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SSUIT Smart Sustainable Urban Infrastructure Transitioning

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Abstract: Transformation towards smart sustainable cities requires transitioning and modernising urban infrastructure systems. This study builds upon previous work and recommendations to address the need for a holistic and comprehensive framework to guide the planning, development, and management of smart sustainable infrastructure transitions. Existing approaches and methods regarding city and infrastructure transitioning were reviewed to draw up an understanding of, the requirements for, and guidelines useful to the design of a conceptual framework. The framework was established through synthesis of the knowledge and insight gathered from the literature. A collective case study analysis was used to verify the theoretical framework and make adaptations 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 based on 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.

Keywords: smart sustainable city; smart city; sustainable city; urban; infrastructure; multi-project; management; transition; framework

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1. Introduction

The current global population for 2022 stands at 8 billion [1]. 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 [2,3].

In 2019, the rate of world urbanisation was already more than 50% faster than the rate of global population growth [4,5]. The 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, the urban population grew by 2.56% annually compared to the global population, which grew by 1.62% [4,5]. Urbanised populations increased from representing 30% of the total global population in 1950 to 56% in 2019 and are predicted to grow to 68% by 2050 [5].

Cities are complex, evolving systems [6]. However immense resource consumption and waste flows, exceeding the carrying capacity of the city, are some of the reasons why cities are unsustainable [7]. The resources that sustain human life are limited and should therefore be managed strategically [8,9].

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" [10]. Sustainable development is an integrated balance of social, environmental, and economic aspects for sustained human wellbeing [11,12]. From the principles of sustainable development and escalating urbanisation challenges, the concept of sustainable cities emerged [13,14].

Planning cities for a better, more sustainable future is not new. In 1987, "Our common future" or "The Brundtland Report" was introduced, focusing on the viewpoint of sustainable development. Agenda 21 is a 40-chapter document providing guidance on sustainable societies, drafted during the Earth Summit in 1992. During the UN Climate Change Conference in Kyoto in 1997, the Kyoto Protocol was signed to reduce greenhouse gasses by 5%. The eight Millennium Development Goals (MDGs) were signed in 2000 by 191 countries and aimed at reducing global challenges, including poverty and hunger.

Seventeen Sustainable Development Goals (SDGs) were initiated in 2012 after the Rio + 20 conference and completed in 2015 in New York at the UN Summit for Sustainable Development. The SDGs were designed to guide activities regarding sustainability and development until 2030. In 2016, the UN (United Nations) initiative U4SSC (United for Smart Sustainable Cities) was shaped by the UNECE, UN-Habitat, and ITU and supported by 14 more UN-associated agencies. U4SSC focuses on providing a platform where cities and communities can find guidance on how to achieve the UN-SDGs, and particularly SDG 11, the goal that focuses on sustainable cities and communities.

Other ongoing efforts to advance sustainable urban development are, for example, the New Urban Agenda, adopted during the Habitat III conference in 2016, and the participation of various nations in the COP summits to report progress and set future targets to reduce climate change impacts through sustainable development decisions. The need for sustainable urban planning and development has become critical due to the increasing urban population and commitments to addressing climate change risks to cities and communities globally [15].

Research presented in [16] illustrates how sustainable cities are starting to consider ICT (information and communication technologies) as a means to help achieve the Sustainable Development Goals. Recent work in [17] showed how smart cities have to think about sustainability in the city to ensure human wellbeing (and happiness), although most smart city research to date has a rather strong focus on the ICT side. It is also mentioned in [17] that using smart technology in a sustainable city would not necessarily make a city a smart city. The same is said for blindly applying sustainability principles to a smart city [16,18].

Cities are of increasing importance in the regional, national, and global economy [19,20]. According to the work in [21], a city's 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 [22]. Urban infrastructure networks form part of a larger system-of-systems in cities, which comprises both social and technical components. For a city to address these challenges requires systemic changes of systems (e.g., transport and energy) referred to as socio-technical transitions, involving technology, infrastructure, policy, culture, and scientific knowledge [23]. Transitions are complex long-term processes with various actors (for example, industries, consumers, society, policymakers, researchers, and engineers) that develop, maintain, and transform these components [24]. The efficient functioning of a city's critical subsystems is very important to supporting future sustainable urban infrastructure development [25]. In this sense, smart ICT approaches provide efficiency, flexibility, and real-time management to infrastructure and the resource flows within it [26]. It is evident in the literature that urban infrastructure transitions are crucial for transitioning a city to both a smart city [27,28] and a sustainable city [18,26]. This need for urban infrastructure transitioning transcends to smart sustainable cities, an amalgamation of both smart city and sustainable city aspects.

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 with helping solve urban sustainability challenges and in doing so benefitting the environment, cities, and society at large. There is a scarcity of literature and an absence of frameworks to guide city-level planning, implementation, and management of smart sustainable city transitions from a holistic perspective. The research presented in [29] 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 the lack of relevant and detailed literature on smart sustainable city development at the time. For this reason, [29] encouraged future research that extends on their work through the development of a transition framework for smart sustainable cities. This also correlates with recent work in [30], 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.

The available research does not provide a framework to guide the planning, management, implementation, and handover of large-scale infrastructure transition projects or long-term intervention programs with the aim of changing an existing city into a smart sustainable city.

The research aim is therefore to develop a conceptual framework to guide and manage smart sustainable city transitions. The framework that is presented in this article was designed to assist city planners, policymakers, city councils, and smart sustainable city architects to better design and execute a smart sustainable city transformation.

In this article, the development of the conceptual framework from existing knowledge and approaches is presented, whereafter verification by case studies is discussed. The framework was validated through a review by industry experts to determine and refine its practicality for application in the real world. The resulting framework is then presented and explained with a concluding discussion on the findings.

2. Materials and Methods

A balance between the goals of a smart city and a sustainable city will have to be carefully forged for each city individually when designing a smart sustainable city. There are many factors that play a role in designing and achieving this balance, including policy, the current city state, future plans and goals, the social context, ecological and biodiversity aspects, and more. The dimensions for a smart sustainable city (SSC) were narrowed in [31] down to five dimensions, which are the three pillars for sustainability (environment, economy, society), urban infrastructure, and governance.

2.1. Framework Development and Refinement

For the theoretical framework, key components from existing roadmaps, frameworks, and models that relate to a smart sustainable city transition were looked at to identify the main stages for the smart sustainable urban infrastructure transition framework (SSUIT). The criteria for selecting these studies include that they are structured as a model, roadmap, or 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 high-level stages. With limited research available, eight studies that span many themes were selected, which include implementation planning [29], governance [30], sustainable cities [32], smart sustainable cities [33], urban design [34], project planning [35], smart cities [36], and integrated and adaptive transitions [37]. The number of studies selected was manageable to work with and provided a well-rounded knowledge base. These studies stood out as the most relevant, informative, and well positioned. From these studies, seven common stages were identified, along with what the most appropriate order of execution would be, and were used in constructing the SSUIT framework. The overall flow of the stages was based on a sustainable urban design framework in [34]. The framework presented in [34] is frequently used as a structure for research in urban design [38], sustainable cities [39], ICT [40], and project planning [41] and is a balanced representation of the general themes identified.

The more detailed composition of the framework was developed using all of the papers from the literature review stage of the research. A systematic literature review was conducted and presented in [42], which explored the existing knowledge landscape regard-

ing smart sustainable cities and urban transitioning. These findings were used to determine the direction of the research. 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 [43] 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 up an understanding of, the requirements for, and guidelines useful to the design of the framework. The conceptual framework was established through the synthesis of approaches, theory, and insight gathered from the literature to form a unique solution for the planning, development, and management of smart sustainable infrastructure transitions. The process that was followed to develop the framework is illustrated in Figure 1.

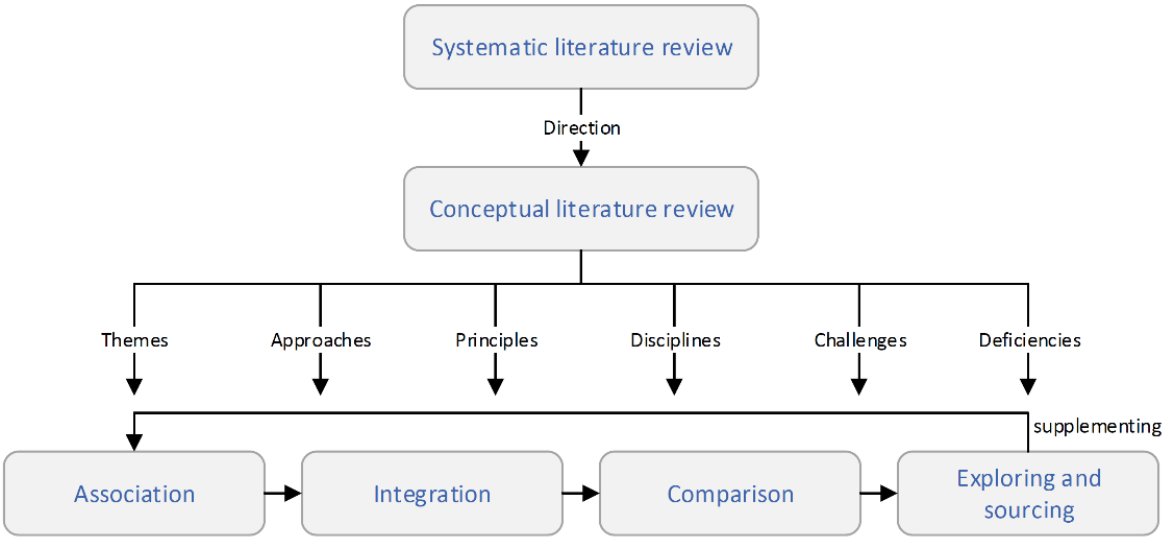

Figure 1. The process followed to develop the conceptual framework.

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 existing methods and implementations were reviewed. Similarities and relations became observable between various pieces 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 were studied and compared with the draft framework to determine whether there were 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 focused, because urban transformations entail multidisciplinary components and processes, various dimensions, and 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. Thereafter, the framework was refined by means of case study verification and validation by multi-disciplinary expert review, as illustrated in Figure 2.

