied in practise. The results from the verification and validation of the framework addresses the third sub-objective of the research, phase three. The final version of the SSUIT framework can be found in Appendix D.

7.2 Contributions and significance of the study

This research contributes to the current knowledge gap in literature about smart sustainable cities, and spurs further research regarding adapting cities in a smart sustainable way. The developed framework provides a holistic set of structured guidelines synthesised from existing knowledge and approaches in literature to guide and manage the smart sustainable city transitioning process in practice. The framework is intended to be used as a generic guideline useful to municipal or city council managers, city-planners, and project portfolio managers appointed to plan, direct, and manage the transition of an existing city towards a smart sustainable city. It can be adapted to align with the unique context and needs of the specific city it is applied to. The framework

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can be useful for single interventions as well due to its consideration for the greater context and existing systems that will also be impacted. Each stage can be used beneficially on its own but would have decreased results, as opposed to efforts based on using the framework from the start, depending on which aspects are overlooked or neglected from other stages.

The framework would be beneficial to governmental departments with regards to strategic planning at municipal level of hard and soft infrastructure, initiatives, policies, budgeting, partnerships and co-creation mechanisms. The framework directly contributes to South Africa's Integrated Development Planning (IDP) Local Government in South Africa (2015) by helping regional and national governments to be informed, develop visions, set objectives, for developing strategies and identifying projects for transitioning their cities towards smart sustainable cities. At a regional and national scale it is recommended that all cities involved try to align their planning with one another according to the guidelines of the framework to work purposively towards national development plans and international agendas and targets, e.g. climate change, carbon emissions and Sustainable Development Goals (SDGs).

By combining smart and sustainable cities their individual strengths can be incorporated so as to better solve many global urban challenges that have for long been unresolved. The concept of smart sustainable cities shows promise to help solve urban sustainability challenges and in doing so benefit the environment, cities and society at large. It can inform urban policy-making by providing insight with regard to developing policies that are effective and sustainable. The framework can aid urban and national governing of infrastructure so as to provide enhanced cities that are effective, equitable, safe, and offer an improved quality of life to their citizens.

Although the study is specific to smart sustainable cities, other studies regarding other urban concepts can also draw on the work done, and insights gathered to develop similar or complimentary research. The study also builds and directly addresses the future research suggested in Pereira and De Azambuja (2022) to use existing roadmaps to develop a more detailed and comprehensive guide or framework for transitioning towards smart sustainable cities.

Due to the vastness of the topic and its related aspects, it shows promise to develop into a wing of research on its own that may be established as a division for new urban management research with multi-disciplinary points of departure and inter-departmental collaboration.

Engineering consultants will be able to utilise the tool to evaluate and develop infrastructure solutions that, not only contribute to the greater goal of a smart sustainable city, but are integrated with the combined efforts of various stakeholders, sectors and departments to improve the collective success of initiatives overall. By transforming a city in such way, a favourable environment for new opportunities and innovations is created by means of

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co-creation, inclusivity, interoperability and accessibility.

The multi-disciplinarity of the research is also another means in which the study was pioneering and challenging. It addresses a topic that is rapidly developing and advancing in industry, and is lacking research. It fills a significant void in the representation of knowledge offered from academia on the subject and will encourage future work to be produced by providing a base of existing research on which can be built. It serves as a common departure point for discussion and cross-pollination between different disciplines regarding various aspects important to transitioning cities in the future. This invites new curiosity, interaction and knowledge across a wide reach.

7.3 Limitations of the study

Transitions in urban infrastructure are really vast in scope and take years or even decades to complete. Due to the complexity of urban systems, interventions have cascading consequences that are difficult to foresee. It would be impossible to completely apply the framework and analyse its long-term implications in this study. As a result of the investigation, a general conceptual framework is produced. It is essential to remember that each city is unique and has distinct criteria. It is suggested that the framework be seen as a guide and that it be customized to match the unique environment and requirements of each city.

Knowledge in the smart sustainable cities domain has not yet reached a mature state, as it has only recently gained attention and development from industry and academia and is still growing and expanding for the time to come. It is unlikely that the current principles, technologies, practices and indicators for smart sustainable cities will remain exactly as it is. The framework contains activities such as benchmarking, evaluation and assessment, but these tools themselves (e.g. indicators, ranking, standards, policies, best practice) are not static and evolve, improve and adjust over time as knowledge systems on smart sustainable cities progress with time. The framework serves the purpose of guiding planning, implementation and management on a strategic level, and many activities, approaches and tools involved in the transition process serve a supportive role to this function. It is likely, and expected, that many activities, standards and tools in industry will vary or change in some way. Yet the awareness of smart sustainable cities as systems-of-systems that are complex and adaptive still remains a key perspective valuable to planning and implementing smart sustainable infrastructure transitions. The fundamental structure and purpose of the framework allows for these adaptations or variations of sub-components or activities. Suggestions or examples of tools or approaches mentioned are not intended as an absolute choice, and each city must determine which options, examples and solutions are most relevant or suitable for their specific context and needs, or use the newest approved best

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practise applicable at the time.

Urban planning is not the central focus or perspective for this study, as the research gap stems from a disconnect between complex engineering projects within a dynamic socio-economic setting, despite the presence of urban design theory as a foundational pillar. For this research it is therefore assumed and implied that cities should practice sound, context-appropriate and up-to-date urban design and development practices, while bearing in mind the guidance regarding smart sustainable city transformations that is useful from this research. This limitation in the scope of the study narrows the vastness of the research problem to specific research perspectives namely, engineering management of urban socio-technical systems with smart sustainability as its aim.

There is an opportunity for future research to broaden the study by amalgamating the findings from this engineering management study and building forth on it within urban planning to create a stronger body of knowledge that continues to refine and improve. This study as a stand-alone research piece is not propagated as an al-encompassing knowledge source or sufficient from all perspectives and fields of study. Rather, it is a boundaried exploration and appropriated solution from certain perspective using limited resources, and serves as a stepping stone and catalyst for further interaction, iteration, refinement and expansion within a very complex and vast collection of questions and challenges that deserves attention for a valid societal purpose, namely, improving the place within which we exist with purpose and care.

7.4 Future research

It is suggested that future research could contribute by further evaluating and refining the usability of the framework by subjecting it to review or in-field testing with municipal and public officials who would benefit from the use of the framework for urban development. For this research study the focus was more on using expertise that is not traditionally directly involved in urban transition planning, due to vertical and horizontal silo phenomena. The expertise is valuable due to these inputs lacking in current planning, and is apparent when reviewing the main challenges and barriers experienced in previous projects. These gaps in knowledge mostly become apparent when viewing historic performance of interventions and systems, usually drawing attention due to technical or social complications arising from operation as time progresses.

Future research is encouraged from various fields to refine aspects of the framework, such as financing to support the planning and feasibility of smart sustainable city projects, as well as adequate technology and asset management practices for smart sustainable cities. Other priority areas that require further

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research and development to pave the way for smart sustainable cities are as follows:

- Integration, intermediaries and communication management: It is important that technical design and implementation of hard infrastructure is integrated with policy design as soft infrastructure. Engineers of systems must provide operation and asset management guidelines that should be communicated effectively to those involved with policy and regulation design, management, finance and occupant education to ensure that the systems function adequately and in a cost-effective manner.

- Significance of Industry 4.0 on urban metabolism and the tracking of material flows in smart sustainable cities. The integrated nature of Industry 4.0 allows to potentially better track material flows in cities. A brief search on Scopus showed that the combination of these keywords is under-represented to date, with a lack of any academic articles and the potential of a research study.

Other opportunities also include:

- The development of universal ICT standards to be interoperable and cross-compatible amongst various platforms, infrastructures and applications to allow seamless transmission and use of data and simplified integration and collaboration. This also reduces barriers for the emergence of economic ecosystems supported and stimulated by the availability and workability of data and information.

- Education and skill reform for the change in work landscape and skill requirements brought forth by smart sustainable cities.

- Accelerated development and availability of security protocols and up-to date best practices that can be implemented and disseminated swiftly to all systems and infrastructures globally to reduce and control vulnerability. It is also important that digitalisation does not reduce transparency and trust, therefore protocols that ensure integrity, authenticity, as well as prevent manipulation and corruption of data and information, would be of great value to society. Digitalisation should not be enforced in a manner that divides, excludes or controls society, but creates opportunities, greater access to information, freedom for creativity and innovation, a medium for collaboration and unification.

- Consulting and education of stakeholders regarding SSC is an important part of designing and implementing a purposeful and successful SSC project. More research is encouraged regarding misconceptions, critical success factors, project challenges and stumbling blocks, integration and

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communication. This is important, because if stakeholders do not have an adequate understanding of the complexities related to SSC projects, they will not understand, support, implement and maintain the needed protocol and design principles. Lack of knowledge could be a source of vulnerability to manipulation that does not have the well-being of the city as its main priority or driver.

- There is still work to be done on smart sustainable city indicators and benchmarking methods. To date the only system that fully focuses on ranking a smart sustainable city is the 'Lisbon ranking for smart sustainable cities in Europe' in Akande *et al.* (2019), but the ranking systems only focuses on the 3 pillars of sustainability and not the 5 pillars of smart sustainable cities, leaving out the urban infrastructure and governance pillars.

7.5 Conclusion

Smart cities and sustainable cities are fundamentally two distinct types of cities. In this research commonalities between smart cities and sustainable cities were identified, focusing on the amalgamation of the concepts known as smart sustainable cities and how existing cities can be transitioned. Urban infrastructure was identified as a point of intervention when transitioning a city to become smart sustainable. Current methodologies and approaches for city and infrastructure transformation were examined in order to derive knowledge, needs and principles for designing a conceptual framework to transition a city to become smart sustainable.

Insights from a literature review were incorporated to synthesise the framework. Verification against a current city case study and two collective case studies revealed a few adaptations that were applied in order to ensure appropriate design for purpose. Validation by industry expert review provided feedback on the adequacy of the framework, and recommended adaptations in order to be suitable for real-world application. The final framework was deemed suitable by the experts for guiding effective transitioning towards smart sustainable cities. The framework allows urban planners and local governments to plan and implement a holistic transition to a smart sustainable city. It directly contributes to South Africa's Integrated Development Planning (IDP) by helping regional and national governments to be informed, develop visions, set objectives, for developing strategies and identifying projects for transitioning their cities towards smart sustainable cities. The study also addresses and builds on the future research suggested in Pereira and De Azambuja (2022) to utilise existing roadmaps and develop a more detailed and comprehensive framework or guide for transitioning towards smart sustainable cities.

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A few areas of discernment regarding broader challenges faced in transitioning existing cities to smart, sustainable, or smart sustainable cities can be identified as follows regardless of the framework. The adoption and integration of the developed framework is determined by 'buy-in' from role players at the top. To propel the necessary transition, requires political will as visionary leadership has limited leverage. In addition, increased cooperation between agencies cannot be overstated as instrument to change. A mindset ingrained in short term thinking, and aversion towards accepting change hinders the process of transformation, as people are an integral part of city dynamics. Budget limitation is another overarching challenge which largely determines the specifics of a transformation and its scale.

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Appendices

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Appendix A

Rating and ranking

A.1 Indicators for smart sustainable cities

The thirty-two indicators used in Akande *et al.* (2019) for ranking smart sustainable cities in the European Union is presented in Table A.1 to Table A.5:

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Table A.1: Smart sustainable city rating indicators (Akande *et al.*, 2019).

Indicator		Topic	Thematic Area	Interpretation	Description of role
Household level of internet access (%)	V1	Infrastructure	Economy	$\frac{Number\ of\ households\ with\ internet\ access}{Total\ number\ of\ households} * 100$	The internet plays a positive role in the economic growth of a city which is a key determinant of how smart and sustainable a city is (Choi & Hoon Yi, 2009). Data on this indicator is widely available with relative long time series.
Total Research and Development (R&D) appropriations (Euro per inhabitant)	V2	Innovation	Economy	$\frac{Total\ R\&D\ appropriations}{Total\ population\ of\ the\ city}$	The amount of money being funnelled into research and development is a key indicator of commercial and technological innovation.
Patent applications to the European Patent Office (EPO) per million of active population	V3	Innovation	Economy	$\frac{Number\ of\ new\ patent\ application}{One\ millionth\ of\ the\ city's\ total\ population}$	This indicator shows how active the research community is. Research spurs innovation which has a positive effect on the economy
Persons employed between the ages of 20 and 64 (%)	V4	Employment	Economy	$\frac{Number\ of\ persons\ between\ 20\ and\ 64\ years\ of\ age\ emplyed}{Total\ number\ of\ population\ between\ 20\ and\ 64\ years\ of\ age} * 100$	This indicator shows how engaged the economically active population of a city is. It also reflects the economic health of the city and how successful its economic policy is (ISO, 2014b).
E-commerce, Customer Relation Management (CRM), and secure transactions (%)	V5	ICT / Trade	Economy	$\frac{Enterprises\ that\ receive\ orders\ via\ computer\ mediated\ networks}{Total\ number\ of\ enterprises} * 100$	This is variable indicates the volume of "smart-trade" occurring in a city which in turn helps to shape the economy of that city.
Share of journeys to work by public transport (rail, metro, bus, tram) (%)	V6	Infrastructure	Economy	$\frac{Transport\ to\ work\ using\ public\ transport}{Transport\ to\ work\ using\ public\ and\ private\ transport} * 100\%$	This indicator reflects how strong the sharing economy is and shows of how diverse the transportation system in a city is.
Length of bicycle network (dedicated cycle paths and lanes) (km)	V7	Infrastructure	Economy	$\sum Length\ of\ dedicated\ bicylce\ paths$	Extensive bicycle paths help to reduce traffic congestion and contributes to better quality within cities. Economic benefits include reduced health care costs and reduced expenditure on fossil fuel (ISO, 2014b).

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Table A.2: Smart sustainable city rating indicators (Akande *et al.*, 2019).

Indicator		Topic	Thematic Area	Interpretation	Description of role
Number of days particulate matter PM10 concentrations exceed 50 µg/m³	V8	Air quality	Environment	$\sum \frac{Days\ where\ PM10\ concentration\ exceeds}{50\mu g/m3}$	This is a measure of the long-term exposure to PM10. High particle levels exposure has been linked with the development of chronic bronchitis and premature deaths in babies. Beyond environmental implications, this indicator also has economic impact on businesses as it reduces foreign investment.
Annual average concentration of NO_2(µg/m³)	V9	Air quality	Environment	$\frac{NO_2\ Daily\ Concentration}{365}$	Nitrogen Dioxide (NO_2) is a key indicator of air quality with significant implication on human health and the environment. Specifically, it contributes to the formation of acidic rain which adversely affects biodiversity and the formation of photochemical smog which leads to various respiratory diseases (ISO, 2014b).
Greenhouse gas (GHG) emissions from transport (million tonnes)	V10	Air quality	Environment	$\sum GHG\ (equivalent\ carbon\ dioxide\ units)\ generated\ over\ a\ year\ by\ transport\ activites\ within\ a\ city$	GHG are gases in the atmosphere that trap heat that would otherwise escape back into space. Hence, they contribute to the warming of our planet and is a key climate change indicator. Only three gases are relevant in the context of transport (Carbon dioxide, methane and nitrous oxide) and these have been aggregated according to their global warming potentials (ISO, 2014b).
Annual average concentration of PM10 (µg/m³)	V11	Air quality	Environment	$\frac{Total\ mass\ of\ collected\ particles > 2.5\mu m\ and \leq 10\mu m}{Volume\ of\ air\ sampled}$	PM10 is primarily created by incomplete combustion, automobile emission, dust and cooking. PM10 is a health concern because they can be inhaled into the respiratory system leading to various heart and lung diseases (ISO, 2014b; Janssen et al., 2011).

