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Digital Solutions for Participative Design and Scenario Modeling in Urban Building Renovation: Integrating Immersive Technologies for Sustainable Energy, Health, and Socio-Economic Impact Assessment

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Abstract

This study focuses and evaluates the integration of digital solutions in urban renovation projects across the world, focusing on implementation technologies, ease of replication, environmental, economic and social impacts. Many different case studies were studied and analyzed providing us with really helpful insights on the practices used, technologies implemented, the areas the solutions focus and also how successful these were, with benefits and barriers met. Challenges such as cost of implementations, data integration issues and complexities, scalability and interoperability problems are identified and have different impacts on the projects but through the implementations we can recognize ways on how to minimize their effects.

The study gives an emphasis on the need for better governance frameworks, targeted stakeholders engagement practices, and also use of policies that support scalability and inclusivity of the projects. Future research could explore on AR/VR use and AI technologies that seem to be extremely effective when used in projects compared to other methods. Using all these can lead to better and higher resilience of the projects that are also sustainable and provide for positive urban transformation that covers the needs of the local communities, and provides for a healthier ecosystem.

Αυτή η μελέτη εστιάζει και αξιολογεί την ενσωμάτωση ψηφιακών λύσεων σε έργα αστικής ανακαίνισης σε όλο τον κόσμο, εστιάζοντας στις τεχνολογίες εφαρμογής, την ευκολία αναπαραγωγής, τις περιβαλλοντικές, οικονομικές και κοινωνικές επιπτώσεις. Μελετήθηκαν και αναλύθηκαν πολλές διαφορετικές μελέτες περίπτωσης, παρέχοντάς μας πραγματικά χρήσιμες πληροφορίες σχετικά με τις πρακτικές που χρησιμοποιήθηκαν, τις τεχνολογίες που εφαρμόστηκαν, τους τομείς στους οποίους επικεντρώνονται οι λύσεις και επίσης πόσο επιτυχημένες ήταν αυτές, με τα οφέλη και τα εμπόδια που αντιμετωπίστηκαν. Προκλήσεις όπως το κόστος των εφαρμογών, τα ζητήματα και οι πολυπλοκότητες ενσωμάτωσης δεδομένων, τα προβλήματα επεκτασιμότητας και διαλειτουργικότητας εντοπίζονται και έχουν διαφορετικές επιπτώσεις στα έργα, αλλά μέσω των εφαρμογών μπορούμε να αναγνωρίσουμε τρόπους για το πώς να ελαχιστοποιήσουμε τις επιπτώσεις τους.

Η μελέτη δίνει έμφαση στην ανάγκη για καλύτερα πλαίσια διακυβέρνησης, στοχευμένες πρακτικές εμπλοκής των ενδιαφερόμενων μερών, καθώς και στη χρήση πολιτικών που υποστηρίζουν την επεκτασιμότητα και την συμπερίληψη των έργων. Μελλοντική έρευνα θα μπορούσε να διερευνήσει τη χρήση AR/VR και τις τεχνολογίες Τεχνητής Νοημοσύνης που φαίνεται να είναι εξαιρετικά αποτελεσματικές όταν χρησιμοποιούνται σε έργα σε σύγκριση με άλλες μεθόδους. Η χρήση όλων αυτών μπορεί να οδηγήσει σε καλύτερη και υψηλότερη ανθεκτικότητα των έργων που είναι επίσης βιώσιμα και παρέχουν θετικό αστικό μετασχηματισμό που καλύπτει τις ανάγκες των τοπικών κοινοτήτων και παρέχει ένα υγιέστερο οικοσύστημα.

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Chapter 1. Introduction and Background info

1.1 Research context and Motivation

Urbanization is a great challenge for modern cities around the world, because of the increasing population that actually stays in large cities. This leads to an increasing demand for new and more innovative solutions, in order to ensure a more sustainable and liveable environment that is available for everyone to live in.