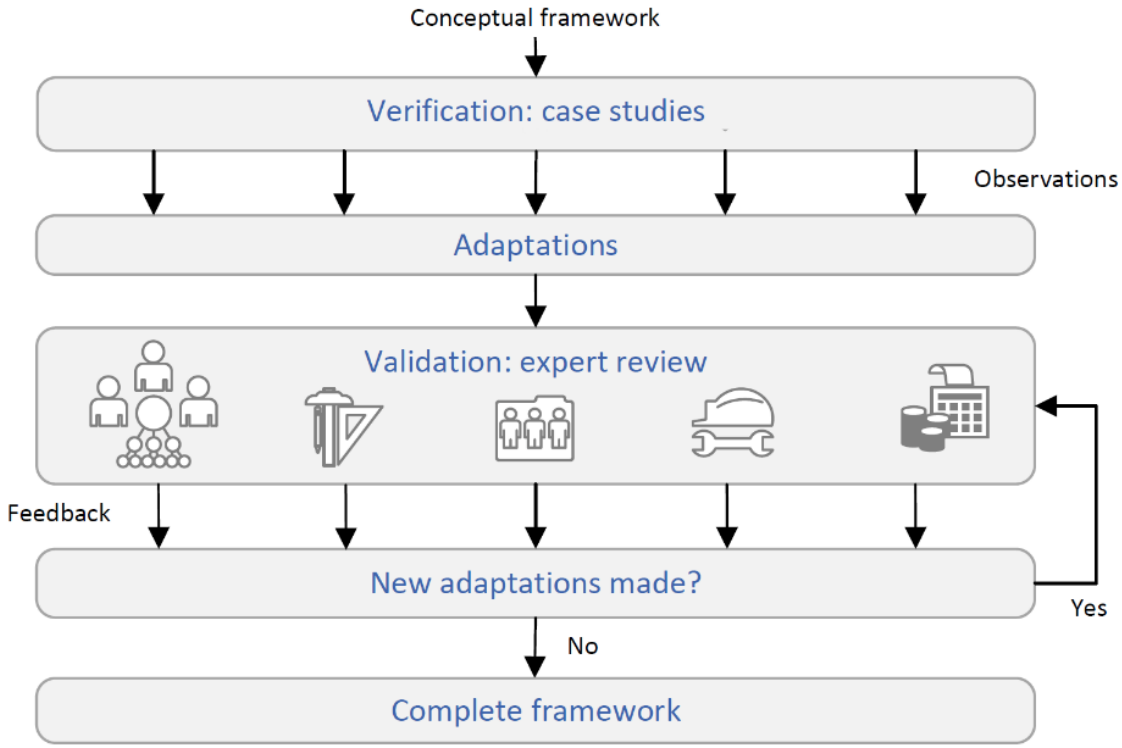

Figure 2. The overall process followed to refine the framework.

2.2. Verification by Case Studies

Due to the long timeframes 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 [29]. The goal of the verification was to determine whether the composition of the framework is fit for its intended purpose by investigating real-world city transition projects as documented case studies. During the process, the components and design of the framework was enhanced and adjusted as necessary.

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 practices, 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 (richness, clarity, and structure);
- Findings and conclusions.

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 inconsistency detection as a means of triangulation of information between the various sources (research articles, industry reports, city information, observations, expert opinions, etc.).

The framework was tested against the collective case studies in [30,44] and Copenhagen as a city. These three sources offer triangulation of the facts and insights and are summarised in Table 1. Copenhagen as a city offers example projects on both smart and sustainable initiatives and is a leading and well-documented global example in the field, especially its synergies with neighbouring cities and higher-level development agendas.

The work in [44] provides an insider's perspective as a practitioner who has worked with and has 20 years of experience on urban transition projects entailing smart technologies in cities and also includes the insights from 25 industry experts. The cases involve successes and failed projects at various urban scales—for example, adoption and scaling efforts of solutions taken on abroad that have succeeded and others that have failed. These cities are Copenhagen, Amsterdam, Stockholm, San Francisco, Singapore, Rotterdam, Dubai, Seoul, Paris, and Abu Dhabi.

Table 1. Three cases chosen for the verification.

Characteristics	City of Copenhagen	Industry Insights	CAP4CITY
Sources	Industry reports, governmental and public platforms, research articles	Practitioners' perspective with 25 industry experts involved [44]	Academic study based on CAP4CITY data [30]
City type	Sustainable, green, liveable, and smart initiatives	Smart technologies in sustainable cities	Smart sustainable
Cities included	Copenhagen and Danish example cities of different categories	3 Asian, 5 Arabian, 3 North American, and 8 European cities	6 European and 6 South American cities
Contribution	Leading global example, single-case study Demonstrates a city integrated in regional, national, and global agendas	Multi-case study Real user perspectives from experience on failures and successes	Multi-case study Peer-reviewed Most successful cases

Case studies used in [30] 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 made up the selection of [30]. These cities were Vienna, Tallinn, Copenhagen, Helsinki, Gdansk, Barcelona, Buenos Aires, Curitiba, Santiago, Bogota, Panama City, and Montevideo. The case studies selected in [30] were focused on the collective requirements for a smart sustainable city governance roadmap.

From the analysis, 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 was described. Adaptations were made where there were components lacking in the framework.

2.2.1. The City of Copenhagen

This section further expands on the case study of Copenhagen. Copenhagen, the capital of Denmark, is the country's largest city, with a population of approximately 1.99 million in the larger metropolitan area. There are around 583,000 residents in the city, resulting in a high population density of 6800 people per square kilometre. The city's population represents nearly 10% of the total population of Denmark. Notably, Copenhagen's population density is about 45 times denser than the national average in Denmark [45]. In Figure 3, the population changes between 2012 and 2021, with varying percentages, are presented for Denmark through the distribution of urban areas and the main cities.

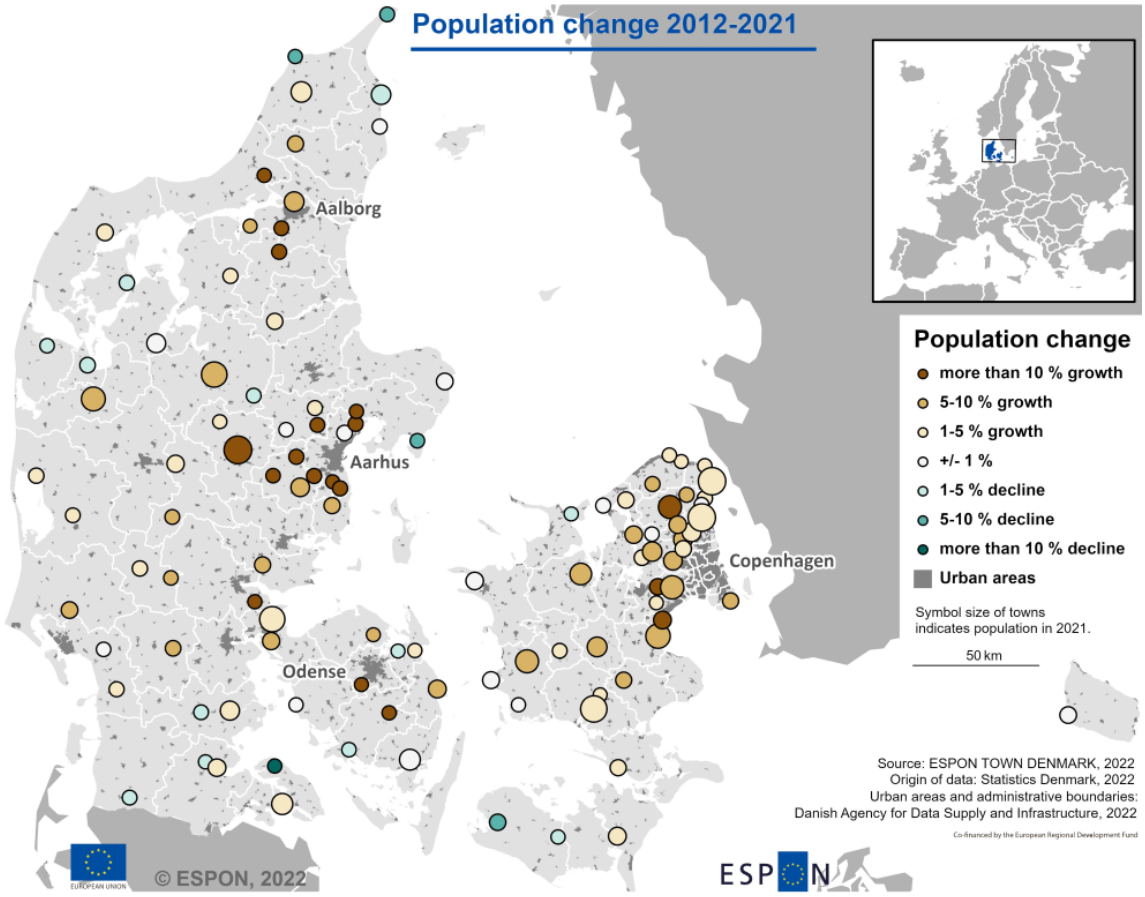

Figure 3. Denmark population size, percentage changes from 2012 to 2021, and distribution of urban areas and main cities, amended with permission from [46]. 2022, © ESPON EGTC.

Copenhagen's population is expected to grow by 110,000 residents and 20,000 new jobs by 2025, requiring approximately 6.8 million m^2 of additional urban built environment to be built. Copenhagen is a growing city with opportunities to test and demonstrate new smart and sustainable urban solutions on both a small and large scale and aims to become the world's first carbon neutral capital [47].

2.2.2. Initiatives and Impact

Copenhagen has made substantial progress in reducing its carbon footprint and achieving its goal of becoming carbon neutral by 2025. The city has implemented an ambitious plan to promote cycling as a primary mode of transportation, resulting in a high percentage of citizens commuting by bike. It has also invested in an extensive public transportation system, including buses, trains, and a metro network, to reduce car dependency [48].

Given Copenhagen's position as a coastal city, it is susceptible to the impacts of rising sea levels. However, by introducing green roofs and parks, the city can mitigate these effects by restoring the natural water cycle and easing the strain on its sewage system [49].