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Table A.3: Smart sustainable city rating indicators (Akande *et al.*, 2019).

Indicator		Topic	Thematic Area	Interpretation	Description of role
Share of the urban waste water load (in population equivalents) treated according to the applicable standard (%)	V12	Water	Environment	$\frac{\text{Perentage of city's waste water receiving treatment}}{\text{Total amount of waste water and collected produced in the city}} * 100$	This indicates how well water is managed in a city. Properly managed and treated water system helps to reduce the number of water-borne disease, improving community health. Treating waste water to the point of reuse is also good for the environment (ISO, 2014b).
Proportion of population living in households considering that they suffer from noise (%)	V13	Noise	Environment	$\frac{\text{Population who declare that they are affected by noise}}{\text{Total population}}$	Prolonged exposure to noise can lead to physical and mental health problems. It is also a good indicator for environmental comfort.
Share of solid waste recycled (%)	V14	Environmental quality	Environment	$\frac{\text{Total amount of recycled city's solid waste}}{\text{Total amount of generated city's solid waste}} * 100\%$	City's often generate more waste than they recycle. Solid waste has several implications on the environment, public health and the local economy. However, its proper management presents an opportunity to the circular economy, generating recycling micro-economies and feeding into the alternative energy stream (ISO, 2014b).
This city is a clean city: strongly agree (%)	V15	Environmental quality	Environment	$\frac{\text{Total number of persons that consider the city clean}}{\text{Total number of person surveyed}} * 100\%$	This is obtained as a result of a perception survey. The cleanliness of a city improves the quality of life of citizens.
Share of land dedicated to green urban areas, sports, and leisure facilities (%)	V16	Environmental quality	Environment	$\frac{\text{Total area of land in a city for green space, sports and leisure facilities}}{\text{Total area of land in a city}} * 100\%$	Green spaces, sports and leisure facilities play important roles in the environment and the social fabric of a city. Green spaces help to capture atmospheric pollutants. Sports and leisure facilities serve as recreational facilities improving the quality of life of citizens (ISO, 2014b).
Protected terrestrial area (%)	V17	Biodiversity	Environment	$\frac{\text{Total area of landed designated as protected natual ares}}{\text{Total area of land in a city}} * 100\%$	This indicator is important because urbanization negatively affects biodiversity through urban sprawl and the spread of non-native species (ISO, 2014b). This in turn threatens the ecological balance of our planet

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Table A.4: Smart sustainable city rating indicators (Akande *et al.*, 2019).

Indicator		Topic	Thematic Area	Interpretation	Description of role
Share of renewable energy in gross final energy consumption (%)	V18	Energy	Environment	$\frac{Total\ consumption\ of\ electricity\ generated\ from\ renewable\ sources}{Total\ energy\ consumption}$	Sustainable urban development requires a shift from fossil-based energy sources to renewable energy sources. Hence, this indicator is important for environmental protection.
Electricity generated from renewable sources (%)	V19	Energy	Environment	$A = \frac{Electricty\ from\ renewable\ energy\ sources}{Total\ electricity\ generation\ (renewable\ and\ fosil\ based\ sources)} * 100$ πr^2	Electricity produced from renewable energy sources comprises the electricity generation from hydro plants, wind, solar, geothermal and biomass/wastes. It indicates growth in the use of sustainable energy sources. It is a core UNEP (United Nations Environment Programme) indicator and considered to be reliable (OECD, 2009).
Persons aged 25-64 with ISCED level 5, 6, 7, or 8 as the highest level of education (%)	V20	Education	Society and Culture	$\frac{Number\ of\ persons\ aged\ 25-64\ with\ ISCED\ level\ 5,6,7\ or\ 8\ as\ the\ highest\ education}{Total\ number\ of\ persons\ aged\ 25-64} * 100$	Wide spread education is an important component of sustainable human development (UNESCO, 2018). This indicator measures the pervasiveness of tertiary education among the citizens in cities
Share of students in higher education in the total population (per 1000 persons) (%)	V21	Education	Society and Culture	$\frac{Number\ of\ citizens\ holding\ higher\ education\ degrees}{one\ 1000th\ of\ the\ city's\ total\ population} * 100$	Education is one of the main opportunities for social class mobility. Hence, it is a primary indicator for economic development and quality of life (ISO, 2014b).
Infant mortality rate (per 1000 live births)	V22	Health	Society and Culture	$\frac{Number\ of\ infants\ that\ die\ before\ the\ age\ of\ 5\ in\ a\ year}{Every\ 1000\ live\ births\ in\ same\ year}$	Infant mortality rate is a leading indicator of the level of child health and the socioeconomic development of a city (United Nations, 2014).
Share of total deaths per year (%)	V23	Health	Society and Culture	$\frac{Number\ of\ deaths\ from\ medical\ cause}{Total\ number\ of\ deaths} * 100$	This is a primary indicator of the state of health care in a city
Index of the number of serious accidents at work per 100,000 persons in employment	V24	Safety	Society and Culture	$\frac{Number\ of\ persons\ involved\ in\ accidents}{Number\ of\ persons\ in\ employment} * 100\%$	This is a primary indicator of health and safety at work. The data refers to accidents at work resulting in more than 3 days' absence from work.

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Table A.5: Smart sustainable city rating indicators (Akande *et al.*, 2019).

Indicator		Topic	Thematic Area	Interpretation	Description of role
share of murders and violent deaths (%)	V25	Safety	Society and Culture	$\frac{Number\ of\ reported\ murders\ and\ violent\ deaths}{Total\ number\ of\ persons\ in\ city} * 100$	This is an indicator for the number of crimes in a city which can affect the feeling of safety by citizens (ISO, 2014b).
Children accessing inappropriate web-sites (%)	V26	Safety	Society and Culture	$\frac{Number\ of\ children\ accessing\ inappropriate\ websites}{Total\ number\ of\ children} * 100$	This is an indicator of the safety of children in the information age. Accessing inappropriate sites can lead to unlawful and dangerous behaviours which can cause a breakdown in the society.
Severe housing deprivation rate by tenure status (%)	V27	Housing	Society and Culture	$\frac{Number\ of\ houses\ that\ exist\ without\ registered\ titles}{Total\ number\ of\ households} * 100$	This is an important indicator for housing security for city residents. This can also serve as a secondary indicator for identifying formal parts of the city from the less formal parts (ISO, 2014b).
Number of public libraries (all distribution points)	V28	Culture	Society and Culture	A count of the number of public libraries in a city	This indicates the amount of public access to information. Libraries also serve as a neutral space for community engagement and recreational activity. Hence they are very important for social inclusion and development.
Number of theatres	V29	Culture	Society and Culture	A count of the number of theatres in a city	Theatres are very important to the social and cultural fabric of any city. This is because the participation of people in local cultural activates improves their quality of life (Duxbury, Hosagrahar, & Pascual, 2016).
Gender pay gap in unadjusted form (%)	V30	Inclusion	Society and Culture	$\frac{Gross\ hourly\ earnings\ of\ (male\ employees - female\ employees)}{Average\ gross\ hourly\ earning\ of\ male\ employees} * 100$	This indicator is key to the United Nations 5th Sustainable Development Goals (SDG) – Achieve gender equality and empower all women and girls.
Voter turnout in national and EU parliamentary elections (%)	V31	Inclusion	Society and Culture	$\frac{Number\ of\ persons\ that\ voted\ in\ national\ and\ EU\ elections}{City\ population\ eligible\ to\ vote} *100$	The electorate turn-out at elections is an indicator of the public participation and interest in policy formulation and community development (ISO, 2014b).
Gini coefficient of equivalized disposable income (%)	V32	Inclusion	Society and Culture	"This is calculated by plotting the cumulative income share on the vertical axis against the distribution of the population on the horizontal axis, thus obtaining a so-called Lorenz curve. The Gini coefficient is then calculated as the area under the curve divided by the area under the Lorenz curve of an equal distribution of income" (Feldmann, 2008)	This is an indicator of income equality distribution within a city. This is related to societal sustainability as income inequality leads to a rise in social vices such as robbery, homicide and imprisonment (Little & Green, 2009).

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Appendix B

Verification case study

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Table B.1: Cities and initiatives that form part of the case studies involved.

Cases	Initiatives
The Netherlands,	Smart energy, water, waste, mobility, governance, education, circular city, citizens and living.
Rotterdam	Roadmap Next Economy, Rotterdam Port.
The Hague	Municipality and Statistics Netherlands (CBS) collaborate in the Urban Data Centre (UDC), uses available data to promote effective policy planning.
Amsterdam	Smart Work Center, Amsterdam Smart City ecosystem.
Denmark, Copenhagen	DOLL (smart city living lab), Smart Solutions Lab, Streetlab, Connecting Copenhagen, smart city initiatives.
Aarhus	Smart Aarhus project, effective and sustainable solutions to urban life challenges.
South Korea,	Smart Work Strategy, 500 Smart Work Centres.
Seoul	Ecube smart waste monitoring system.
Songdo	New greenfield city.
UAE,	UAE Happiness Agenda.
Abu Dhabi	Masdar City, promotes clean energy usage.
Dubai	Government runs at least one service on blockchain within each department.
Singapore, Funan	Smart Nation Digital Government Office (SNDGO), drives e-governance and manages Smart Nation projects.
Sweden,	Roadmap Next eEconomy initiative.
Stokholm	STOKAB dark fiber initiative.
Spain, Barcelona	Digitalisation of parking, waste, mobility and security by Cisco, 39 projects under Digital Transformation, -Innovation and -Empowerment.
Bahrain	Bahrain Vision 2030.
Qatar, Doha	Education City, development central to knowledge and research facilities.
Saudi-Arabia	Neom city, Vision 2030.
Canada, Quebec	Sherbrooke Innopole, economic development organisation providing free support to industrial and technological sector entrepreneurs.
USA, Illinois, 'New Athens'	Aspire Air, city utilising Living Lab to design and adapt solution to air pollution.
San Francisco	Municipality successfully initiated entrepreneur / start-up in-residence program.
France, Paris	Smart Work Center (SWC), Grand Paris special economic zone participation in Roadmap Next Economy initiative.

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Inputs from twenty-five industry leaders interviewed as part of the work in Boorsma (2017), which determined a set of fundamental community digitalisation guidelines for the successful implementation of smart cities, is listed by name and company at the time of interview:

1. John Chambers, Executive Chairman, Cisco
2. John Baekelmans, Managing Director and Vice President, IMEC
3. Ger Baron - CTO, City of Amsterdam
4. Jesse Berst, Founder and Chairman, Smart Cities Council
5. Hardik Bhatt - Chief Digital Officer and Secretary, Innovation & Technology, State of Illinois
6. Niels Carsten Bluhme, Technical Director, City of Albertslund (Greater Copenhagen), Denmark
7. Phillip Bouteiller, CEO of Tegel Project, Berlin, Germany
8. Robert Elbrink - Strategy Director, City of Eindhoven, the Netherlands
9. Wim Elfrink, Private Investor and Former Executive Vice President at Cisco
10. Gordon Feller, Founder, MeetingoftheMinds.org, San Francisco, California
11. Roberta Gamble, Partner and Vice President, Energy & Environment, Frost & Sullivan
12. Raffaele Gareri, Deputy Secretary General and Chief Digital Officer, Province of Brescia, Italy
13. Carsten Kølbek, Co-founder of Rainmaking and Startupbootcamp
14. Poul Erik Lauridsen, CEO of Gate21, Denmark
15. Gerd Leonhard, author of 'Technology vs. Humanity: The Coming Clash Between Man and Machine'
16. Scott Mauvais, Director, Technology & Civic Innovation, Microsoft
17. Anil Menon, Senior Vice President, Smart+Connnected Communities, Cisco
18. Teppo Rantanen, Executive Director, Growth, Innovation and Competitiveness, City of Tampere, Finland

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19. Dr. Jonathan Reichental, Chief Information Officer, City of Palo Alto, California

20. Óskar J. Sandholt, Director, the City of Reykjavik, Iceland

21. Martin Stewart-Weeks, Community Digitalization Thought Leader, and Independent Consultant

22. Chris Vein, Partner at PwC, Former Deputy US CTO, Obama White House, and Former CIO for San Francisco

23. Nicola Villa, Vice President and Executive Partner, Global Government Industry, IBM

24. Antoni Vives, Former Deputy Mayor of Barcelona, CEO at City Transformation Agency

25. Willen van Winden, Professor of Urban Economic Innovation, Amsterdam University of Applied Sciences

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Appendix C

Detailed Framework

In this appendix, detailed framework diagrams are provided for the smart sustainable city transformation frameworks in Chapter 4, 5 and 6. Diagrams of the framework stages in Chapter 4, 5 and 6 are shortened versions of the diagrams in this appendix. The overall flow of the framework's stages is provided in Figure C.1 (also presented in Section ??, Chapter 4).

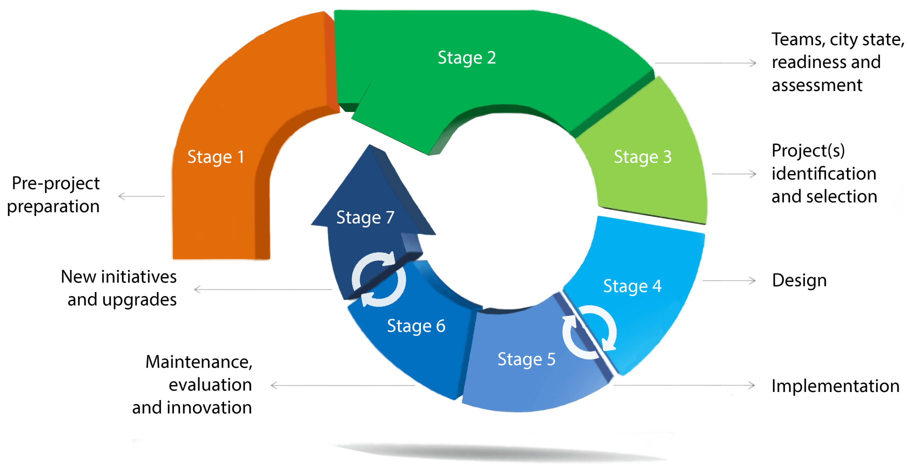

Figure C.1: The framework's overall flow of stages (see Section 4.1, Chapter 4).