Urbanization led the world to higher population density, environmental degradation and also higher demand for resources in urban environments. Cities are thought of as engines of economic growth but now they face many challenges, mostly coming from rapid urbanization that cripples their ability to be efficient. These can be problems like traffic congestion, pollution, housing problems this way leading to problems of inequality between the citizens. (Glory Shan, 2023)

In order to deal with the rapid expansion of needs in urban areas and with the problems coming from urbanization, a mechanism for effective planning and design is of crucial importance. The traditional methods are slowly becoming obsolete and are not able to deal with all the complex issues arising, mainly due to their nature, and the lack of engagement from the stakeholder's side. More dynamic approaches are needed, with the aid of technology, in order to create more inclusive urban spaces that will be able to respond to the complex and increasing challenges and needs of modern cities.

The traditional methods used until now, mainly did focus only on the physical upgrades side, this way neglecting the multifaceted needs that are associated with implementation of such projects in urban areas. These could be social and environmental impacts. Newer approaches help in the adoption of collaborative design practices that include community members in the decision-making process, from which changes can be carried out during the process, so that the projects will meet the real needs and wishes of the residents. (Delaqua, 2021) Using this approach that has inclusivity as a foundation, gives enhances relevance and acceptance for the renovation projects and offers a sense of ownership. It also adds to community cohesion and promotes co-working for achieving a better living environment for everyone.

Participative design and scenario modeling in urban building renovations, make use of digital solutions and tools, so that they can build stakeholders engagement in the process. Innovative technologies like Augmented Reality and Virtual Reality are being used, to fabricate more interactive solutions and spaces, that boost the way the stakeholders engage with the design, and actually experience how these changes would look. This way they can give feedback and work together with the design team, in order to advance sustainability in urban environments, and be consistent with the solutions providing sustainability and be more energy efficient as well, while in the process, taking in consideration socio-economic dynamics shaping the process. (ERRIN, 2024)

With using digital solutions, the level of involvement of stakeholders within the community is increased, and high level of diversity is achieved, as many more people are given the opportunity to share their ideas and give feedback through various collaboration platforms and tools. This is very important and crucial in order to guarantee that urban projects fir and really reflect the needs and the desires of the residents, and most importantly of the ones that are usually left out from the development decisions, this way enhancing inclusivity. Some challenges remain, starting from superficial participation to data privacy issues, and lead to

some worries that newer ways will not actually make it for real engagement. (Saßmannshausen, 2021) (Stephen Marshall, 2018)

The process of participative design, firstly and most importantly, must be inclusive and accessible for everyone, regardless of demographic background of the stakeholders. All voices must be equal and represented equally in the process and planning stages. All smart city projects depend also on the actual commitment of the administration to the actual participation of the citizens, and their insights and preferences on creation of the projects, so that these are accepted and viable for urban renovations. Digital solutions are the means for a more equitable, resilient and sustainable urban environment that embraces future challenges like climate change and social-economic disparities. (ERRIN, 2024)

The benefits of digital solutions in urban renovations have great potential, when the process is followed and there is a constant and productive engagement from the stakeholder's side. Their opinion and needs must be taken into account for the success of the projects, in order to create a more successful and sustainable urban development, targeting the diverse needs of urban population. In order to achieve that a balanced approach between technology and meaningful participation must be the target.

Smart cities are recognized as innovative ecosystems that use technology in order to enhance urban living, improving their operation efficiency and giving solutions to environmental challenges arising in their environments. The main driver of this shift is Internet of Things, which allows for real time data collection and analysis, this way enabling optimization of city services and infrastructure in real time. Rapid urbanization presents significant challenges for the planners, architects and engineers but also for the citizens. Over 55% of the global population resides in urban areas, and this is expected to reach 68% by 2050, creating an urgent need for innovative solutions that use participatory design techniques and planning for all smart cities projects to make them more sustainable and viable. (UN, 2018)

This research aims to explore how immersive technologies can be used and integrated into participatory design process, so that enhanced sustainability and inclusivity in urban area and building renovations can be achieved. We will examine the intersection of digital tools, with community engagement and sustainable development, by studying case studies from other papers, and analysing real world solutions, and discussing on how successful these are.

We will try to contribute to the creation of an overview of practises for urban spaces and environments that are not only environmentally responsible but also promote inclusivity and lead to better health and well-being for the citizens of the city.

1.2 Research Problem

Fast urbanization and complexity of the urban environment rising, both lead for the requirement of use of effective participatory design and plan. The traditional methods used until now did not properly engage planners and designers with the communities they serve, leading to disconnections and this way producing results and projects that have not taken into account residents needs and desires. This was leading to projects that were not sustainable and most of the times made urban spaces that were not ideal to live in and did not respond to what the community needed.