The city has placed a strong emphasis on renewable energy sources and has made substantial investments in wind power. It aims to generate 100% of its energy from renewable sources by 2025. Additionally, Copenhagen has implemented energy efficient measures in buildings, encouraged green building practices, and integrated sustainable urban planning principles into its development projects [47].

Copenhagen is also renowned for its commitment to smart technology and data-driven solutions. It has implemented various smart city initiatives, such as intelligent street-lighting systems, real-time data monitoring to optimise energy consumption, and

smart waste management systems. These efforts have helped improve the city's overall efficiency, reduce resource consumption, and enhance the quality of services provided to its residents [50].

Copenhagen has also focused on creating green spaces, promoting biodiversity, and ensuring a high quality of life for its citizens. It has transformed industrial areas into sustainable neighbourhoods, prioritised pedestrian-friendly environments, and emphasised the importance of green areas for recreation and wellbeing [48].

Overall, Copenhagen's comprehensive approach to sustainability, coupled with its integration of smart technologies and dedication to creating a high quality of life, has positioned it as a leading smart sustainable city on a global scale. Copenhagen has implemented numerous initiatives to promote sustainability and improve the quality of life for its residents:

1. *Cycling Culture*: Copenhagen has developed an extensive cycling infrastructure, including dedicated bicycle lanes, bike-sharing programs, and parking facilities. The city's efforts to promote cycling have resulted in a high percentage of citizens commuting by bike, reducing congestion and air pollution. Additionally, the improved cycling infrastructure has contributed to a healthier and more active population [51,52].
2. *Green Energy Transition*: Copenhagen is committed to becoming carbon neutral by 2025. It has invested significantly in renewable energy sources, particularly wind power. The city has offshore wind farms, such as the Middelgrunden Wind Farm, that generate a substantial amount of clean energy. Copenhagen's focus on renewable energy has reduced its reliance on fossil fuels and contributed to a significant reduction in carbon emissions [53].
3. *Energy Efficient Buildings*: The city has implemented stringent energy efficiency standards for buildings. New constructions are required to meet rigorous environmental criteria, including high energy efficiency, the use of sustainable materials, and integration of green technologies. Retrofitting existing buildings with energy-saving measures has also been prioritised. These efforts have reduced energy consumption, lowered greenhouse gas emissions, and created healthier indoor environments [54].
4. *District Heating*: Copenhagen has one of the world's largest district-heating systems. Waste heat from electricity production and industrial processes is captured and used to provide heating to residential and commercial buildings. This system has significantly reduced the city's reliance on individual heating systems and contributed to energy savings and emissions reductions [55].
5. *Smart City Solutions*: Copenhagen has embraced smart technologies to optimise various urban services. Intelligent street-lighting systems have been implemented that adjust lighting levels based on the presence of pedestrians and vehicles, saving energy. Real-time data monitoring and analysis are used to optimise energy consumption in buildings and improve waste management processes. These smart city initiatives have enhanced efficiency, reduced resource consumption, and improved the overall urban environment [54].
6. *Green Spaces and Biodiversity:* Copenhagen has focused on creating and preserving green spaces within the city. Parks, urban gardens, and rooftop greenery have been integrated into the urban fabric, providing areas for recreation, improving air quality, and supporting biodiversity. The city has also adopted nature-based solutions, such as rain gardens and green roofs, to manage stormwater runoff and mitigate the effects of climate change [56].
7. *Waste Management:* Copenhagen has implemented an ambitious waste management strategy to achieve its goal of recycling 70% of its municipal waste by 2024. The city has implemented separate waste collection systems, including organic waste, recyclables, and residual waste. It has also implemented a comprehensive recycling program, with a high recycling rate. These efforts have reduced the amount of waste sent to landfills, minimised resource consumption, and increased the recycling of valuable materials [56,57].

8. *Water Management:* Copenhagen has implemented sustainable water management strategies to address the challenges posed by climate change and urbanisation. The city has implemented initiatives such as rainwater harvesting, green roofs, and permeable pavements to manage stormwater runoff and reduce the strain on the sewage system. These measures help mitigate flooding and improve water quality in rivers and coastal areas [48].
9. *Green Procurement:* Copenhagen has integrated sustainability criteria into its procurement processes. The city gives preference to environmentally friendly products and services, promoting the use of sustainable materials, energy efficient technologies, and low-carbon solutions. By setting high sustainability standards in its procurement practices, Copenhagen encourages the development and adoption of more sustainable products and services [58].
10. *Climate Adaptation:* Copenhagen has implemented measures to adapt to the impacts of climate change, such as rising sea levels and more frequent extreme weather events. The city has constructed protective infrastructure, including flood barriers and sea defences, to safeguard vulnerable areas from storm surges. It has also created urban green spaces that can absorb excess rainwater and act as buffer zones during floods. These adaptation measures aim to enhance the city's resilience to climate change and minimise potential damage [48].

2.2.3. Intervention Results and Performance

- *Carbon Emissions Reduction*: Copenhagen has made significant progress in reducing carbon emissions. According to the City of Copenhagen's Climate Accounts, carbon emissions decreased by around 42% between 2005 and 2019, despite population and economic growth. This reduction is attributed to the city's focus on renewable energy, energy efficiency measures, and sustainable transportation.
- *Cycling Mode Share*: Copenhagen's efforts to promote cycling have resulted in a high cycling mode share among residents. The City of Copenhagen regularly collects data on cycling patterns and behaviour. According to the latest available data, around 62% of residents in Copenhagen commute to work or school by bicycle. This high mode share demonstrates the success of the city's initiatives in encouraging sustainable transportation.
- *Energy Efficiency in Buildings*: The impact of energy efficiency measures in buildings is evident in Copenhagen. The city has set strict energy efficiency standards for buildings, both new and existing. According to the Copenhagen Energy and Climate Accounts, energy consumption in buildings decreased by approximately 28% between 2005 and 2019. This reduction indicates the effectiveness of energy efficient building practices and retrofits.
- *Renewable Energy Production*: Copenhagen's commitment to renewable energy is supported by evidence of increased renewable energy production. The city has invested significantly in wind power, and offshore wind farms such as the Middelgrunden Wind Farm contribute to the energy supply. Data from the Danish Energy Agency show a substantial increase in renewable energy production in the city, highlighting the impact of these investments.
- *Waste Management and Recycling*: Copenhagen's waste management strategies have shown positive outcomes in waste reduction and recycling. The city has implemented separate waste collection systems and recycling programs. According to the Copenhagen Resource and Waste Strategy, the recycling rate in the city increased from 22% in 2008 to over 46% in 2019. This demonstrates the effectiveness of waste management policies and the commitment to a circular economy approach.
- *Air Quality Improvement:* Although air quality is influenced by multiple factors, Copenhagen's focus on sustainable transportation and reduced car dependency has contributed to improvements. The Danish Air Quality Monitoring Program provides data

on air pollutant levels. The measurements show a decreasing trend in air pollutants, indicating improved air quality in the city.

2.2.4. Strategies and Policy Tools

The impact achieved in Copenhagen through smart sustainable interventions has been accomplished through a combination of policy tools and strategies. Here are some key policy tools that have played a significant role [50]:

1. *Policy Frameworks*: Copenhagen has developed comprehensive policy frameworks and action plans that set the vision and goals for sustainable development. These frameworks provide a roadmap for guiding initiatives and actions in areas such as transportation, energy, waste management, and urban planning. They help prioritise sustainability objectives, ensure coordination among various stakeholders, and provide a basis for decision-making and resource allocation.
2. *Regulatory Measures*: Copenhagen has implemented regulations and standards to enforce sustainability practices. For example, the city has set strict energy efficiency standards for buildings, requiring new constructions to meet specific environmental criteria. These regulations create incentives for developers and building owners to adopt sustainable practices and technologies. Copenhagen also imposes waste management regulations that promote recycling and waste reduction, and it has implemented zoning regulations to protect green spaces and promote sustainable urban development.
3. *Financial Incentives*: The city has introduced financial incentives to encourage sustainable behaviour. These incentives may include grants, subsidies, tax benefits, and low-interest loans. For instance, Copenhagen offers subsidies for renewable energy installations, energy efficient retrofits, and sustainable transportation initiatives. Financial incentives play a crucial role in driving private investments, stimulating innovation, and accelerating the adoption of sustainable technologies and practices.
4. *Collaborative Partnerships*: Copenhagen has fostered collaborative partnerships with various stakeholders, including businesses, research institutions, and civil society organisations. These partnerships promote knowledge sharing, innovation, and the co-creation of sustainable solutions. Collaborations with businesses have led to the development and implementation of smart city technologies, whereas partnerships with research institutions have facilitated data analysis and evidence-based decision-making.
5. *Public Engagement and Awareness*: Copenhagen has prioritised public engagement and awareness campaigns to encourage behaviour change and active participation in sustainable initiatives. The city has conducted public consultations, awareness campaigns, and educational programs to inform and involve residents in sustainable practices. Engaging the public helps build support, generate ideas, and mobilise collective action towards sustainable goals.
6. *International Cooperation and Knowledge Exchange*: Copenhagen actively participates in international networks, collaborations, and knowledge-sharing platforms focused on sustainable urban development. The city shares its experiences, best practices, and lessons learned with other cities and learns from their experiences as well. International cooperation enhances policy learning, facilitates access to funding and technical assistance, and promotes global sustainability agendas.

By employing these policy tools, Copenhagen has created a conducive environment for implementing smart sustainable interventions and achieving their desired impact. The combination of regulatory measures, financial incentives, collaborative partnerships, public engagement, and international cooperation has supported the city's transformation into a leading sustainable and smart city.

2.2.5. Takeaways and Lessons

The experience of Copenhagen in implementing smart sustainable interventions can serve as a valuable model for other cities looking to enhance their sustainability efforts. Here are some key considerations for transferring this experience elsewhere:

Adaptation to local context: Each city has its unique characteristics, challenges, and resources. It is important to adapt the Copenhagen experience to the specific context of the target city. This involves conducting a thorough assessment of the local environment, transportation patterns, energy sources, waste management systems, and public preferences. By understanding the local context, city leaders can identify which initiatives and strategies from Copenhagen are most applicable and feasible.