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C.1 Conceptual framework

Provided are the detailed stage diagrams for the conceptual framework:

Figure C.2: Stage 1 Pre-project preparation;

Figure C.3: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure C.4: Stage 4 (Design) and Stage 5 (Implementations); and

Figure C.5: Stage 6 (Maintenance, evaluation and innovation) and Stage 7 (New initiatives and upgrades).

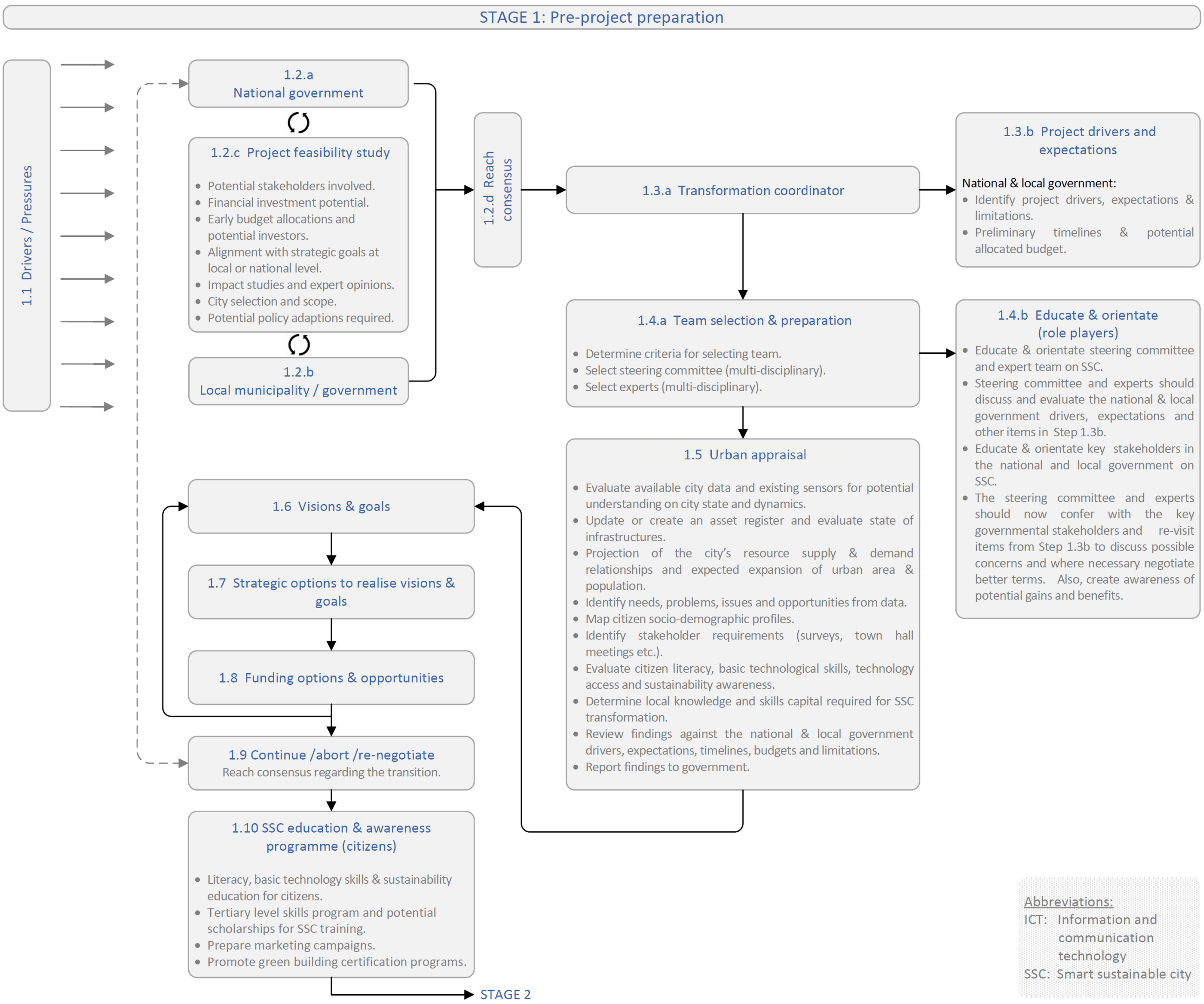

Figure C.2: Detailed pre-project preparation as Stage 1 of the framework.

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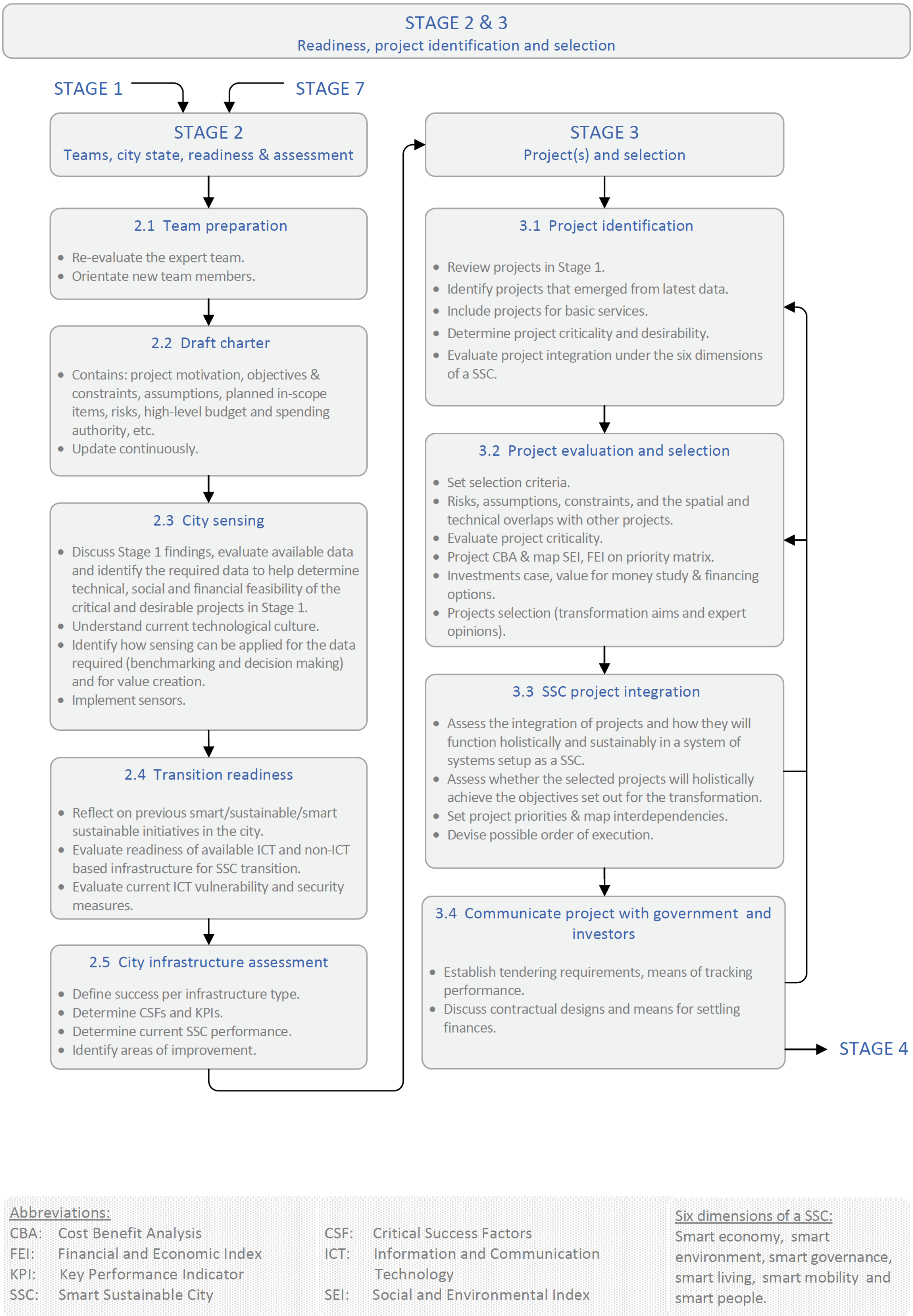

Figure C.3: Detailed Stages 2 and 3 of the developed framework.

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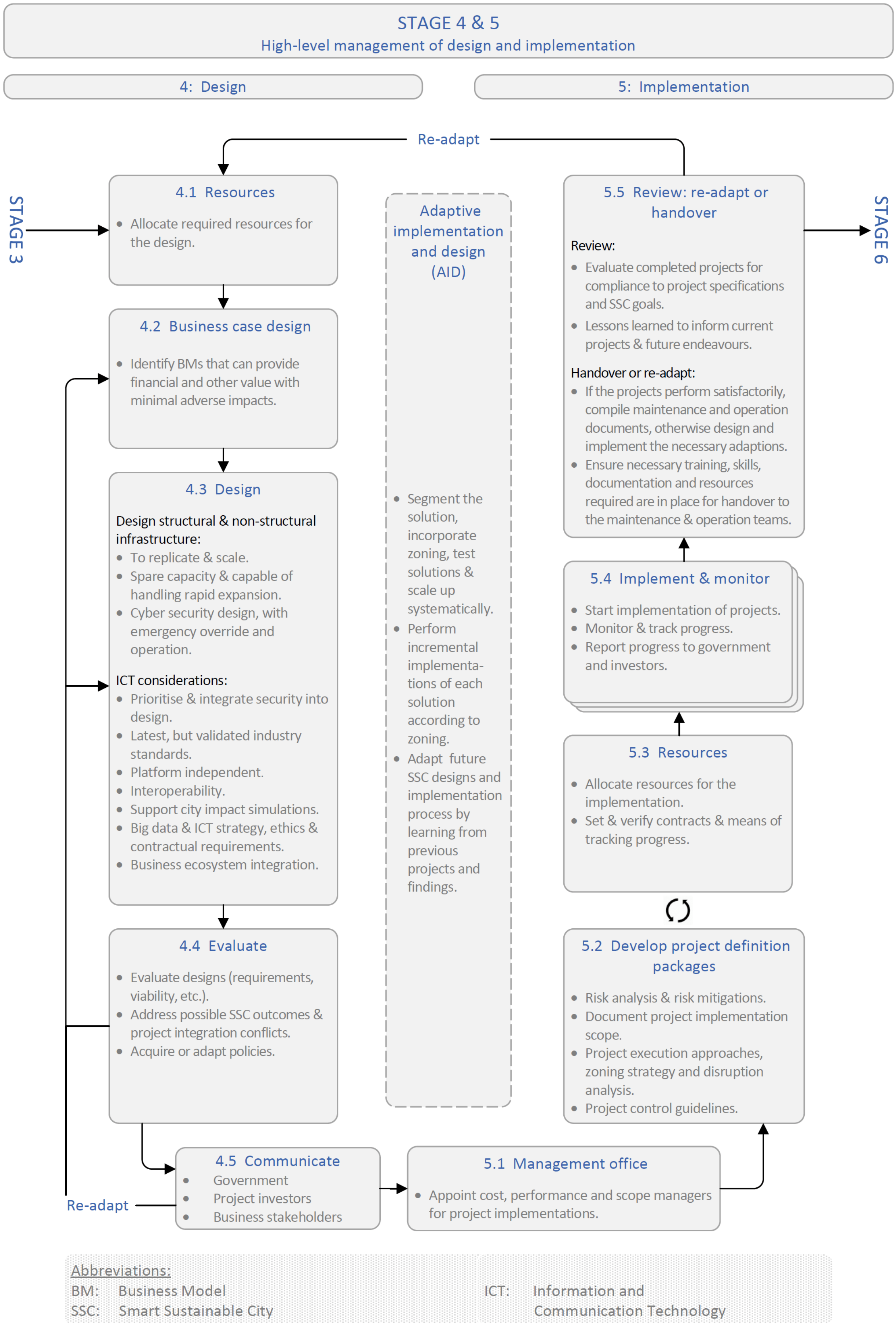

Figure C.4: Detailed Stages 4 and 5 of the developed framework.

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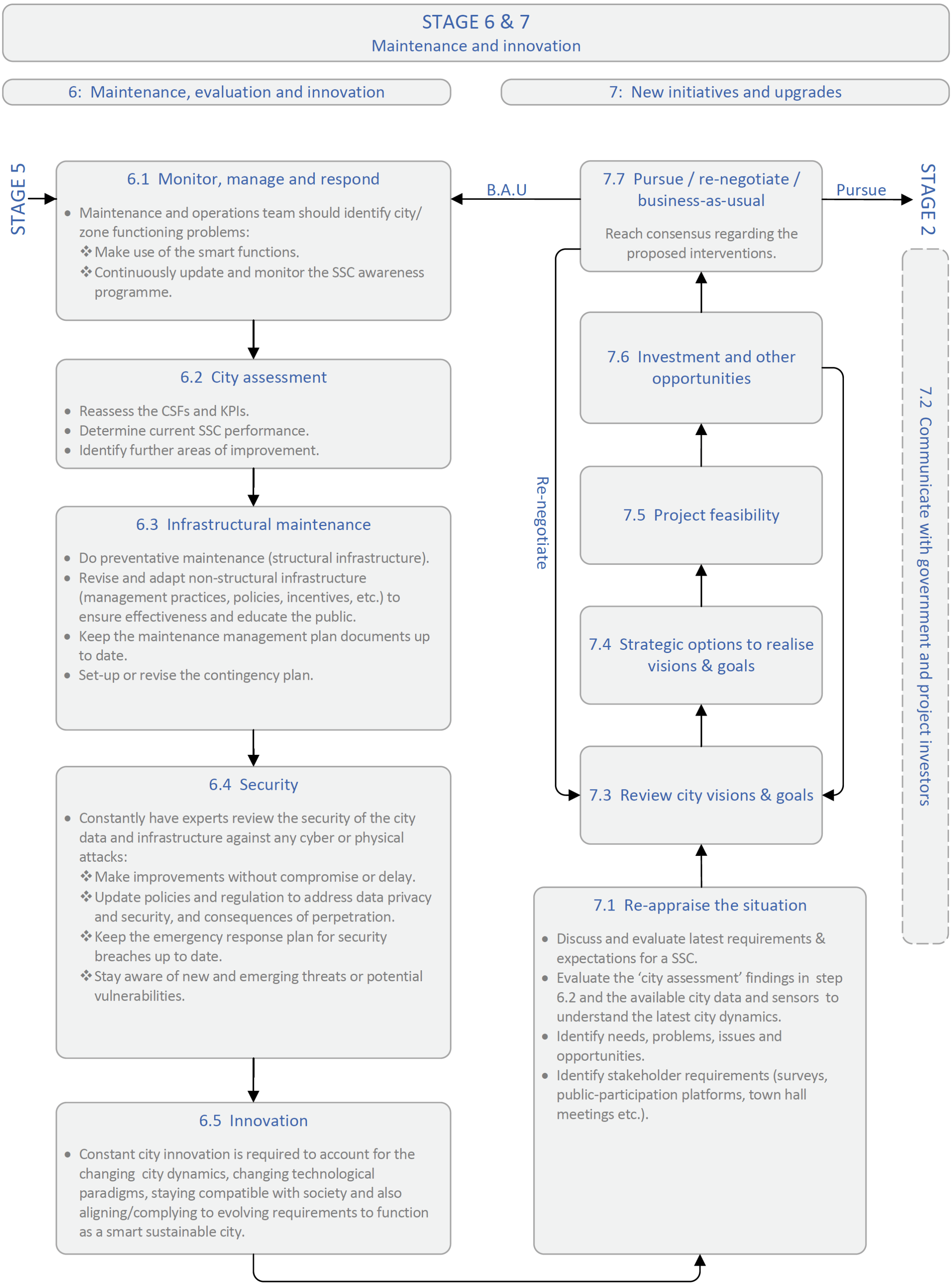

Abbreviations:
B.A.U: Business As Usual
ICT: Information and Communication Technology
CSF: Critical Success Factors
KPI: Key Performance Indicator
SSC: Smart Sustainable City

Figure C.5: Detailed Stages 6 and 7 of the developed framework.