Cities are in a position that need to address important challenges like, cutting energy consumption, enhancing living environment of citizens, facilitating better mobility while also positively affecting the society and economy, all that within the framework of rapid urbanization, it is of critical nature that we have digital tools that actually support participative design, based on visualization, analysis, and data interaction.

Key issues can be summarized as:

1. **Limited Citizen engagement**: Classic methods with no participation of citizens in the decision-making process, usually leads to public opposition against the projects that do not reflect the needs of the community. Can lead to lack of trust and transparency since citizens are not involved in the process. (Jos P. van Leeuwen, 2018)
2. **Technological Misalignment**: All digital technologies, like VR/AR and immersive solutions give a great promise for enhancing participatory design, but have some barriers to the successful implementation of these. Main ones include usability, accessibility and socio-tech alignment with the community needs. Also flaws in the design of the tools themselves can lead to platforms that do not meet the needs of all stakeholders. (Francesca De Filippi, 2020)
3. **Digital Divide**: One of the most important barriers to equitable participation in urban planning and e-governance in general. Communities that have limited access to technology and limited knowledge on how to actually use technology and digital tools, leads them being excluded from the participatory design process. This is one of the reasons that can really undermine the goal of inclusive urban development and can lead to many stakeholders not taking part in the process, this way leading to failing projects. (Yuchen Wang, 2024)
4. **Utilization of data that is not effective**: Usually large amounts of data is gathered and collected by urban planners, but this data sometimes is not being used properly for the final decisions. Without proper tools to actually analyze the data, and this way led to better results for the final design, important insights are overlooked, leading to suboptimal plans and decisions for the project. A need for effective analysis and visualization is of great importance for success. (Francesca De Filippi, 2020) The challenge also includes translating the data in a proper way so that actionable insights can lead the designer team to more sustainable urban development.

There is also one **wider issue** that has to do with the **actual complexity of the Urban systems**. These systems are characterized by a **complex interplay of various other interconnected systems**. These can include, energy use systems, transportation networks, public health infrastructure, socio-economic dynamics and environmental factors, that are closely coupled in a complex fashion. Understanding all these interdependencies is extremely essential in order to achieve a level of urban planning and decision making that is actually effective.

Many **challenges** are met in modelling these systems such as:

- Nonlinear relationships
- Uncertainty and variability
- Dynamic Nature
- Data limitations

Importance of effective modelling:

- Informed decision making
- Identifying synergies
- Identifying trade offs
- Resilience planning

Approaches to Modeling Urban Systems:

Agent-based modeling: This approach involves the simulation of individual agent (e.g. people, vehicles, buildings) behavior as well as their interaction and their emergent properties.

System dynamics modeling: The approach involves representing the dynamic relationships between different parts of a system using feedback loops and stock and flow diagrams.

Integrated assessment modeling: This approach is to use the combination of several modeling techniques to examine how different scenarios affect many outcomes such as economic growth, environmental good, and social equity. (Christakis, 1969)

Addressing all the above challenges requires a nuanced understanding both on technological and also human factors that affect the success of such projects. With this research we will try to fill this gap, with investigating how these immersive technologies can be successfully integrated into the process of participatory design in order to enhance the sustainability and achieve the desired inclusivity for urban renovation projects.

1.3 Research Questions and Objectives

This thesis will try to answer on:

RQ1: How can immersive technologies, such as virtual and augmented reality, be effectively integrated into participative design and scenario modelling for urban building renovations to enhance sustainable energy solutions, health outcomes, and socio-economic impact assessments?

With the above question we aim to explore the role of these technologies in enhancing citizen engagement, and allowing better visualization this way leading to better decision making.

RQ2: What are the impacts of immersive digital solutions on energy efficiency, health outcomes, and socio-economic factors in urban renovation projects?

With the above question we address the actual effectiveness of digital tools in improving sustainability and well-being.

RQ3: What are the benefits and challenges of using these digital solutions?

With the last RQ we will try to uncover both technical and societal challenges posed by the use of immersive technologies, and also show the practical advantages these offer in urban design.

By addressing all the above this thesis can contribute to the development of innovative digital tools that enable more sustainable, equitable and citizen centred urban planning practices.