Political will and leadership: Successful implementation of sustainable initiatives requires strong political will and leadership. City leaders need to be committed to sustainability goals and have a clear vision for the transformation of their city. They must prioritise sustainability on the political agenda and garner support from various stakeholders, including government departments, businesses, and the public.

Stakeholder engagement: Engaging stakeholders is crucial for the transfer of sustainable practices. Collaboration with businesses, community organisations, research institutions, and residents fosters a sense of ownership and promotes a shared responsibility for sustainability. It is important to involve stakeholders from the early stages of planning, implementation, and evaluation to ensure a comprehensive and inclusive approach.

- *Policy Framework and Regulations*: Developing a policy framework and a regulatory framework that support sustainability is essential. This may involve enacting laws, setting targets, and implementing regulations to incentivise sustainable practices. It is crucial to create an enabling environment that encourages sustainable behaviour through financial incentives, subsidies, tax benefits, and supportive regulations.
- *Capacity Building and Knowledge Sharing:* Transferring the Copenhagen experience requires building local capacity and knowledge. This can be achieved through training programs, workshops, and knowledge-sharing platforms. Leveraging partnerships with academic institutions, research organisations, and other cities can facilitate the exchange of best practices, lessons learned, and technical expertise.
- *Long-term Planning and Monitoring*: Sustainability is a long-term endeavour, and a comprehensive plan is necessary. Developing a long-term sustainability strategy that outlines goals, targets, and a roadmap for implementation is critical. Regular monitoring, data collection, and evaluation of progress help assess the effectiveness of interventions, identify areas for improvement, and ensure accountability.
- *Communication and Public Awareness*: Effective communication and public awareness campaigns are essential for engaging the public and generating support. Transparent communication about the benefits of sustainability, involvement opportunities, and progress updates fosters a sense of shared responsibility and encourages behaviour change.

By considering these factors and tailoring the Copenhagen experience to the local context, cities can transfer and adapt sustainable practices effectively. Collaboration, policy alignment, capacity building, and public engagement are key elements in replicating and scaling up successful initiatives. Sharing knowledge, experiences, and lessons learned between cities can accelerate global efforts towards sustainability.

2.3. Validation by Expert Review

For models that are difficult to validate on actual instances, the Delphi approach is extensively employed in social and urban studies, such as evaluating success factors from the construction industry perspective for applying smart mobility [59], forming urban policy scenarios to manage sustainable growth [60], developing sustainable city indicators [61], identifying smart city perceptions [62] and evaluating smart city KPIs [63], and conducting research on smart sustainable cities, as in [64]. 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 [64,65].

As transitioning a city towards a smart sustainable city is multi-disciplinary oriented [66], experts were chosen accordingly to represent a wide variety of fields collectively instead of a single niche competency. Participants were identified based on the skill contribution they could fulfil in the group.

A group of five multi-disciplinary experts participated in the validation process for the proposed framework. The selection of experts was based on their availability to participate in the validation, and their industry experience in terms of years and depth of exposure to diverse projects relevant to smart or sustainable infrastructure development. Each participant was asked to rate their level of skill based on 18 domains related to smart sustainable city transitions. Figure 4 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. Of the 18 domains listed in Figure 4, all of the domains were at least represented by a skilled level in the group, of which 12 were represented by highly skilled participants.

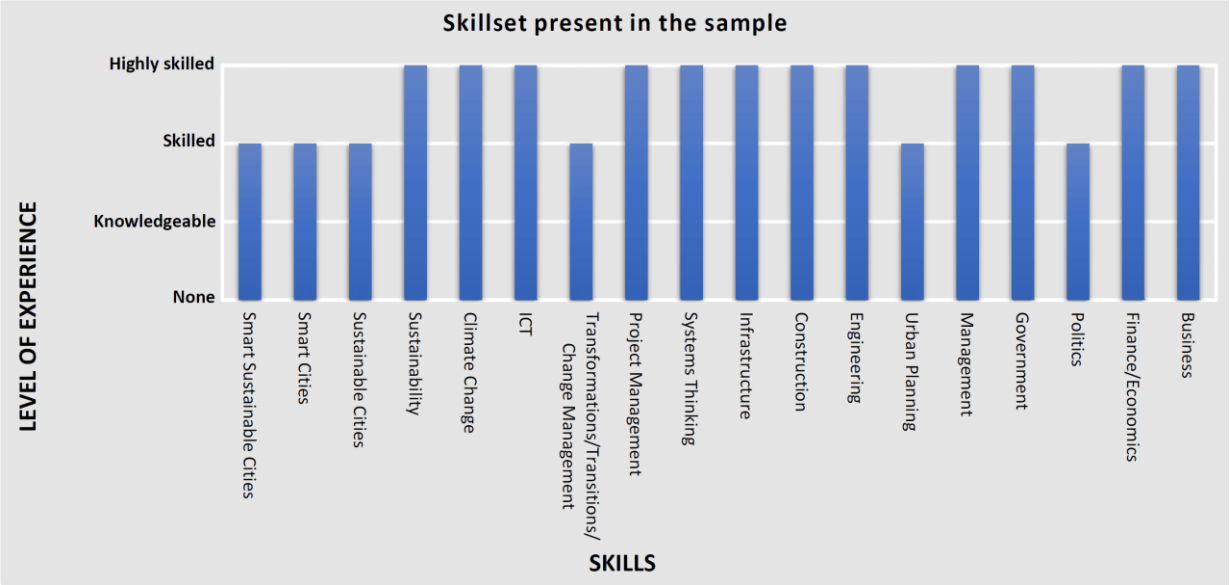

Figure 4. The combined skillset of the validation participants.

In the literature review [42], it was observed that the literature available is most dominant in urban, ICT, and sustainability studies, which were represented lower by the skillsets of the participants. Policy development was the strongest aim present within the reviewed literature, and research funded by governmental organisations was most dominant in number. Some of the scarcer fields for the available literature were well represented by the skillsets of the survey participants. The smart, sustainable, and smart sustainable city skill levels were only represented at skilled levels in the group, which correlates to the observation that there are not many experts in practice in these fields and none that were available at the time to participate in the study. However, the case study verification of the framework contributed insights that were very strong in the domain of smart, sustainable, and smart sustainable cities, which also incorporated the collection of practitioners' perspectives documented in [44] that were directly involved with using smart technology and design to accomplish urban sustainability aims whilst working for reputable and established companies in the field on various urban projects globally.

Finally, although only five participants were used for the validation, a significant number in years of experience was 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 was not only diversely represented by the different years of experience brackets, but each participant also offered a unique viewpoint based on their background and field of work.

The 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 that could have been absent or overlooked 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 better insight into the specific knowledge each participating expert had in each of the 18 selected domains relating to the developed framework. These domains were smart sustainable cities, smart cities, sustainable cities, sustainability, climate change, ICT (information and communication technology), transitions and change management, project management, systems thinking, infrastructure, construction, engineering, urban planning, management, government, politics, finance and economics, and business.

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 one was chosen to prevent respondents from clustering responses towards a middle or neutral category [67]. The participants were required to rate every step and stage on a 4-point Likert scale. The input provided by the experts was utilised to adapt and update the framework where required by modifying the existing components or adding missing components [64]. This contributes to the framework's credibility when applied to real-world systems and instances [68].

3. Resulting SSUIT Framework

The seven stages that were identified were incorporated as the overall main stages in the SSUIT framework, which is presented in Figure 5. These stages are (1) pre-project preparation; (2) teams, city state, readiness, and assessment; (3) project identification and selection; (4) design; (5) implementation; (6) maintenance, evaluation, and innovation; and (7) new initiatives and upgrades. 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. For each of the seven SSUIT stages, a separate framework was developed and is included in Appendix A.

3.1. SSC Initiation Stage

Stage 1 (Figure A1) was renamed from the *pre-project preparation* stage to the *initiation* stage after the validation of the framework by the experts. The stage starts with establishing the *facilitators and expert team*, determining the *infrastructure hierarchy* of the city, and finding *benchmark projects* or examples of successful smart or sustainable urban initiatives. Determining the city's *infrastructure hierarchy* entails developing a layout or network representation thereof, identifying the major role players at each level of the branch or node, and determining dependencies on one another. During the *benchmark projects* step, information should be drawn from successful real-world smart and 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 based on the recommendations of the panel of experts.

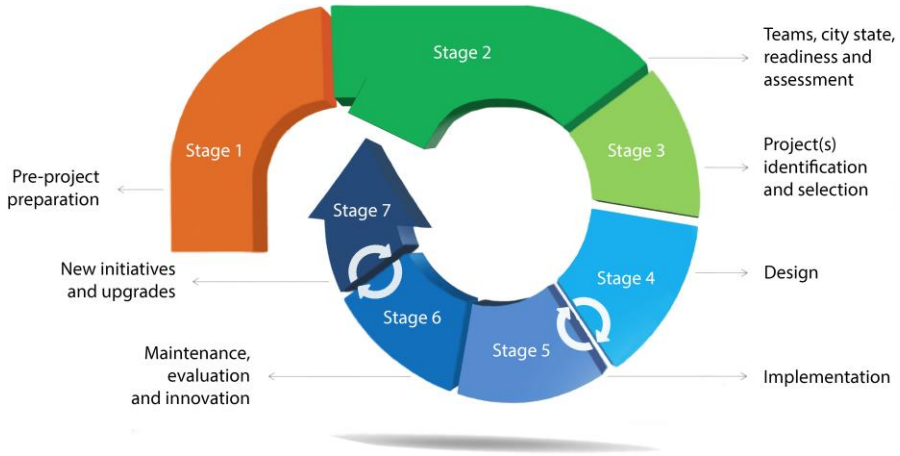

Figure 5. Overall flow of the stages within the SSUIT framework.

The *city background and transition drivers* step addresses two aspects of the city. The background of the city is beneficial in better understanding the political, social, and historical context when designing and executing workshops later in Stage 1. Transition drivers, highly regarded by the experts, help with understanding the motivations for the smart sustainable city transition.

The next part of Stage 1 is to start with *workshops* using the EDASS method, which consists of three components: Explore, Design, and Act for smart sustainability. The EDASS method is based on work carried out in [69] that was used to perform sustainability planning for energy infrastructure in the Western Cape Province of South Africa.