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C.2 Verified framework

Provided are the detailed stage diagrams for the verified framework:

Figure C.6: Stage 1 Pre-project preparation;

Figure C.7: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure C.8: Stage 4 (Design) and Stage 5 (Implementations); and

Figure C.9: Stage 6 (Maintenance, evaluation and innovation) and Stage 7 (New initiatives and upgrades).

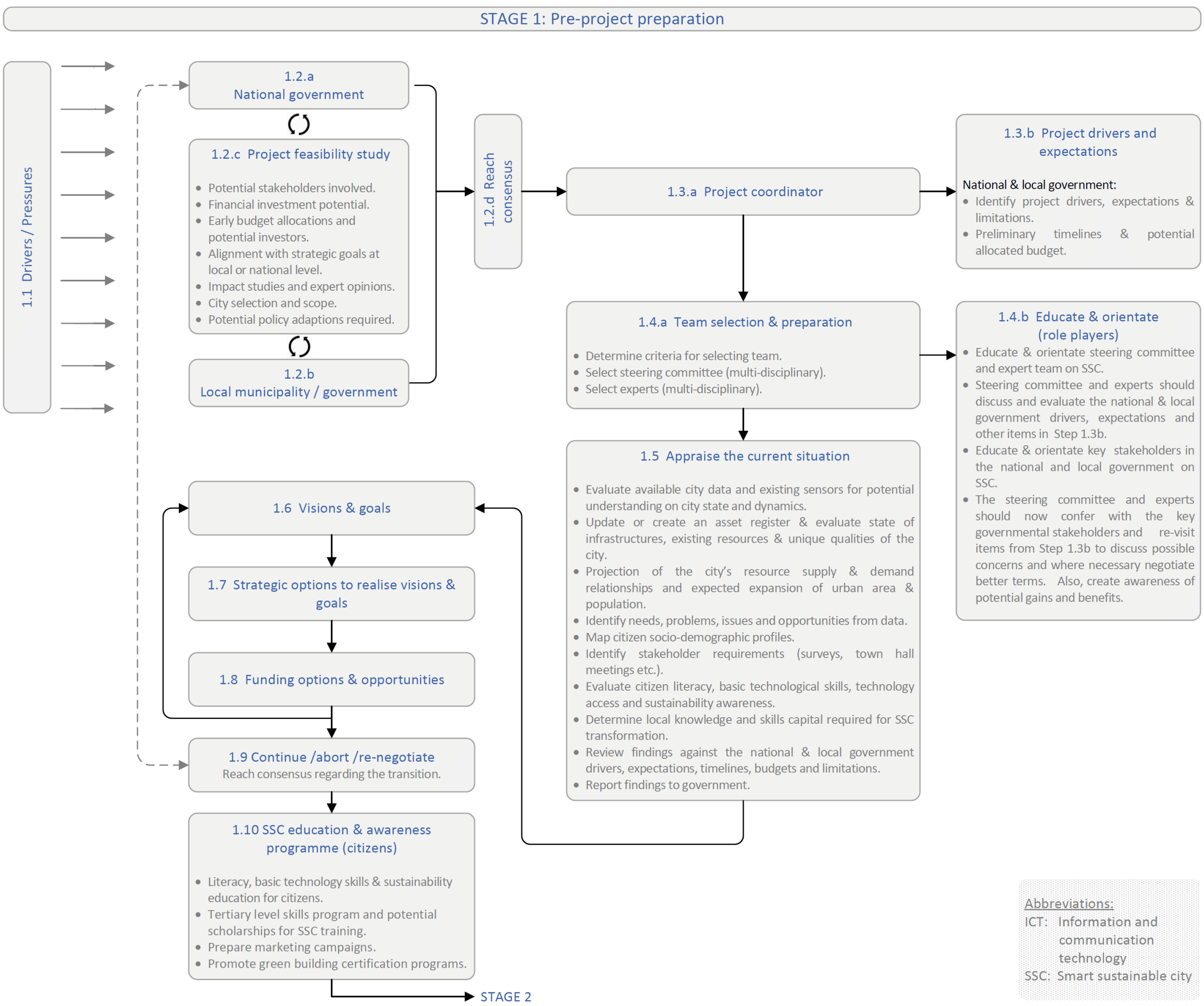

Figure C.6: Detailed pre-project preparation as Stage 1 of the verified framework.

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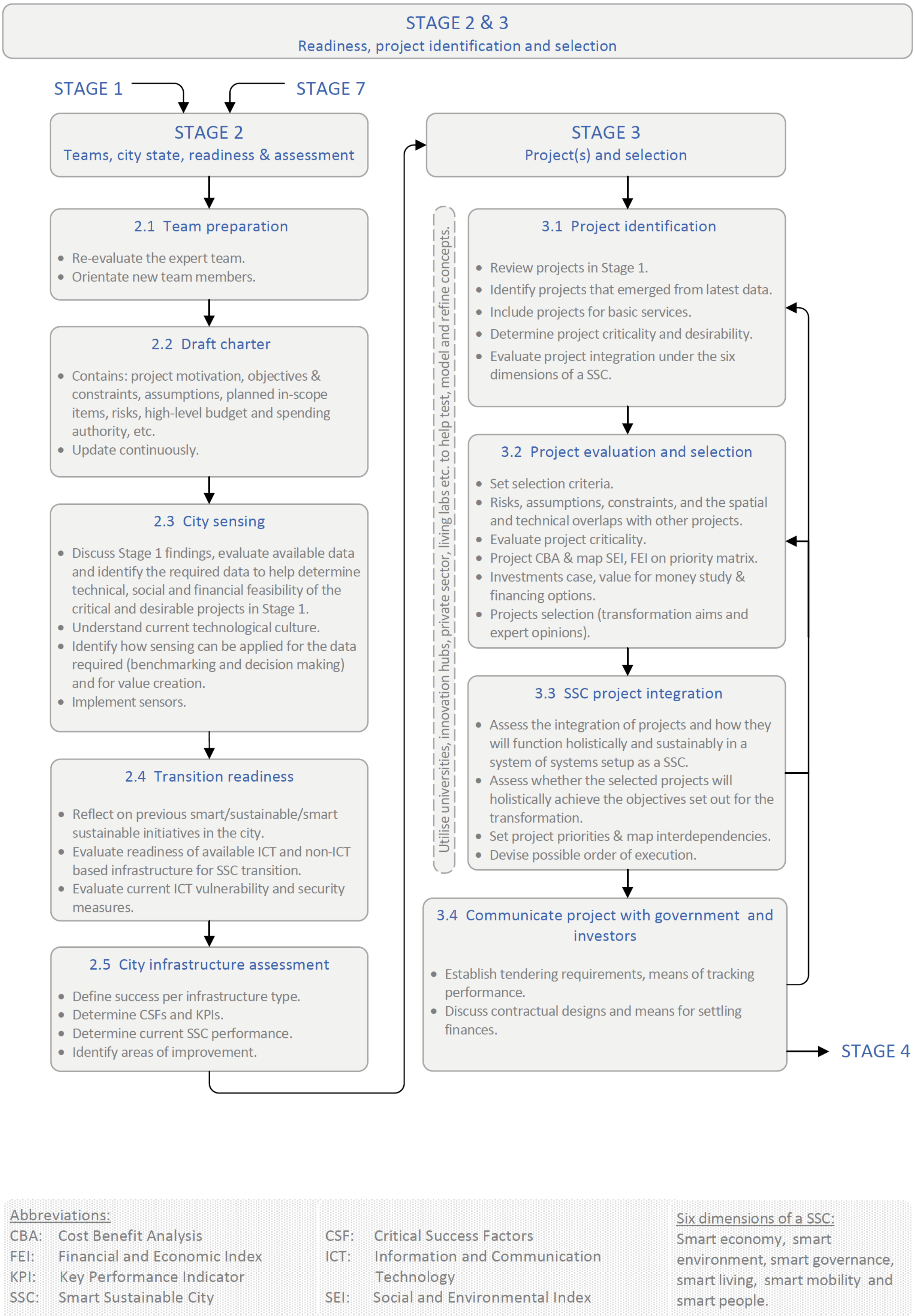

Figure C.7: Detailed Stages 2 and 3 of the verified framework.

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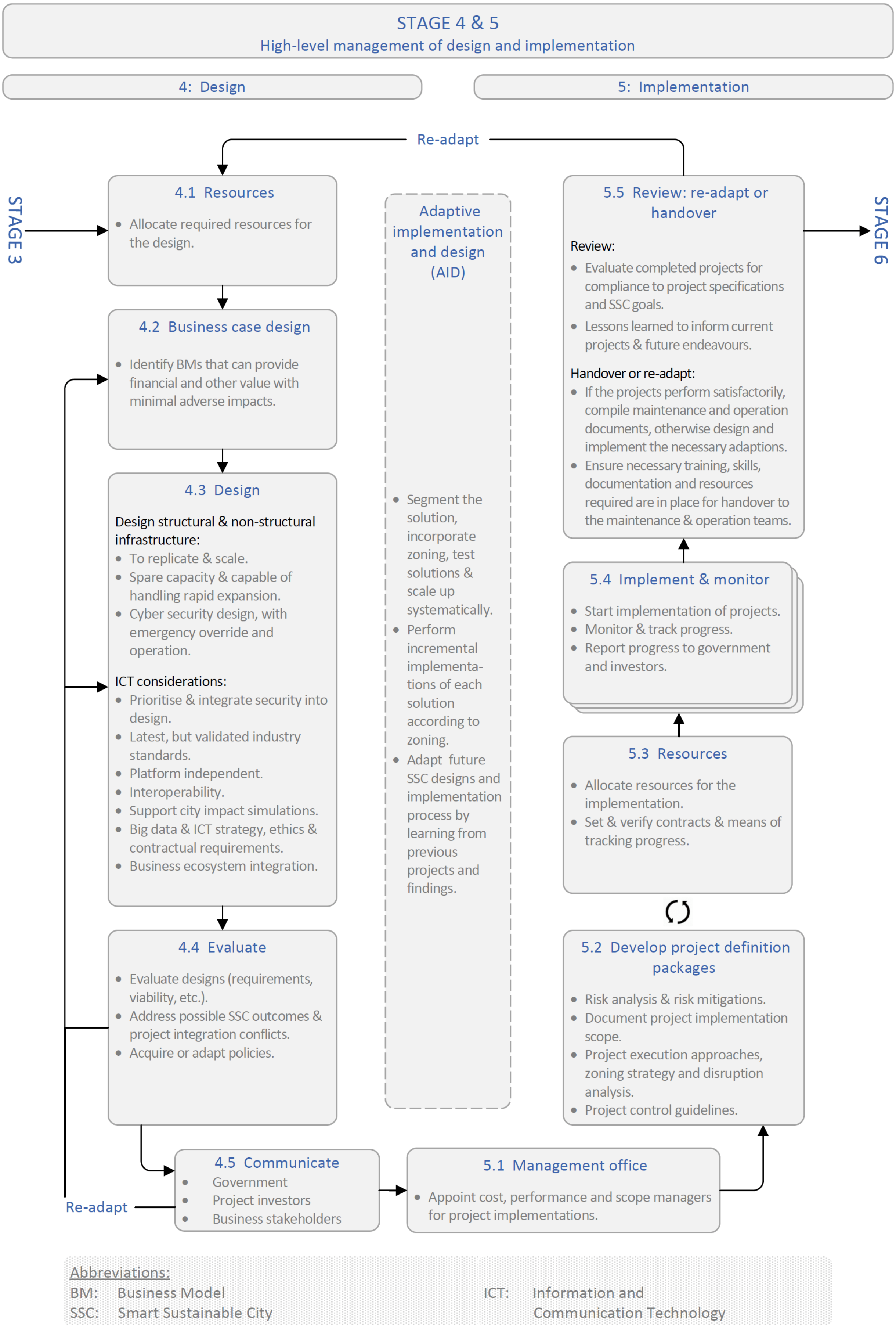

Figure C.8: Detailed Stages 4 and 5 of the verified framework.

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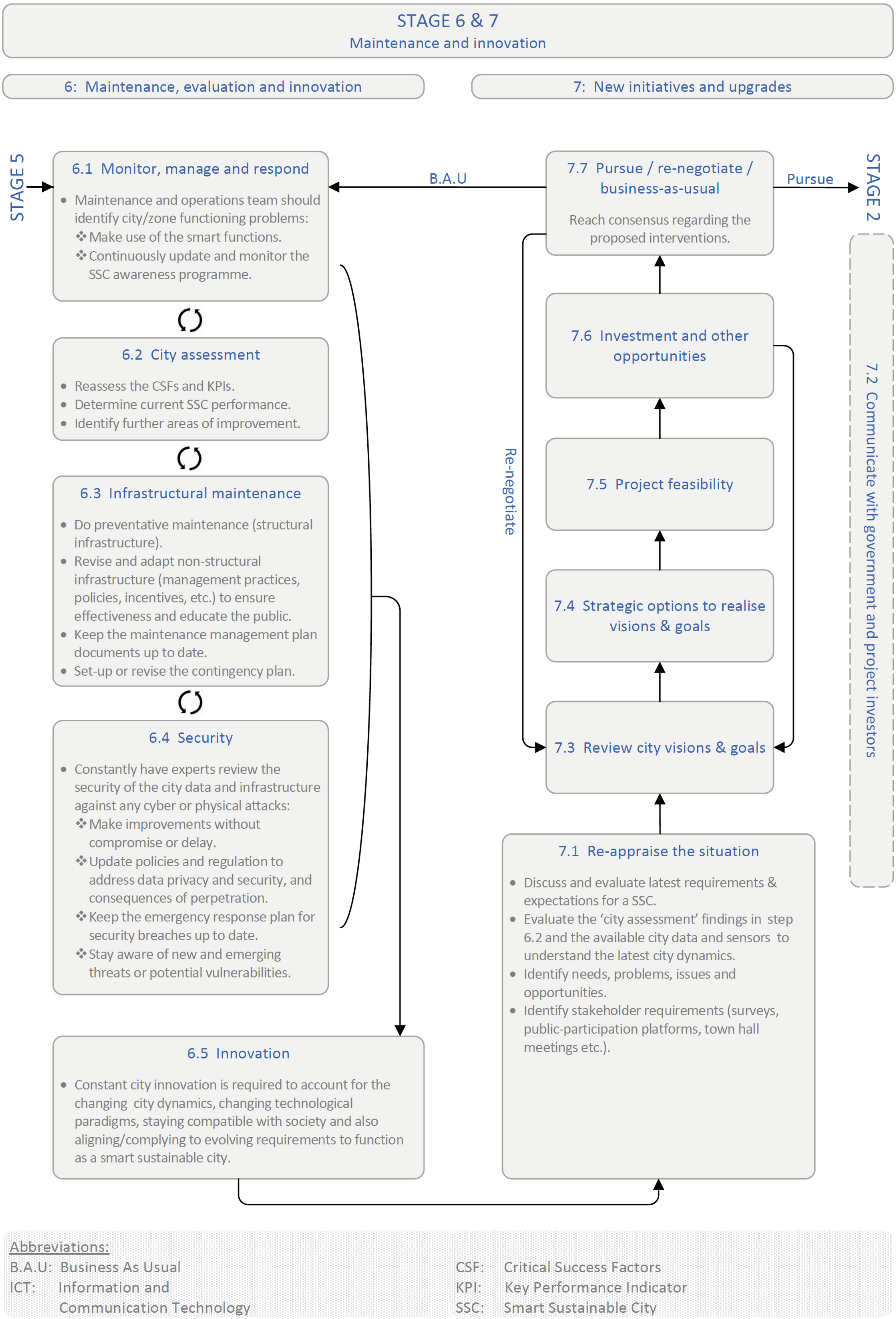

Figure C.9: Detailed Stages 6 and 7 of the verified framework.