The *Explore* component, like in [69], is intended for developing viable, smart sustainable city options within the given infrastructure's context. It has three steps that are executed after assigning workshop participants into groups. The three steps for the Explore section are envisage the future, smart sustainable options, and future conditions. *Envisage the future* touches on how the particular infrastructure can be envisioned in 30 years' time. It gives participants a chance to broaden perspectives on smart sustainability by showcasing, discussing, and debating contemporary smart sustainability advancements. The *smart sustainable options* step determines which of the smart sustainable possibilities are perceived as plausible given the context and envisaged future. This functions as a means of identifying smart sustainable alternatives. Regarding *future conditions*, which is the third step of the Explore segment, the aim is to find a collection of possible futures representing non-controllable future circumstances. An optimistic, negative, and most probable outlook can be applied. A PESTLE analysis that considers political, economic, social, technological, legal, and environmental factors [70] can also be used.

The *Design* component is based on [69] 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 of the system's objectives. After defining the system, specific smart sustainable strategies may be developed. The aim is to keep the system description in mind while generating no more than five to nine suitable solutions. The chosen smart sustainable 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 are used as part of the assessment, with the lowest risks being most appealing. The level of risk that stakeholders are willing to take on affects the number of viable options. The most ideal solutions are then used to determine the proper action stages and follow-up activities necessary to turn the desired plan into a reality.

The *Act* component is the last component of the EDASS method based on [69]. This component is actuated 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 representatives who will advocate for the action points, and a commitment regarding when the action points will be completed.

After the first round of workshops is completed, the facilitators and expert teams have to confer to work out an integration of all the 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 be summarised and that all participants receive feedback. More workshops will follow, as this is an iterative process. After the first round, the second workshops continue at the same functional division level until the integration of options provided by these divisions start to converge. Thereafter, the workshops are *integrated* on a holistic scale where joint planning efforts of the appropriate representatives from each of the divisions sit together during new EDASS iterations. Once sufficient consensus is reached among the various division representatives, the EDASS iterations are concluded.

The *buy-in* step determines the governmental and investor interest within the options concluded from the EDASS rounds. The potential buy-in is a determining factor for whether the smart sustainable city is able to continue to Stage 2. A valuable tool in this first phase of pre-project preparation is Shmelev's publication [71] on a multicriteria approach that can be used to determine linkages between various dimensions for a city and anticipate which potential interventions would have more effective results in the specific urban context. This aids in the analysis of investment potential and opportunities.

3.2. Teams, City State, Readiness, and Assessment Stage

Stage 2 in Figure A2 was introduced in [34] as part of a sustainable urban design framework and was further amended for smart sustainable cities with the work from [29,35,64]. The stage consists of four steps and involves preparing the team, developing a draft charter, determining the city state and readiness for transformation, and completing a city assessment and benchmarking. For this stage, it is important to revisit the example benchmark projects investigated in Stage 1 for guidance. The insights from [71] also help to understand how to form an objective perspective of the specific city being transformed, and in what way it is comparable to other cities on the grounds of context, as this plays a determining role in the decision-making process and should not be directed by ungrounded assumptions or preconceptions.

3.3. Project(s) Identification and Selection Stage

Stage 3 from Figure A2 starts with *identifying* all plausible infrastructural projects that fall under the five dimensions of a smart sustainable city (environment, economy, social, urban infrastructure, governance). The *project evaluation and selection* step follows, which helps to determine which projects to select from all the possible projects for the smart sustainable city transformation. Next is the *project evaluation and selection* step, which helps to determine which projects to select from all the possible projects for the smart sustainable city transformation. A *project integration* step follows and is aimed at determining how well the resulting solutions and systems of the projects selected in the project evaluation step will integrate and function in conjunction for the purpose of a smart sustainable city. This step requires consideration of the interconnected and interdependent nature of city systems [72] and the systemic functioning needed [73] to bring together different chains of processes and ecosystems [74] while holistically achieving the objectives set out for the smart sustainable city [22].

The final steps include refining the *business case* and financing for the various projects and initiatives and arriving at a final *selection* of projects and effectively communicating with government and investors. At this point, smart sustainable city education and awareness programs should be initiated to help prepare city occupants to understand the smart sustainable city concepts, how they can be utilised, and the potential visions and goals set for the city.

It is also advised throughout the project identification and selection stage that the public, universities, innovation hubs, living labs, and private sector are involved and can make valuable contributions in terms of guiding, testing, modelling, and refining concepts for the city's smart sustainable transition. Structurally, the project identification to selection and communication stages allow previous steps to be revisited in order to adapt or refine decisions according to insights that develop in the process. After Stage 3 has completed, the framework continues to Stage 4.

3.4. Design Stage

Stage 4, *design* in Figure A3, consists of five steps: resources and procurement, business case design, designing, evaluating, and communicating. As recommended by experts, there is also a responsibility to oversee the design tendering process and allocations, especially during the initial steps.

The *resources* step consists of allocating the required resources for the design stage of the projects and procuring the design teams. This step also includes setting and verifying contracts with the involved design teams and deciding on the means of tracking the design progress. The *business case design* step focuses on quality of life, sustainability, futureproofing, and value creation in a city. During the *design* step, multiple designs by various teams for different parts of the transformation and of the city are developed. It is important that the 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 management and use of intermediaries or knowledge brokers. The *design* step entails developing structural solutions and management solutions (non-structural) that function together effectively to serve the city. ICT solutions should be based on the latest validated industry standards to stay relevant and compatible and provide seamless integration. Design requirements regarding data ethics, platform accessibility, and the business ecosystem needs should be addressed. As recommended in [75], ICT solutions should also be platform independent, as exclusive solutions may come with closed contracts and agreements could entail lock-in. The evaluation of the designs during the *evaluate* step focuses on determining whether the proposed projects are still viable and whether the transformation objectives will be met if implemented. This includes any possible conflicts that a project has with other projects, or the desired outcomes of the smart sustainable city that should be addressed. Finally, the findings from the evaluation step should be *communicated* to key governmental representatives, business ecosystem stakeholders, and project investors. A decision should be made on whether the project may continue to the implementation (Stage 5) or requires further iterations of the business case design or design steps before continuing to the implementation stage.

Adaptive implementation and design is displayed in the column between Stages 4 and 5 (design and implementation stages, respectively) in Figure A4 and must be taken into consideration throughout Stages 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 [76,77]. 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 [78].

3.5. Implementation Stage

Stage 5 (Figure A3) the *implementation*, consists of five steps: management office, development of project definition packages, resources, implementation and monitoring, and re-adaptation or handover. The programme manager in the *management office* step 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 [79].

The *development of project definition packages* step can include analysing the construction risks of the project, documenting the project implementation scope, and defining the project execution approaches. The *resources* step consists of allocating the required resources for the implementation stage of the projects and procuring the construction teams. Contracts are also set and verified with the involved design teams and decisions are made on the means of tracking the design progress.

The *implement and monitor* step consists of the following activities: initiating the implementation of multiple projects (indicated by a multi-layered block) based on the determined schedule, monitoring and controlling projects, tracking progress, adjusting schedules and resources accordingly while keeping all projects informed and involved regarding changes, communicating project and transition progress to key governmental stakeholders and investors, and updating relevant documentation with any changes during the implementation.

Finally, the *review, re-adapt, or handover* step includes evaluating completed projects for compliance with project specifications and smart sustainable city goals, capturing the lessons learned to inform current projects in design, and identifying future endeavours or completed projects that require adaptations. If a project is built according to construction specifications and achieves the set smart sustainable city goals, operation and maintenance documents should be compiled, and the necessary training, skills, and resources should be prepared and established for handover to the maintenance and operation teams in Stage 6.

3.6. Maintenance, Evaluation, and Innovation Stage

Stage 6 (Figure A4), the *maintenance, evaluation, and innovation* stage, consists of five steps. These steps are monitoring, managing, and responding; city assessment; infrastructure maintenance; security, and innovation. The *monitor, manage, and respond* 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. *City assessment* entails the performance evaluation of the city and is similar to the city assessment and benchmarking step in Stage 2. The *infrastructural maintenance* step consists of completing 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. During the *security and innovation* step, high security should always be of utmost importance and the security measures should be kept up to date with emerging threats. Improvements should continuously be made without compromise or delay and the emergency response plan for security breaches should be kept up to date. During the innovation step, constant city innovation is required to account for the changing city dynamics, changing technological paradigms, maintaining compatibility with society, and aligning or complying with the evolving requirements for a city to keep functioning as a smart sustainable city. It is necessary to re-evaluate the urban context continuously and make the necessary adaptions.

3.7. New Initiatives and Upgrades Stage

Lastly, Stage 7 in Figure A4 consists of seven steps that include re-appraising the city, re-assess visions and goals, strategic options to realise visions and goals, a project feasibility study, investment/development companies or other opportunities, and lastly, pursuing, re-negotiating, or business as usual. During the re-appraise the situation step, data and analytics available to evaluate the smart sustainable city performance and to identify problems, opportunities, and other needs should be utilised. The latest requirements and expectations for a smart sustainable city should be discussed and evaluated. Further, the latest stakeholder requirements should be identified through surveys and town hall meetings.

The *communicate with government and project investors* step informs these parties about the city state and the proposed initiatives and upgrades. The *strategic options to realise visions and goals* step is about determining the possible paths to realise the visions and goals. During

this early evaluation, a PESTLE analysis, which takes political, economic, socio-cultural, technological, legal, and environmental factors into account, can be used as recommended in [69] to explore the potential strategic options and the potential consequences.

During the *project feasibility study* step, a feasibility study should be conducted for each of the interventions suggested. The investment or development companies and other opportunities step deals with seeking funding or investment opportunities or potential business opportunities to help finance and realise the visions and goals of new innovations or significant upgrades. According to the work in [22,80], it is important to have sustainable broad-based funding to prevent the project direction from being dictated in future by the pursuit of funding.

Finally, during the *pursue, re-negotiate, or business as usual* step, all findings regarding the planned maintenance or innovations or upgrades in Stage 7 should be presented to the key governmental representatives and project investors so that a decision can be made regarding whether the project(s) suggested should continue to Stage 2, be completely aborted, be postponed, or be re-negotiated and restructured.

4. Discussion

In the work presented in [29] a high-level transformation readiness roadmap for smart sustainable cities is featured that highlights the essential stages. The results in [29] urge future research to build on the roadmap by establishing a transition framework for smart sustainable cities. Future research suggestions in [30] indicated that a more comprehensive and detailed guide or framework that is based on existing smart sustainable city roadmaps should be developed for the transition towards a smart sustainable city. The present research does not offer a framework to guide large-scale infrastructure transition projects or long-term intervention programs to transform existing cities into smart sustainable cities. The objective of this research was to consequently develop such a conceptual framework for smart sustainable city transitions. The framework can aid urban and national governing of infrastructure so as to provide enhanced cities that are effective, equitable, and safe and offer an improved quality of life to their citizens.

Validation of the framework was conducted to determine whether the framework is suitable for its application in practice. Using the Delphi technique, multidisciplinary industry experts examined and critiqued the framework. The feedback was used to modify the framework until the experts were 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 [69], was found to be a suitable guide for the pre-project planning stage, based on requirements determined from participant feedback during the expert review. The final feedback indicated that the experts were satisfied with the new Stage 1 design and felt that the framework will be effective when applied in practice.

The framework 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 the municipal level of hard and soft infrastructure, initiatives, policies, budgeting, partnerships, and co-creation mechanisms. The framework can help regional and national governments be informed, develop visions, set objectives, develop strategies and identify projects for transitioning their cities towards smart sustainable cities.

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 they are. The framework contains activities such as benchmarking, evaluation,

and assessment, but the tools themselves (e.g., indicators, rankings, standards, policies, best practices) 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, such as the resource from [71] that guides the understanding of the linkages and dimensions of a city contextually before assuming the impacts of specific intervention options. It is likely and expected that many activities, standards, and tools in the industry will vary or change in some way. Yet the awareness of smart sustainable cities as systems-of-systems that are complex and adaptive 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.

5. Conclusions

Smart cities and sustainable cities are fundamentally two distinct types of cities. By combining smart and sustainable cities, their individual strengths can be incorporated so as to better solve many global urban challenges that have for so 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 policymaking by providing insight with regard to developing policies that are effective and sustainable. Urban infrastructure was identified as a point of intervention when transitioning a city to become smart and sustainable.

This study addresses the future research suggested in [30] to build on existing roadmaps to develop a more detailed and comprehensive guide or framework for transitioning towards smart sustainable cities. The framework can aid urban and national governing of infrastructure so as to provide enhanced cities that are effective, equitable, and safe and offer an improved quality of life to their citizens.

Insights from a systematic and conceptual literature review were incorporated to synthesise the framework. Verification against a collective case study revealed adaptations that were applied in order to ensure appropriate design for the 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 an effective transition towards smart sustainable cities.

The framework is intended to be used as a generic guideline that is 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. 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 the Sustainable Development Goals (SDGs).

Engineering consultants will be able to utilise the SSUIT framework to evaluate and develop infrastructure solutions that not only contribute to the greater goal of a smart sustainable city but also are integrated with the combined effort 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 co-creation, inclusivity, interoperability, and accessibility. 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.

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A.C.B.; supervision, A.C.B. and I.H.D.K.; funding acquisition, A.C.B., I.H.D.K. and H.J.G. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Disclaimer: The interpretation of ESPON material does not necessarily reflect the opinion of the ESPON Monitoring Committee.

Appendix A

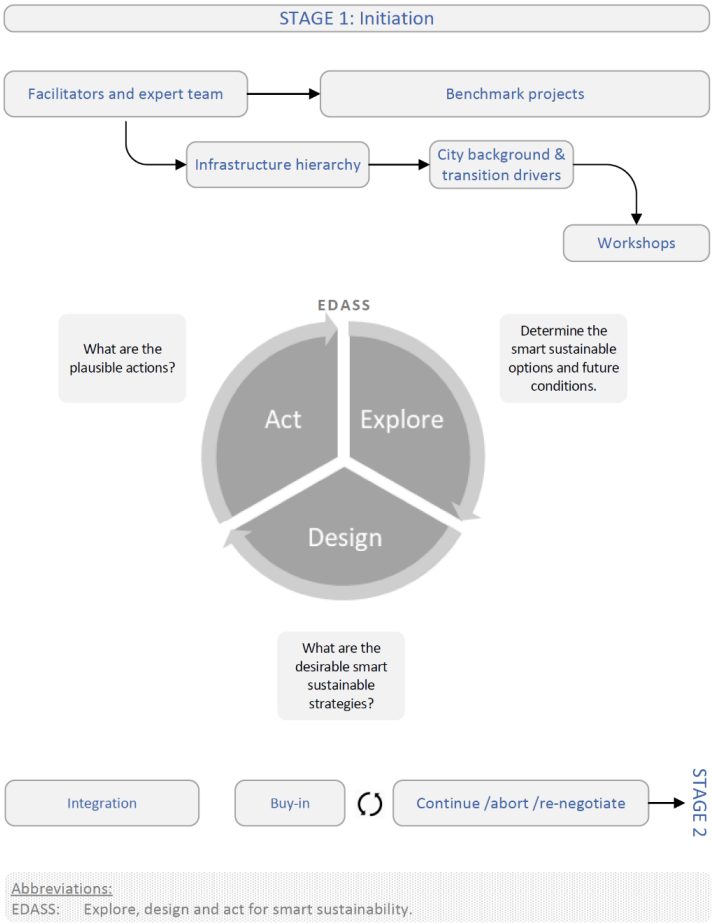

Figure A1. Pre-project preparation or SSC initiation as Stage 1 of the framework.

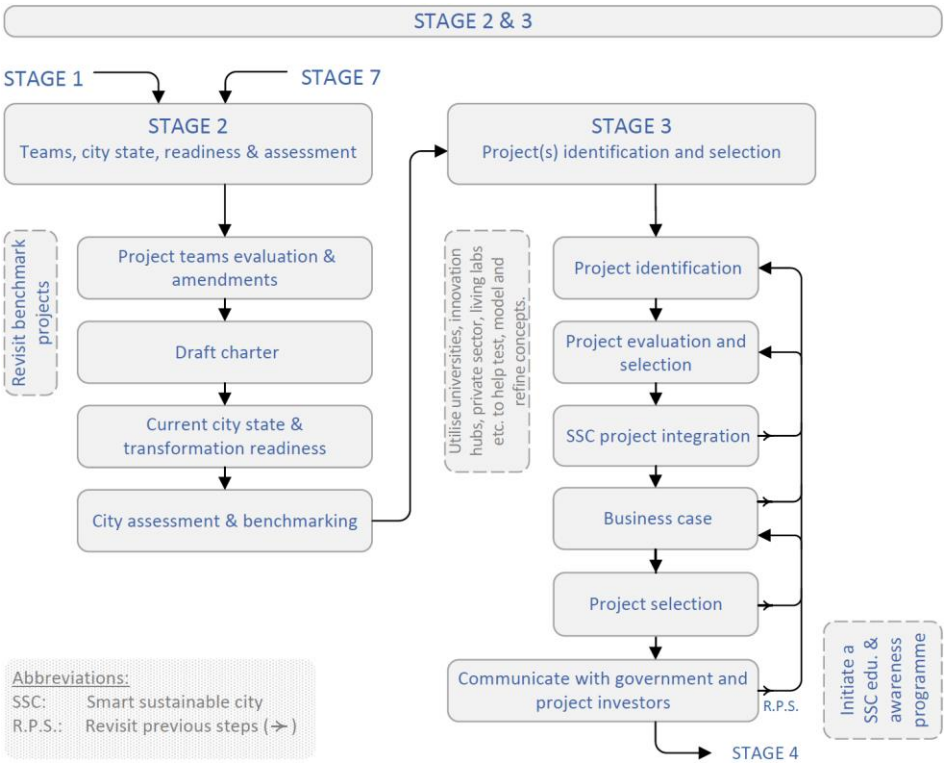

Figure A2. Stages 2 and 3 of the final framework.

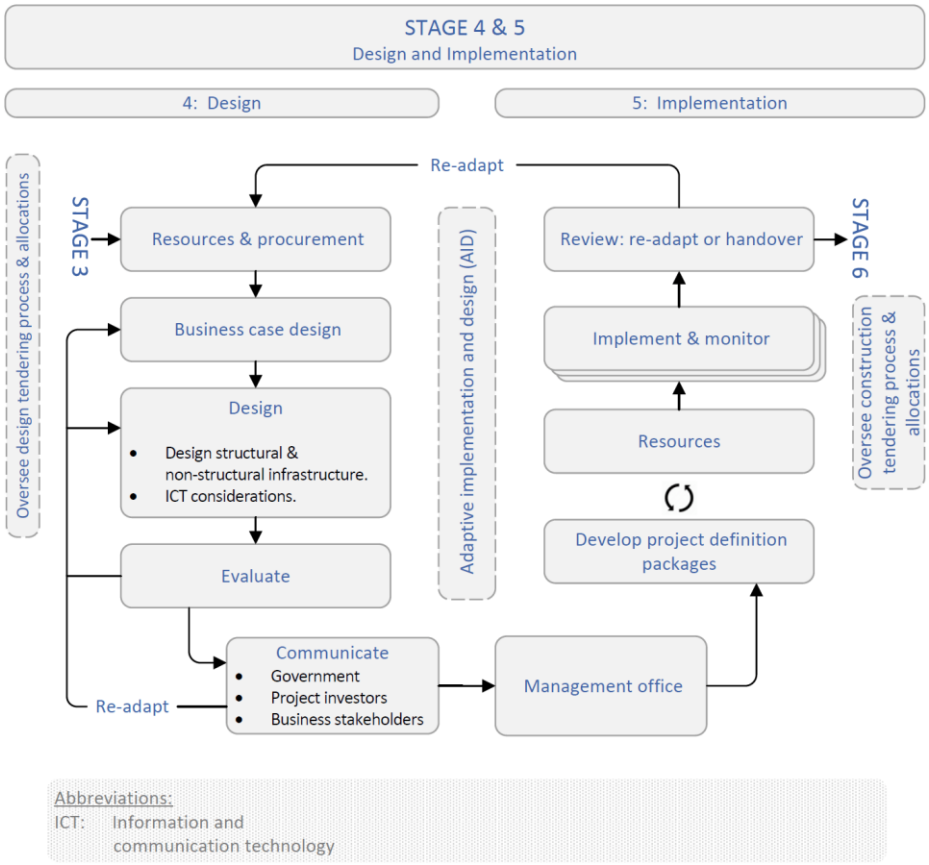

Figure A3. Stages 4 and 5 of the final framework.