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C.3 Validated framework

The following detailed stage diagrams for the validated framework are provided:

Figure C.10: Stage 1 Pre-project preparation (Round 2 of validation);

Figure C.11: Stage 1 SSC initiation;

Figure C.12: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure C.13: Stage 4 (Design) and Stage 5 (Implementations); and

Figure C.14: Stage 6 (Maintenance, evaluation and innovation) and

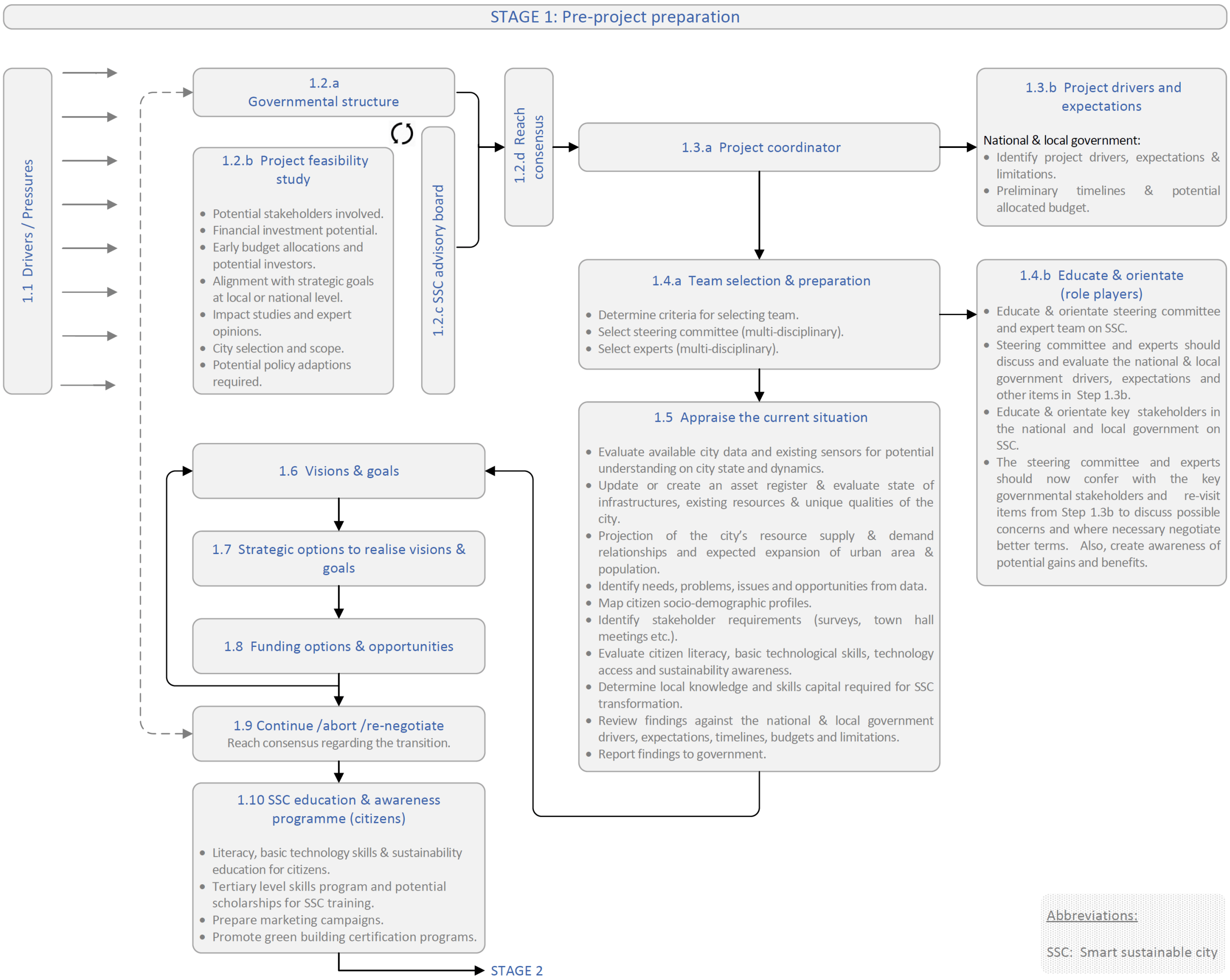

Figure C.10: Detailed pre-project preparation as Stage 1 for Round 2 of the framework validation.

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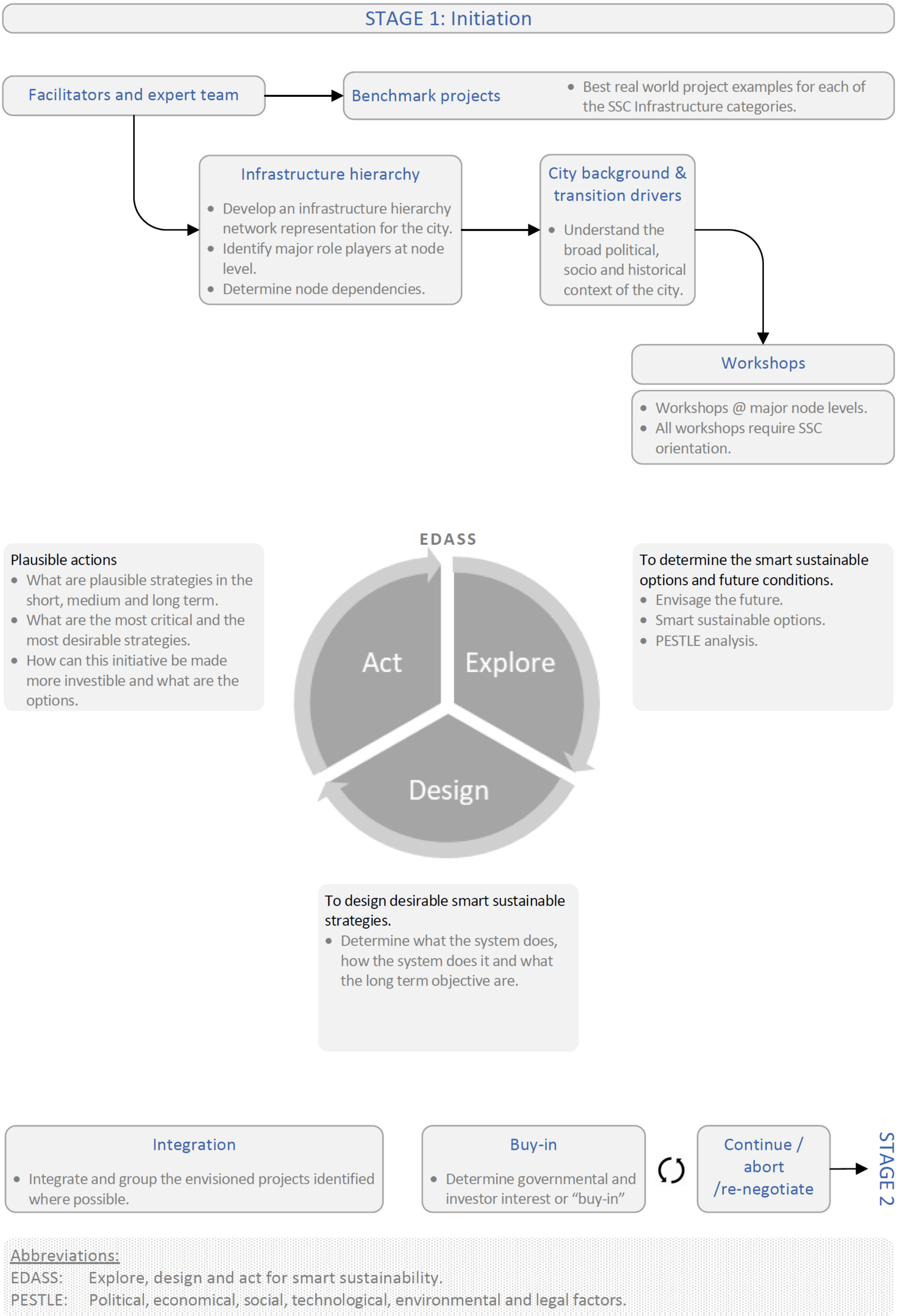

Figure C.11: SSC Initiation as Stage 1 of the validated framework.

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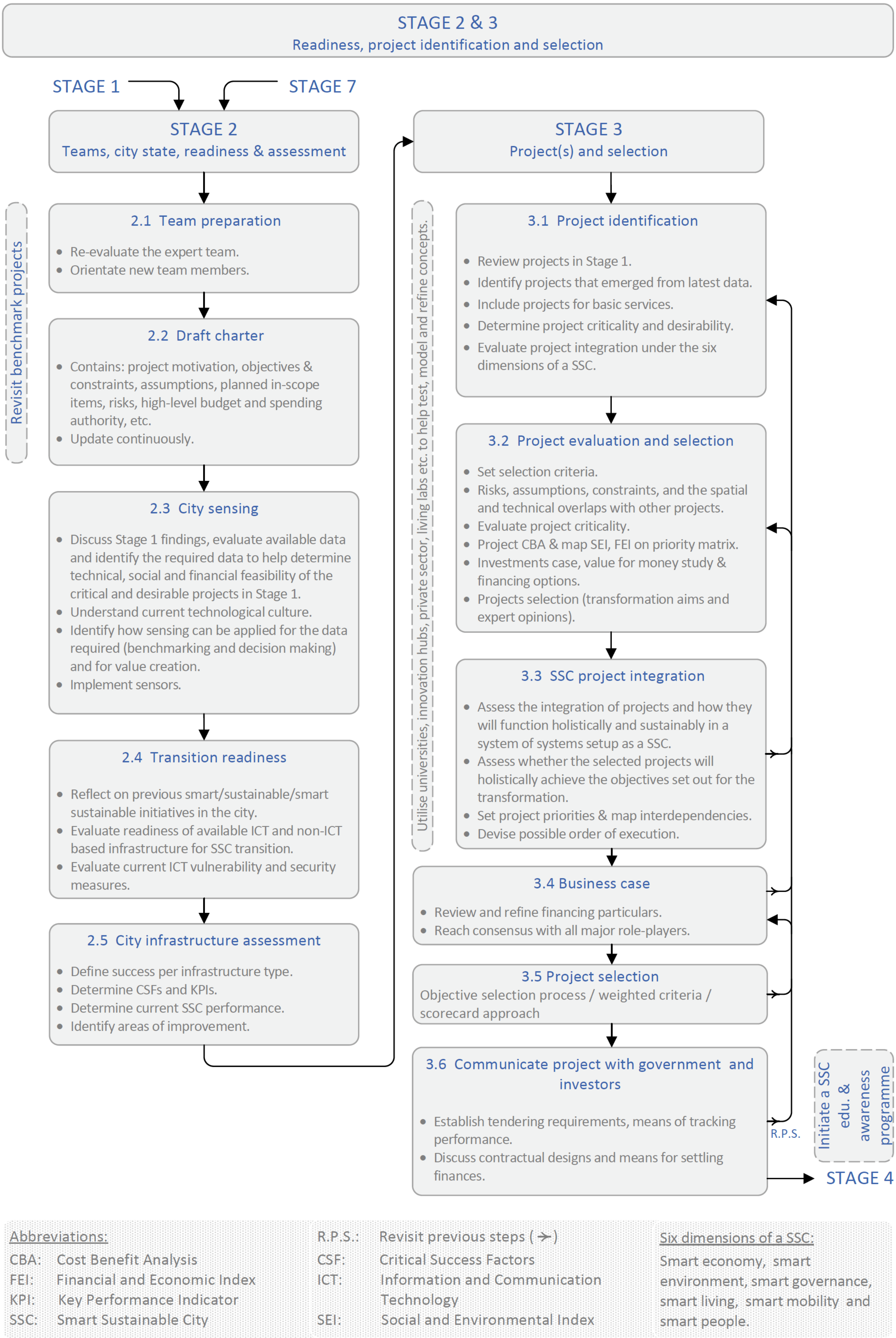

Figure C.12: Detailed Stages 2 and 3 of the validated framework.