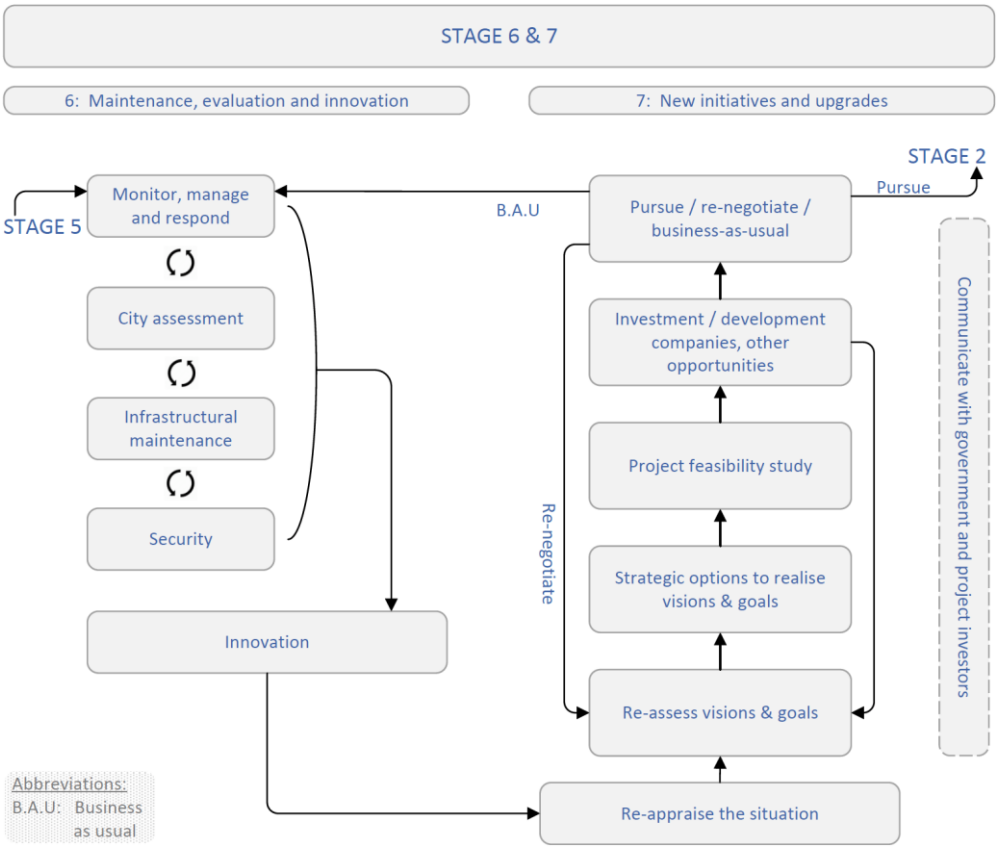

Figure A4. Stages 6 and 7 of the final framework.

References

1. UN-DESA, United Nations, Department of Economic and Social Affairs. *Population Division: Data Query—Annual Urban Population at Mid-Year*; UN-DESA: New York, NY, USA, 2022.
2. Das, S.; Angadi, D.P. Assessment of urban sprawl using landscape metrics and Shannon's entropy model approach in town level of Barrackpore sub-divisional region, India. *Model. Earth Syst. Environ.* **2020**, *7*, 1071–1095. [CrossRef]
3. Zhang, X.Q. The trends, promises and challenges of urbanisation in the world. *Habitat Int.* **2016**, *54*, 241–252. [CrossRef]
4. UN-DESA, United Nations, Department of Economic and Social Affair. *Population Division: Total Population—Both Sexes. De Facto Population in a Country, Area or Region as of 1 July of the Year Indicated*; UN-DESA: New York, NY, USA, 2019.
5. UN-DESA, United Nations, Department of Economic and Social Affair. *Population Division: Annual Percentage of Population at Mid-Year Residing in Urban Areas by Region, Subregion and Country, 1950–2050*; UN-DESA: New York, NY, USA, 2019.
6. Sorensen, A.; Brenner; Cities, A.-K. Cities, Urban Property Systems, and Sustainability Transitions: Contested Processes of Institutional Change and the Regulation of Urban Property Development. *Sustainability* **2021**, *13*, 8429. [CrossRef]
7. Batty, M. The size, scale, and shape of cities. *Science* **2008**, *319*, 769–771. [CrossRef]
8. Chofre, I.L.; Gielen, E.; Jiménez, J.S.P. Approach to urban metabolism of Almassora municipality, Spain, as a tool for creating a sustainable city. *WIT Trans. Built Environ.* **2018**, *179*, 209–219.
9. Agudelo-Vera, C.M.; Mels, A.R.; Keesman, K.J.; Rijnaarts, H.H. Resource management as a key factor for sustainable urban planning. *J. Environ. Manag.* **2011**, *92*, 2295–2303. [CrossRef] [PubMed]
10. Brundtland, G.H. *Report of the World Commission on Environment and Development: Our Common Future*; Oxford University Press: Oxford, UK; United Nations: New York, NY, USA, 1987.
11. Cibulka, S.; Giljum, S. Towards a comprehensive framework of the relationships between resource footprints, quality of life, and economic development. *Sustainability* **2020**, *12*, 4734. [CrossRef]
12. Litman, T.; Burwell, D. Issues in sustainable transportation. *Int. J. Glob. Environ. Issues* **2006**, *6*, 331–347. [CrossRef]
13. Lee, S.-W.; Seow, C.-W.; Xue, K. Residents' sustainable city evaluation, satisfaction and loyalty: Integrating Importance-Performance Analysis and Structural Equation Modelling. *Sustainability* **2021**, *13*, 6766. [CrossRef]
14. Perlman, J.E.; Sheehan, M.O. "Fighting Poverty and Environmental Injustice in Cities": From State of the World 2007: Our Urban Future (2007). In *Sustainable Urban Development Reader*; Routledge: Milton Park, UK, 2007; p. 172.
15. Shmelev, S.E.; Shmeleva, I.A. Global urban sustainability assessment: A multidimensional approach. *Sustain. Dev.* **2018**, *26*, 904–920. [CrossRef]

16. Blasi, S.; Ganzaroli, A.; De Noni, I. Smartening sustainable development in cities: Strengthening the theoretical linkage between smart cities and SDGs. *Sustain. Cities Soc.* **2022**, *80*, 103793. [CrossRef]
17. Schiavo, F.; de Magalhães, C. Smart Sustainable Cities: The Essentials for Managers' and Leaders' Initiatives within the Complex Context of Differing Definitions and Assessments. *Smart Cities* **2022**, *5*, 994–1024. [CrossRef]
18. Höjer, M.; Wangel, J. Smart Sustainable Cities: Definition and Challenges. In *ICT Innovations for Sustainability*; Springer International Publishing: Berlin/Heidelberg, Germany, 2015; pp. 333–349.
19. Ranđelović, M.; Nedeljković, S.; Jovanović, M.; Čabarkapa, M.; Stojanović, V.; Aleksić, A.; Ranđelović, D. Use of Determination of the Importance of Criteria in Business-Friendly Certification of Cities as Sustainable Local Economic Development Planning Tool. *Symmetry* **2020**, *12*, 425. [CrossRef]
20. Snieška, V.; Zykiene, I. The Role of Infrastructure in the Future City: Theoretical Perspective. *Procedia—Soc. Behav. Sci.* **2014**, *156*, 247–251. [CrossRef]
21. Monstadt, J. Urban Governance and the Transition of Energy Systems: Institutional Change and Shifting Energy and Climate Policies in Berlin. *Int. J. Urban Reg. Res.* **2007**, *31*, 326–343. [CrossRef]
22. Hodson, M.; Marvin, S. Can cities shape socio-technical transitions and how would we know if they were? *Res. Policy* **2010**, *39*, 477–485. [CrossRef]
23. Elzen, B.; Geels, F.W.; Green, K. *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*; Edward Elgar Publishing: Cheltenham, UK, 2004.
24. Geels, F.W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environ. Innov. Soc. Transit.* **2011**, *1*, 24–40. [CrossRef]
25. Bulu, M. *City Competitiveness and Improving Urban Subsystems: Technologies and Applications*; IGI Global: Hershey, PA, USA, 2011.
26. Dong, L.; Wang, Y.; Scipioni, A.; Park, H.-S.; Ren, J. Recent progress on innovative urban infrastructures system towards sustainable resource management. *Resour. Conserv. Recycl.* **2018**, *128*, 355–359. [CrossRef]
27. *PD 8101*; Smart Cities—Guide to the Role of the Planning and Development Process. BSI Standards Publication: London, UK, 2014.
28. 28. *PAS 181*; Smart city framework—Guide Customer Service to Establishing Strategies for Smart Cities and Communities. BSI Standards Publication: London, UK, 2014.
29. Ibrahim, M.; El-Zaart, A.; Adams, C. Smart sustainable cities roadmap: Readiness for transformation towards urban sustainability. *Sustain. Cities Soc.* **2018**, *37*, 530–540. [CrossRef]
30. Pereira, G.V.; de Azambuja, L.S. Smart Sustainable City Roadmap as a Tool for Addressing Sustainability Challenges and Building Governance Capacity. *Sustainability* **2021**, *14*, 239. [CrossRef]
31. De Azambuja, L.S. Drivers and Barriers for the development of Smart Sustainable Cities: A Systematic Literature Review. In Proceedings of the ICEGOV, Athens, Greece, 6–8 October 2021.
32. Fu, Y.; Zhang, X. Planning for sustainable cities? A comparative content analysis of the master plans of eco, low-carbon and conventional new towns in China. *Habitat Int.* **2017**, *63*, 55–66. [CrossRef]
33. ITU-T FG-SSC. *Smart Sustainable Cities: A Guide for City Leaders*; FG-SSC: Geneva, Switzerland, 2015; pp. 1–16.
34. Boyko, C.T.; Cooper, R.; Davey, C. Sustainability and the urban design process. In *Proceedings-Institution of Civil Engineers Engineering Sustainability*; Thomas Telford Ltd.: London, UK, 2005.
35. Gibson, G.E., Jr.; Kaczmarowski, J.H.; Lore, H.E., Jr. Preproject-planning process for capital facilities. *J. Constr. Eng. Manag.* **1995**, *121*, 312–318. [CrossRef]
36. Dirkx, M.; Van Gastel, M.; Keutgens, W.; Paridaens, T.; Ursachi, D. *D6.3 EPIC Roadmap for Smart Cities*; EPIC Consortium: Paris, France, 2013.
37. Mendizabal, M.; Heidrich, O.; Feliu, E.; García-Blanco, G.; Mendizabal, A. Stimulating urban transition and transformation to achieve sustainable and resilient cities. *Renew. Sustainable Energy Reviews* **2018**, *94*, 410–418. [CrossRef]
38. Arslan, Ö. Participatory Approach in Urban Design: Evaluating the Process in the Case of İzmirdeniz. Ph.D Thesis, Izmir Institute of Technology, Izmir, Turkey, 2021.
39. Gün, A.; Demir, Y.; Pak, B. Urban design empowerment through ICT-based platforms in Europe. *Int. J. Urban Sci.* **2019**, *24*, 189–215. [CrossRef]
40. Dias, N.; Amaratunga, D.; Keraminiyage, K.; Haigh, R. *Balanced Urban Design Process to Create Resilient and Sustainable Urban Environments*; Routledge: London, UK, 2018.
41. Mneimneh, F.; Srour, I.; Kaysi, I.; Harb, M. Eco-City Projects: Incorporating Sustainability Requirements during Pre-Project Planning. *J. Urban Technol.* **2016**, *24*, 47–74. [CrossRef]
42. Geldenhuys, H.J.; Brent, A.C.; De Kock, I.H. Managing urban infrastructure transitions for smart sustainable cities. In Proceedings of the IAMOT 2020: Towards the Digital World and Industry X.0, Giza, Egypt, 13–17 September 2020.
43. Deljoo, A.A.J.M. Conceptualizing Public Service Networks as Complex Adaptive Systems. In Proceedings of the European Conference on e-Government, Koblenz, Germany, 16–19 September 2013.
44. Boorsma, P.B. A new Digital Deal: Beyond Smart Cities. In *How to Best Leverage Digitalization for the Benefit of Our Communities*; Rainmaking Publications: Copenhagen, Denmark, 2017.
45. Review, W.P. Copenhagen Population 2023. World Population Review. 20 June 2023. Available online: https://worldpopulationreview.com/world-cities/copenhagen-population (accessed on 20 June 2023).