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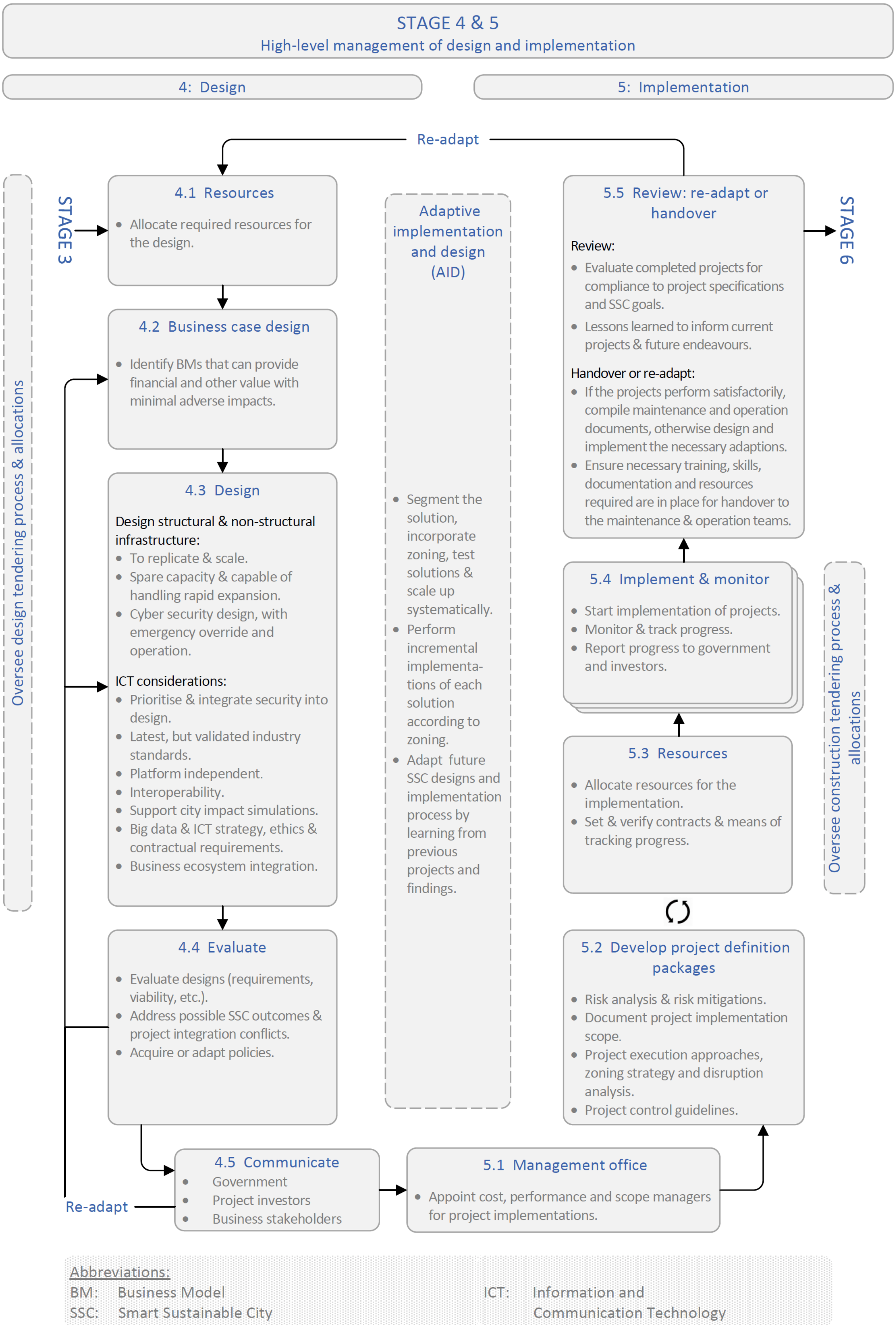

Figure C.13: Detailed Stages 4 and 5 of the validated framework.

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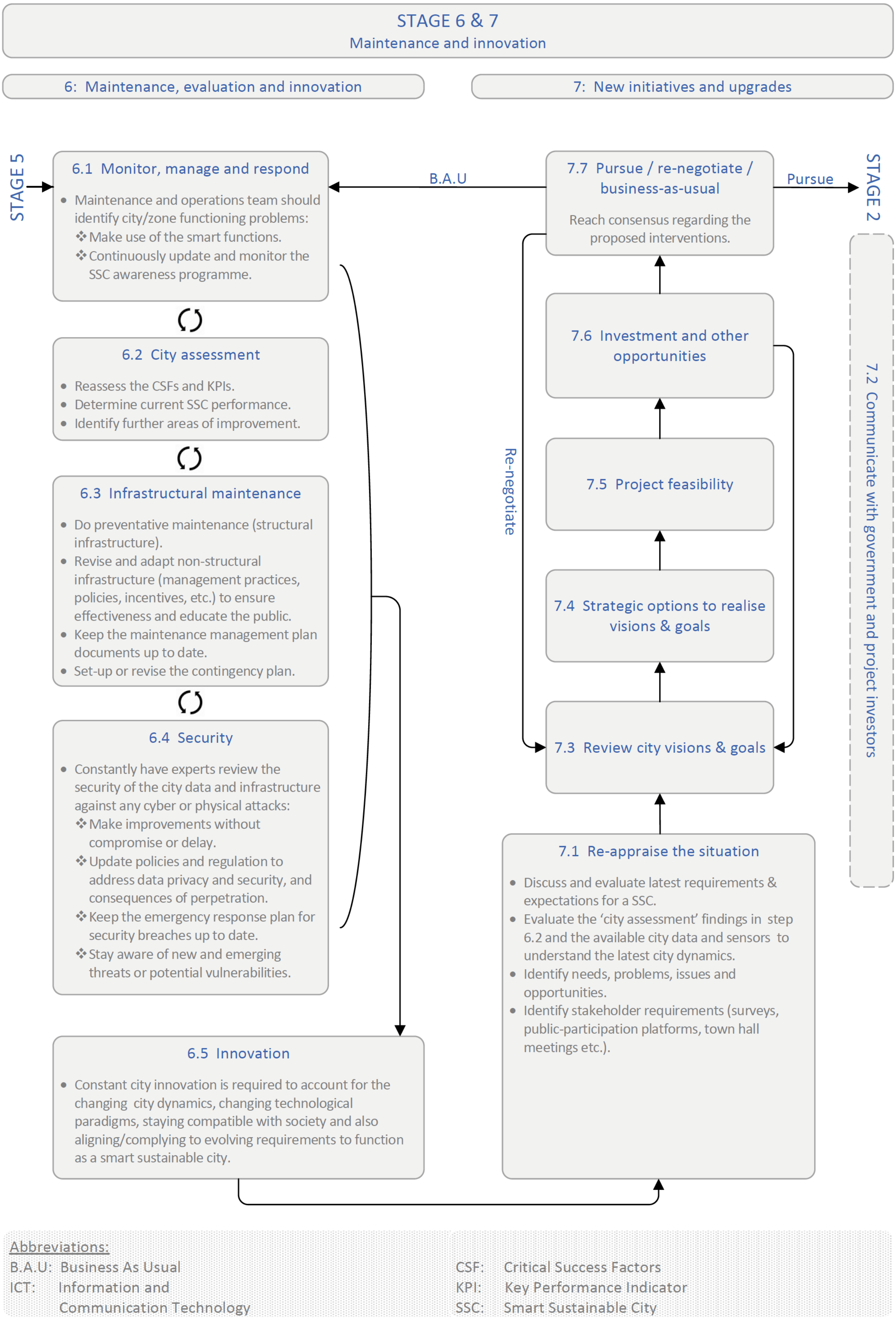

Figure C.14: Detailed Stages 6 and 7 of the validated framework.

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Appendix D

Results: SSUIT Framework

In this chapter, the finalised version of the smart sustainable urban infrastructure transitioning (SSUIT) framework is presented. The framework was developed from conceptual literature in Chapter 4 which forms part of sub-objective one and two, phase two of the main research objective in Figure D.1. In Chapter 5 the framework was verified by means of an analysis of collective case studies and finally validated by a panel of experts in Chapter 6. The verification and validation of the framework forms part of sub-objective three, phase three in Figure D.1.

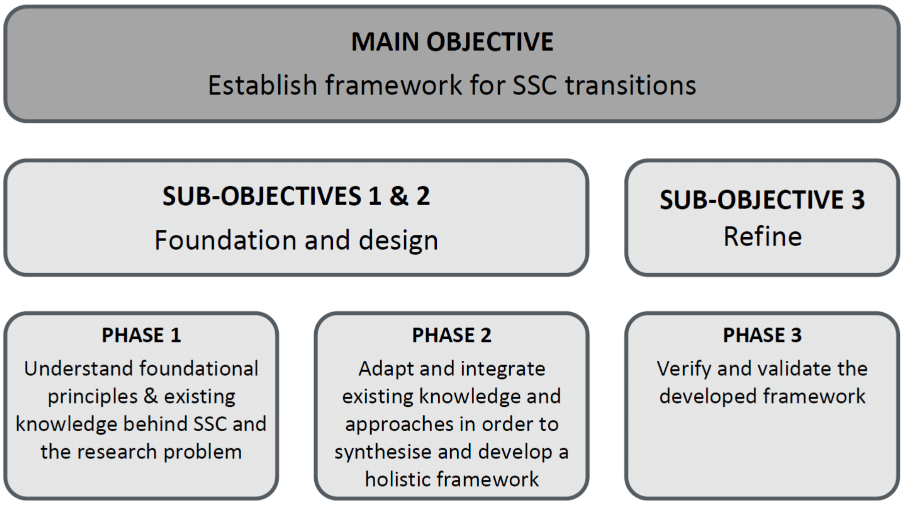

Figure D.1: Approach followed during the research.

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D.1 SSUIT Framework

The following shortened versions of the SSUIT framework stages are presented:

Figure D.2: Overall flow of the SSUIT framework stages;

Figure D.3: Stage 1 SSC initiation;

Figure D.4: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure D.5: Stage 4 (Design) and Stage 5 (Implementations); and

Figure D.6: Stage 6 (Maintenance, evaluation and innovation) and Stage 7 (New initiatives and upgrades).

Expanded versions of the SSUIT frameworks stages are also provided in Appendix D.2:

Figure D.7: Overall flow of the SSUIT framework stages;

Figure D.8: Stage 1 SSC initiation;

Figure D.9: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure D.10: Stage 4 (Design) and Stage 5 (Implementations); and

Figure D.11: Stage 6 (Maintenance, evaluation and innovation) and Stage 7 (New initiatives and upgrades).

In Figure D.2, the overall flow of the SSUIT framework stages is illustrated and shows how the SSC transition is initiated in Stage 1. Team preparation, determining the city state, readiness and infrastructure assessment in Stage 2 will commence once Stage 1 has been completed. After Stage 2, the project identification and selection in Stage 3 will commence. Stage 4, the design, will be initiated once Step 3.6 in Stage 3, which includes the government and investor communication, has been completed and the initiation of the SSC education and awareness programme has commenced. Stage 5 is the implementation stage, and once project have progressed to the last Step in Stage 5, they will be re-adapted in Stage 4 or handed over to Stage 6, which is the maintenance, evaluation and innovation step. New initiatives and upgrades in Stage 7 will commence as determined by Stage 6.

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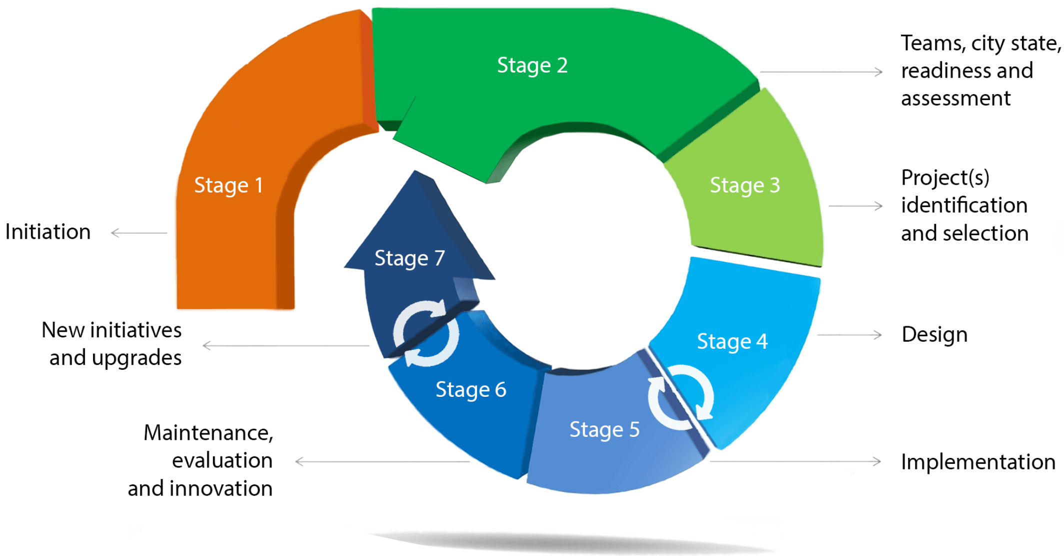

Figure D.2: Overall flow of the stages within the SSUIT framework.

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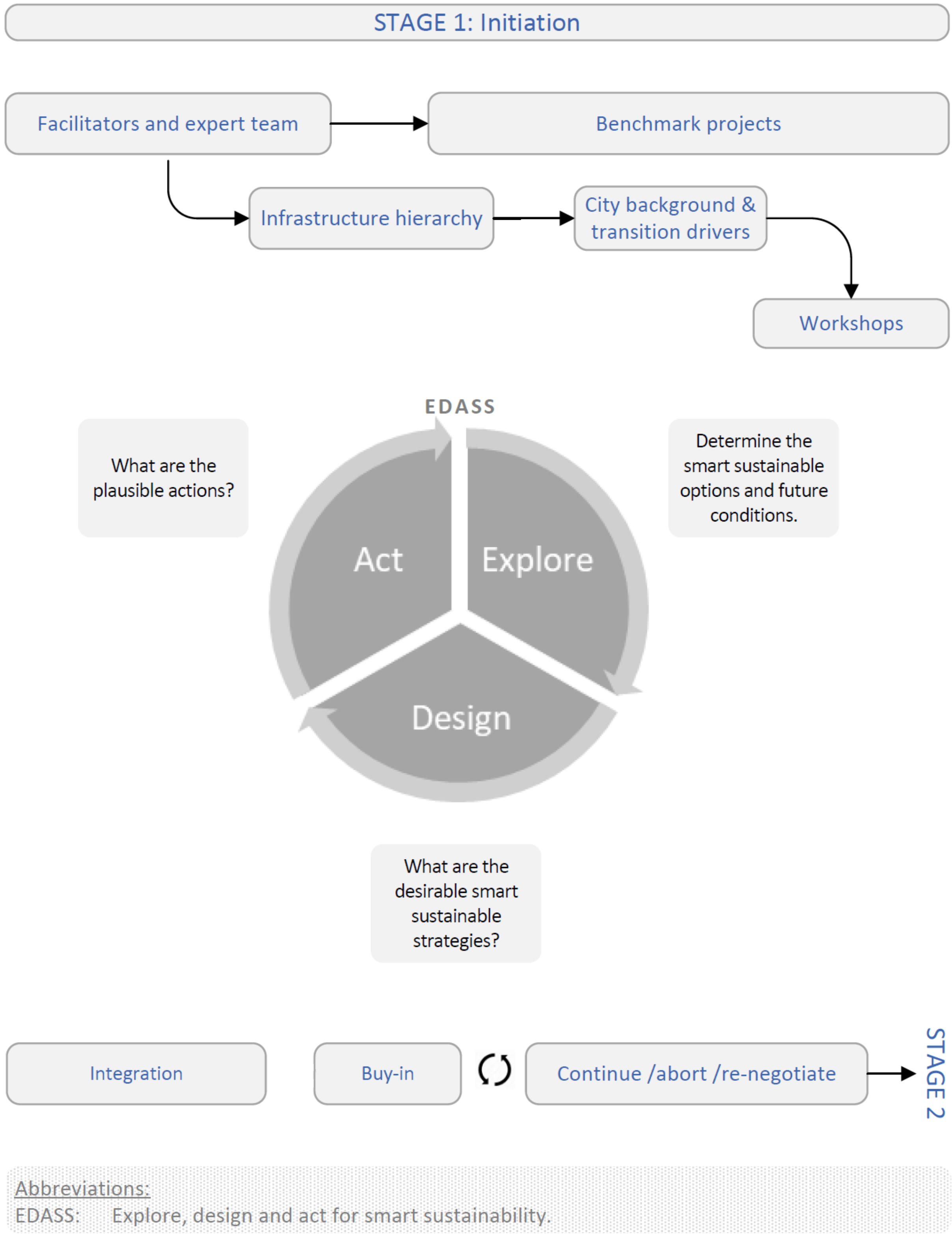

Figure D.3: SSC initiation as Stage 1 of the final framework.

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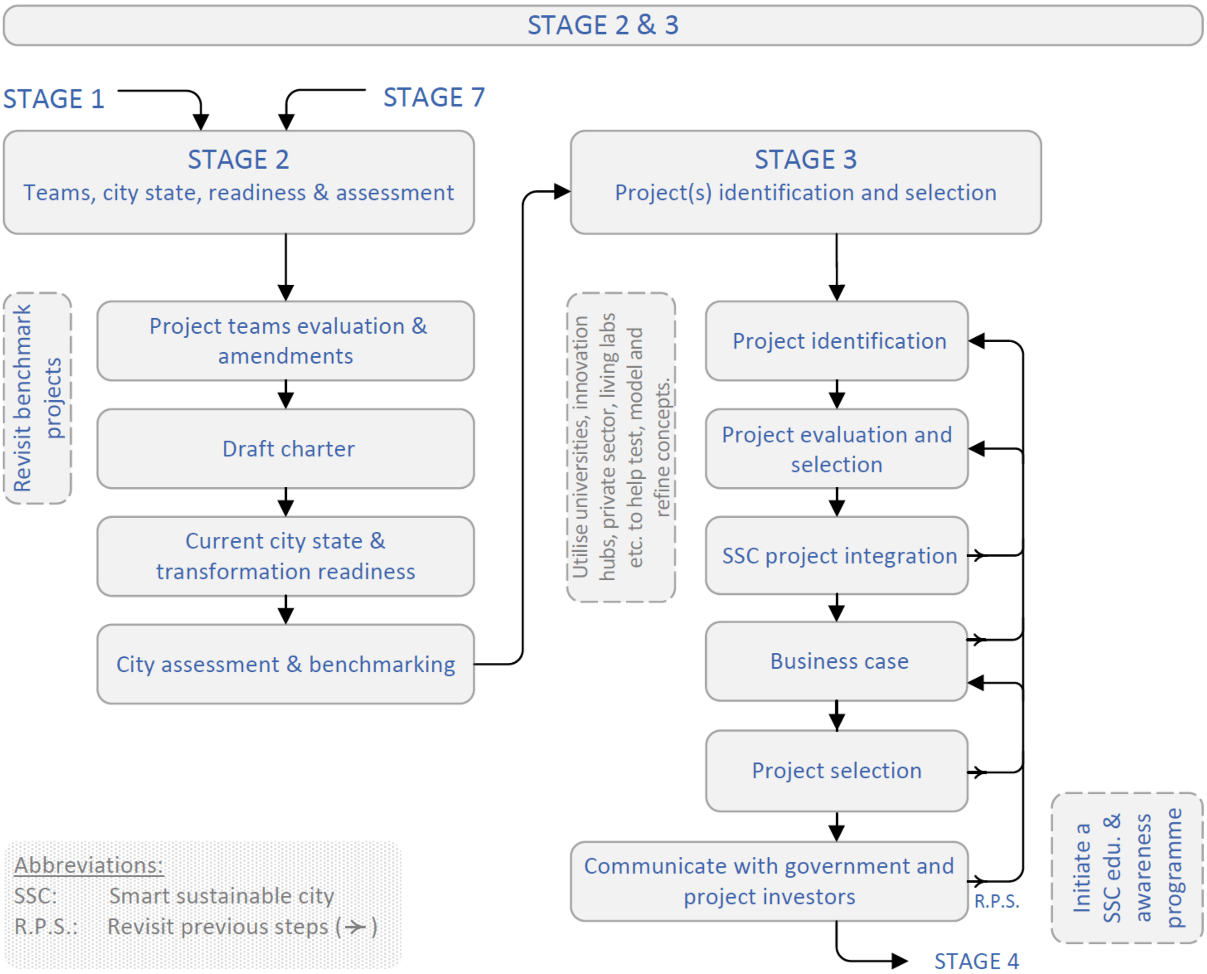

Figure D.4: Stages 2 and 3 of the final framework.

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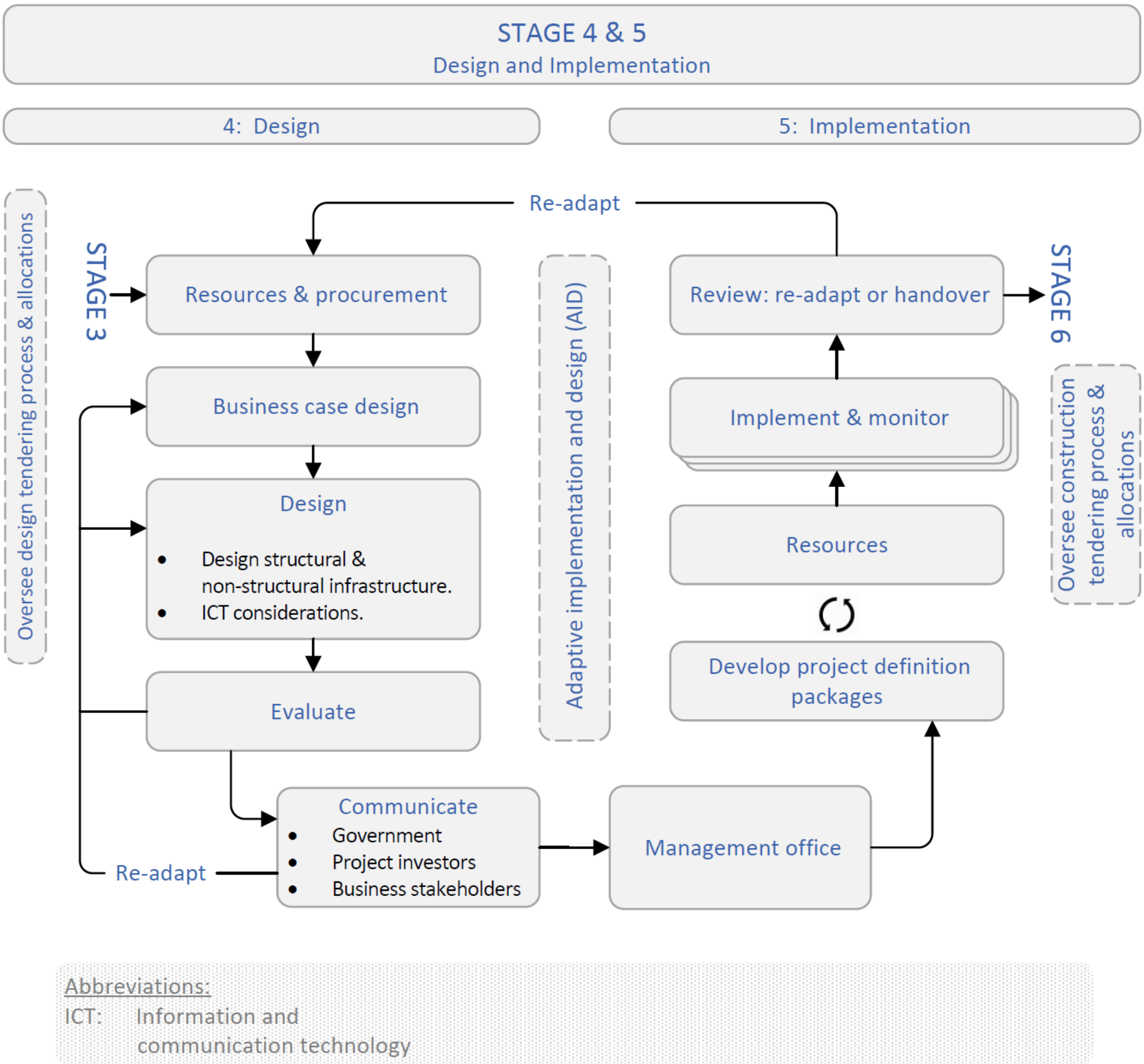

Figure D.5: Stages 4 and 5 of the final framework.

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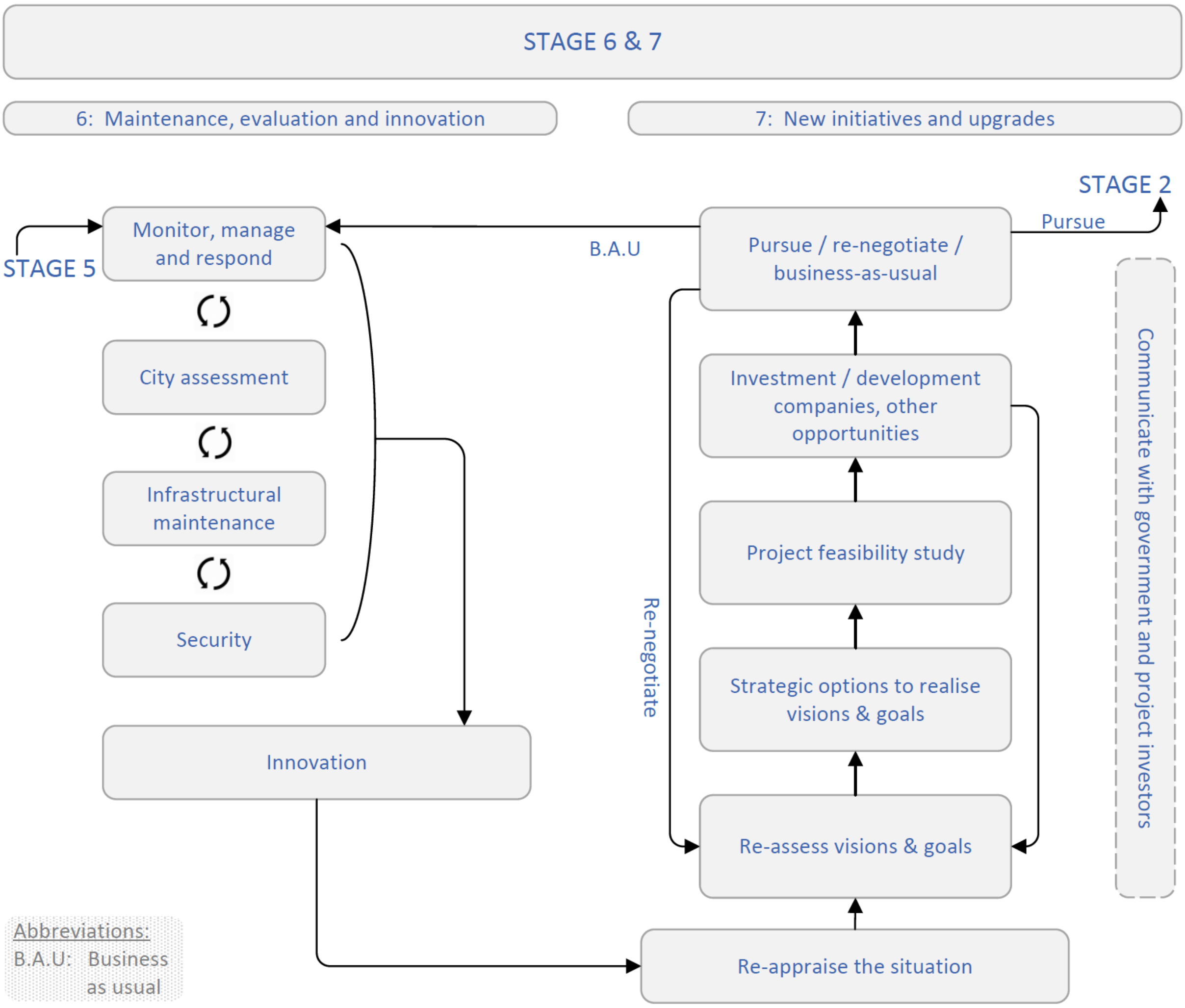

Figure D.6: Stages 6 and 7 of the final framework.

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D.2 Detailed SSUIT Framework

The following detailed stage diagrams for the SSUIT (smart sustainable urban infrastructure transitioning) framework stages are provided:

Figure D.7: Overall flow of the SSUIT framework stages;

Figure D.8: Stage 1 SSC initiation;

Figure D.9: Stage 2 (Teams, city state, readiness and assessment) and Stage 3 (Project(s) identification and selection);

Figure D.10: Stage 4 (Design) and Stage 5 (Implementations); and

Figure D.11: Stage 6 (Maintenance, evaluation and innovation) and Stage 7 (New initiatives and upgrades).

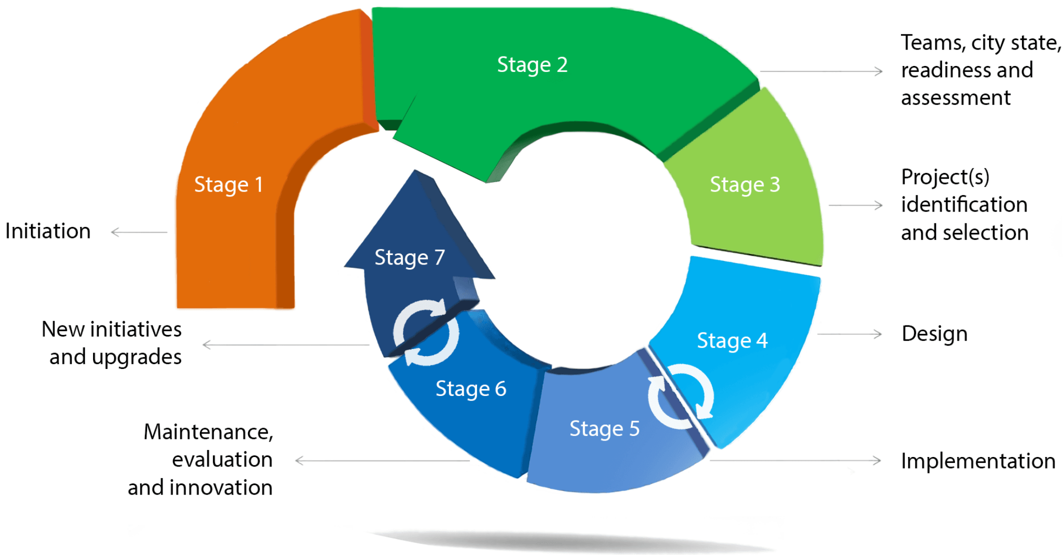

Figure D.7: Overall flow of the stages within the SSUIT framework.