46. ESPON. Denmark, Small and Medium Sized Cities. ESPON. 25 August 2022. Available online: https://www.espon.eu/towns%20Denmark (accessed on 12 June 2023).
47. Urban Development. *The CPH 2025 Climate Plan*; City of Copenhagen: Copenhagen, Demark, 2021.
48. Green, S.O. *Think Denmark White Papers for Green Transitions—Urban Innovation for Livable Cities*; State of Green: Copenhagen, Demark, 2016.
49. Samuels, S.; Karasapan, A. *A Case Study of one of the Most Sustainable Cities in the World*; Digital Commons Colby: Colby, KA, USA, 2014.
50. Doody, L.; Walt, N.; Dimireva, I.; Nørskov, A. *Growing Smart Cities in Denmark: Digital Technology for Urban Improvement and National Prosperity*; Arup: London, UK, 2016.
51. Municipality, C. Cycling in Copenhagen. 1 June 2023. Available online: https://international.kk.dk/live/transport-and-parking/cycling-in-copenhagen (accessed on 25 June 2023).
52. Pucher, J.; Buehler, R. Cycling for Everyone: Lessons from Europe. In *Transportation Research Board*; Transportation Research Board: Washington, DC, USA, 2008.
53. Huovila, A.; Siikavirta, H.; Rozado, C.A.; Rökman, J.; Tuominen, P.; Paiho, S.; Hedman, Å.; Ylén, P. Carbon-neutral cities: Critical review of theory and practice. *J. Clean. Prod.* **2022**, *341*, 130912. [CrossRef]
54. Copenhagen Centre on Energy Efficiency. Energy Efficiency in the City of Copenhagen. 30 October 2015. Available online: https://seforallateccj.org/wpdata/wp-content/uploads/2015/11/2.Jyoti-Prasad-Painuly-Copenhagen.pdf (accessed on 24 June 2023).
55. Nordhavn, E. A Smart City Energy Lab. 2023. Available online: http://www.energylabnordhavn.com/ (accessed on 9 June 2023).
56. European Commission. *Commission Staff Working Document: 2022 Country Report—Denmark*; European Commission: Brussels, Belgium, 2022.
57. C40 Cities. Circular Copenhagen—70% Waste Recycled by 2024. 1 December 2019. Available online: https://www.c40.org/case-studies/circular-copenhagen-70-waste-recycled-by-2024/ (accessed on 23 June 2023).
58. Ministry of Environment of Denmark. Partnership for Green Public Procurement. Environmental Protection Agency. 2023. Available online: https://eng.mst.dk/sustainability/sustainable-consumption-and-production/sustainable-procurement/partnership-for-green-public-procurement/ (accessed on 24 June 2023).
59. Okafor, C.C.; Aigbavboa, C.; Thwala, W.D. A Delphi approach to evaluating the success factors for the application of smart mobility systems in smart cities: A construction industry perspective. *Int. J. Constr. Manag.* **2021**, *23*, 1289–1298. [CrossRef]
60. Perveen, S.; Kamruzzaman, M.; Yigitcanlar, T. Developing Policy Scenarios for Sustainable Urban Growth Management: A Delphi Approach. *Sustainability* **2017**, *9*, 1787. [CrossRef]
61. Chan, P.; Lee, M.-H. Developing Sustainable City Indicators for Cambodia through Delphi Processes of Panel Surveys. *Sustainability* **2019**, *11*, 3166. [CrossRef]
62. Muse, L.P.; Frazer, J.J.; Fidler, E. The IEEE P2784 Standardization Process Workshop: The use of Delphi method and interactive evaluation tools to identify perceptions about Smart Cities. In Proceedings of the 2020 IEEE International Smart Cities Conference (ISC2), Piscataway, NJ, USA, 28 September–1 October 2020.
63. Chowdhury, S.N.; Dhawan, S. Evaluation of key performance indicators of smart cities by Delphi analysis. In Proceedings of the 2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), Bangalore, India, 20–21 May 2016.
64. Ibrahim, M. Developing Smart Sustainable Cities: A Validated Transformation Framework. In Proceedings of the 2019 International Conference on Smart Applications, Communications and Networking (SmartNets), Sharm El Sheikh, Egypt, 17–19 December 2019.
65. Abduh, M.; Wirahadikusumah, R.D.; Messah, Y. Framework Development Methodology for Sustainable Procurement of Construction Works in Indonesia. *MATEC Web Conf.* **2018**, *203*, 02014. [CrossRef]
66. Bibri, S.E.; Krogstie, J. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustain. Cities Soc.* **2017**, *31*, 183–212. [CrossRef]
67. McMillan, J.H.; Schumacher, S. *Research in Education: Evidence-Based Inquiry*; Pearson Education: London, UK, 2014.
68. Beceiro, P.; Brito, R.S.; Galvão, A. The Contribution of NBS to Urban Resilience in Stormwater Management and Control: A Framework with Stakeholder Validation. *Sustainability* **2020**, *12*, 2537. [CrossRef]
69. Fouché, E.; Brent, A. Explore, design and act for sustainability: A participatory planning approach for local energy sustainability. *Sustainability* **2020**, *12*, 862. [CrossRef]
70. Basu, R. *PESTLE Analysis—Implementing Quality: A Practical Guide to Tools and Techniques*; Basu, R., Ed.; Cencage Learning EMEA: Hampshire, UK, 2013; pp. 98–100.
71. Shmelev, S.E. *Sustainable Cities Reimagined: Multidimensional Assessment and Smart Solutions*; Routledge: London, UK, 2019; p. 312.
72. Nel, D.; du Plessis, C.; Landman, K. Planning for dynamic cities: Introducing a framework to understand urban change from a complex adaptive systems approach. *Int. Plan. Stud.* **2018**, *23*, 250–263. [CrossRef]
73. Sharif, A.R.; Pokharel, S. Smart City Perspectives in the Context of Qatar. *Lect. Notes Netw. Syst.* **2021**, *253*, 103–113.
74. Hodson, M.; Marvin, S.; Robinson, B.; Swilling, M. Reshaping Urban Infrastructure: Material Flow Analysis and Transitions Analysis in an Urban Context. *J. Ind. Ecol.* **2012**, *16*, 789–800. [CrossRef]

75. Koo, J.; Kim, Y.-G. Interoperability requirements for a smart city. In Proceedings of the 36th Annual ACM Symposium on Applied Computing, Virtual Event, 22–26 March 2021.
76. European Union. *Smart Cities and Communities Guidance Document—Public Procurement for Smart Cities*; European Union: Brussels, Belgium, 2013.
77. Del Esposte, A.D.M.; Santana, E.F.; Kanashiro, L.; Costa, F.M.; Braghetto, K.R.; Lago, N.; Kon, F. Design and evaluation of a scalable smart city software platform with large-scale simulations. *Future Gener. Comput. Syst.* **2018**, *93*, 427–441. [CrossRef]
78. Tahvonen, O. Scalable Green Infrastructure—The Case of Domestic Private Gardens in Vuores, Finland. *Sustainability* **2018**, *10*, 4571. [CrossRef]
79. CIDB. *Infrastructure Programme Management Plan (IPMP)*; CIBD: Pretoria, South Africa, 2006.
80. Dana, L.-P.; Salamzadeh, A.; Hadizadeh, M.; Heydari, G.; Shamsoddin, S. Urban entrepreneurship and sustainable businesses in smart cities: Exploring the role of digital technologies. *Sustain. Technol. Entrep.* **2022**, *1*, 100016. [CrossRef]