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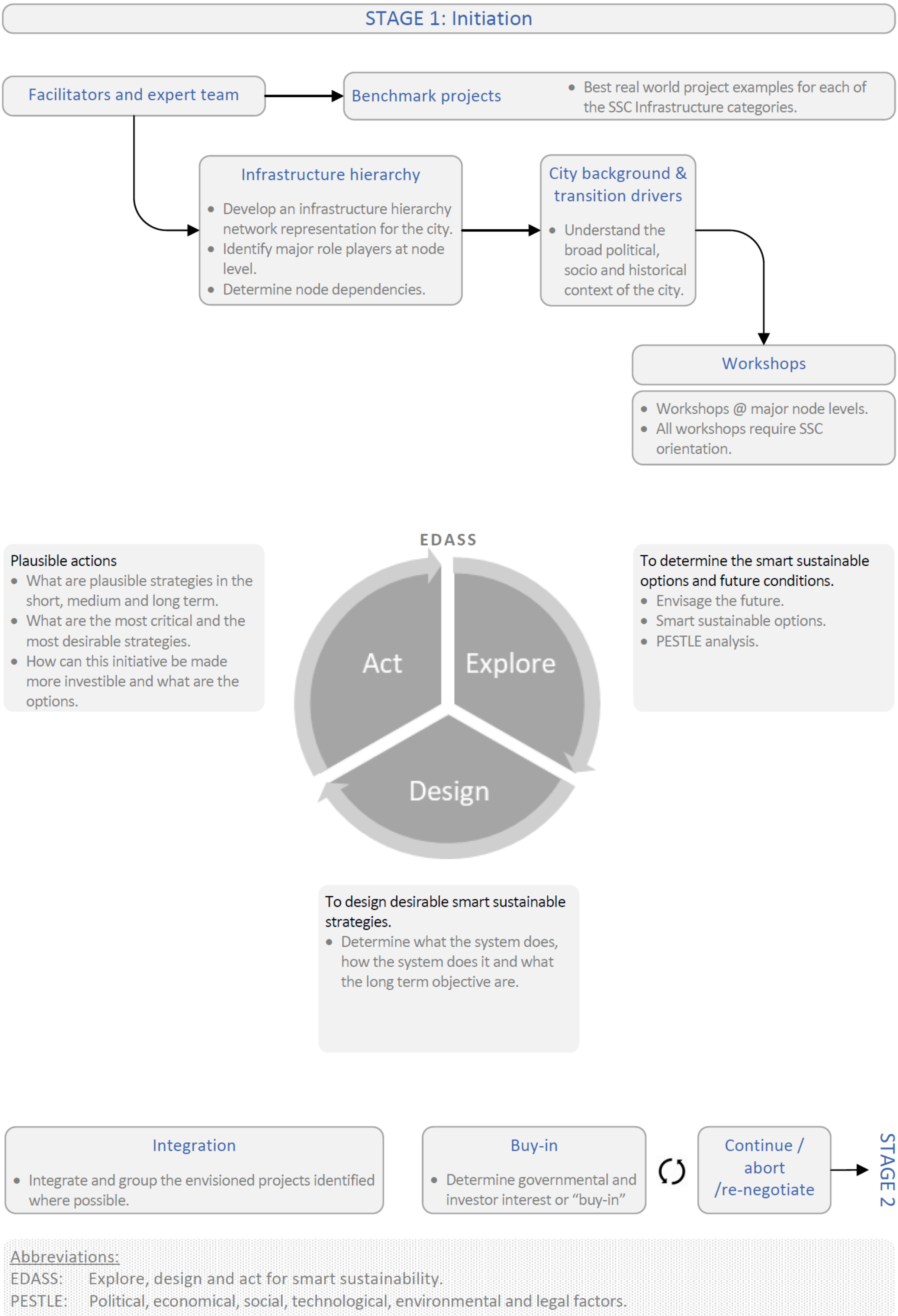

Figure D.8: Detailed SSC initiation as Stage 1 of the SSUIT framework.

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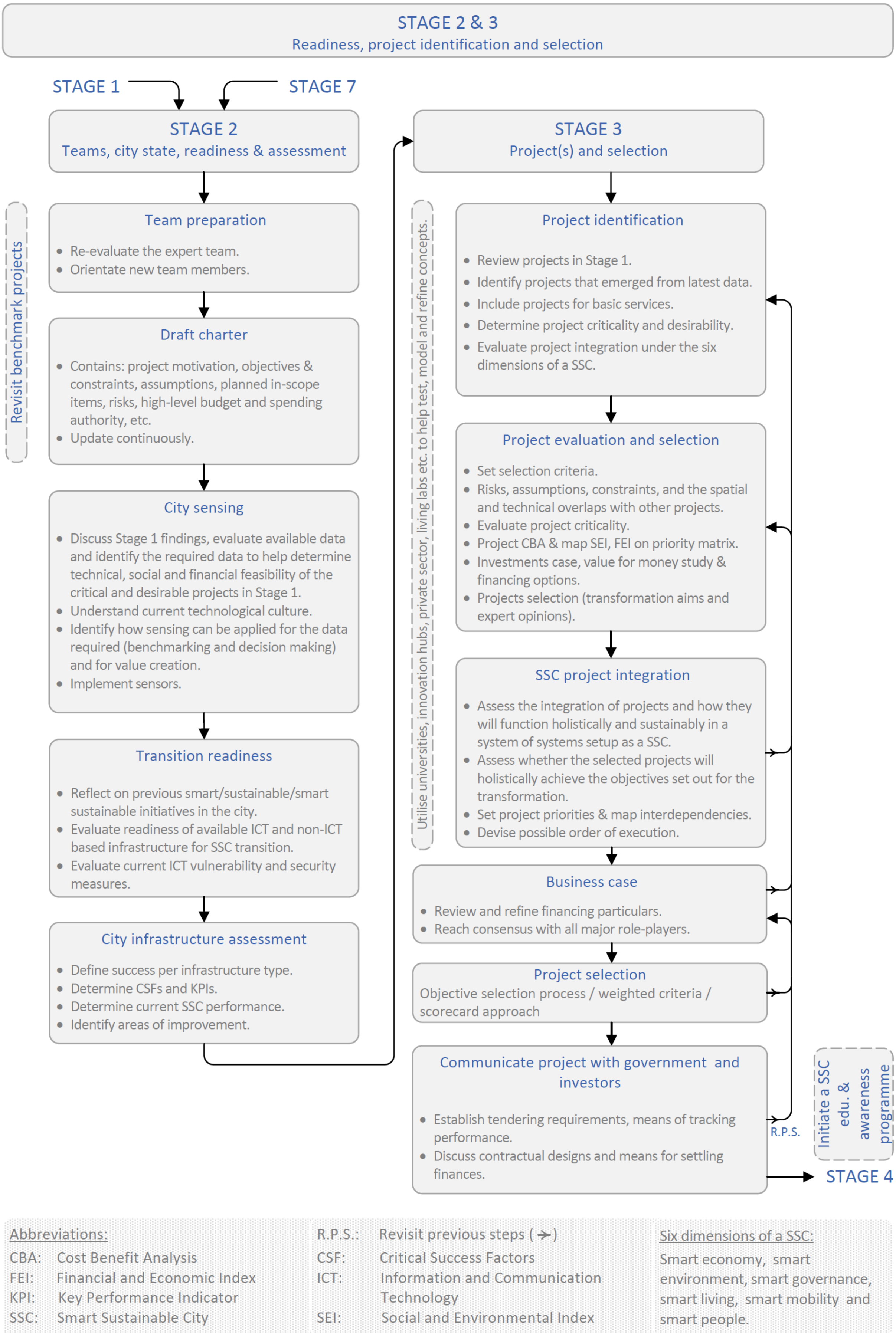

Figure D.9: Detailed Stages 2 and 3 of the SSUIT framework.

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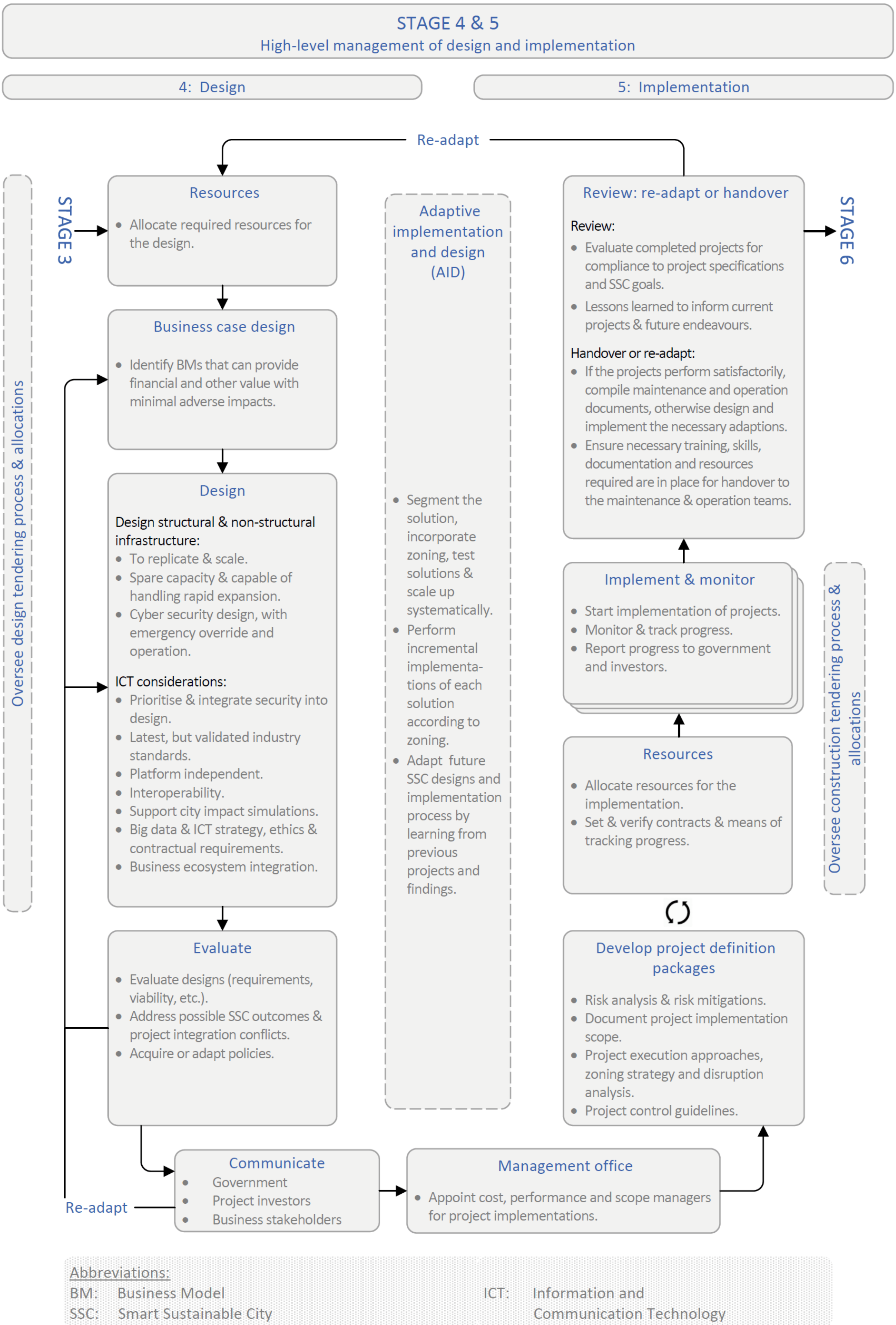

Figure D.10: Detailed Stages 4 and 5 of the SSUIT framework.

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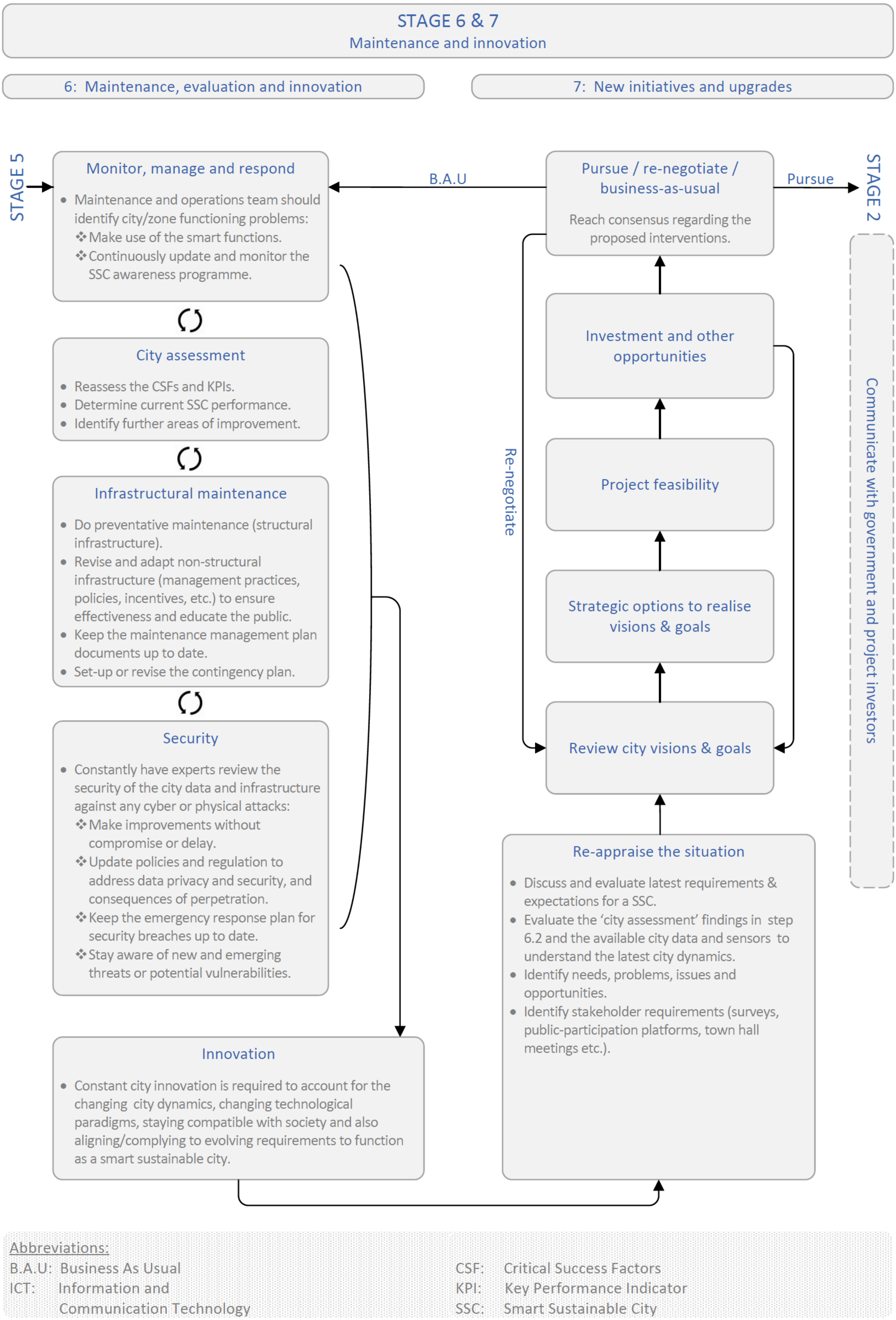

Figure D.11: Detailed Stages 6 and 7 of the SSUIT framework.

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