Objectives

Primary objectives:

To **study and evaluate** the digital solutions that enable effective participatory design and planning in urban environments, to foster collaboration, inclusivity and informed decision making amongst citizens, building users and stakeholders.

Impact assessment of the sustainability impacts (energy use reduction, environmental impact) and socio-economic benefits (health improvement, job creation, inclusivity) of integrating immersive technologies.

Develop Recommendation: To propose actionable insights on how to improve participatory design using immersive technology for urban planners, policymakers and technology developers.

1.4 Scope of the Study and Methodology

Scope:

Urban Environments: The case studies will be urban building renovations in medium to large cities in which new technologies can be most effectively integrated into the existing infrastructure. The research will also examine community driven, participatory projects where citizens are participating directly in the decision-making process.

Digital Tools: The key of such study will be on using immersive technologies (VR, AR) and scenario modeling tools (BIM, GIS) together with other simulation software in urban renovation projects.

Methodology:

Research Design: To resolve the research questions, a mixed methods research design has been selected and will include the use of both qualitative and quantitative approaches to gather, analyze and interpret data from literature, case studies and real-world implementations. We will evaluate a set of specific urban renovation projects making use of immersive technologies, participatory design, and digital modeling tools case study approach.

Case Study Approach: Case studies, using real world urban renovation with immersive technologies, will be analyzed in order to provide insights of the practical applications of immersive technologies in participatory design.

Feature analysis and comparison: Feature analysis and comparison of solutions implemented in real world. Comparison between them and assessment of the impact of each solution, trying to focus on the more successful ones.

Chapter 2. Background information

2.1 Overview of Urban building renovation

Cities around the world are experiencing great pressure, as their size increases, they grow in age and consume more resources, due to rapid urbanization. These problems require very **radical approaches** in order to renew urban spaces, paying attention to **more sustainable** solutions and characteristics for **energy efficiency and environmental sustainability**.

Defining Sustainable Urban Renovation

Sustainable renovation of cities entails a process of **refurbishing already existing buildings** and facilities, in order to make them conform to the new improved standards of sustainability, less energy consumption and improved health conditions for those using them. Some key strategies include:

- **Energy efficiency:** initiatives to preserve energy, by insulating, using energy efficient heating/cooling systems, use smart lights and energy efficient appliances.
- **Green building standards:** New green standards and guidelines are now implemented as construction is concerned. Some of these are:
  - **Leadership in Energy and Environmental Design (LEED):** Assessment method and certification system for property the determines the performance of it. Environmental indicators used for energy, lights, water, building materials.
  - **Building Research Establishment Environmental Assessment Method (BREEAM):** A popular system driven approach to the assessment of projects within infrastructure, possibilities of power consumption, healthy climate, spaces, other resources etc.
  - **Eco-Friendly materials:** Use of materials that are sustainable and minimize environmental impact.

2.2 Theoretical Frameworks in Participative Design

This chapter deals with a more comprehensive exploration into the many-sided field of digital solutions in urban planning, participatory design, scenario modeling, sustainable energy systems, health and well-being in buildings, socio-economic impacts and the role of using immersive technologies like VR and AR.

Participatory Design

This is a **pivotal approach** in urban planning and development, and it **emphasizes in active involvement of stakeholders in the design process**. This method enhances the relevance and the effectiveness of the solutions and also fosters a sense of ownership among the different stakeholders.

Participatory design has several core elements:

- **Collaborative workshops**: Through these the members of the community can engage directly with the designers and other stakeholders. Using discussions and brainstorming sessions, the needs, preferences and concerns of each party can be expressed. This process of co-creation helps in tailoring each solution to the needs of the local population

- **Digital Tools for engagement**: VR/AR tools enable stakeholders to visualize the changes in their environment thus making complex data and designs easier to understand and more engaging.
- **Feedback loops**: Continuous feedback, through various mechanisms is crucial to participatory design. Through feedback there is a way to make changes on the fly and improve the design. It also enhances cooperation and trust between the different parties. (Ben, 2020)

Methodologies in participatory design:

There are various methodologies that help in engaging stakeholders:

- **Community Based Participatory Research (CBPR):** The strength of this approach is that community members are equal partners in the research process. This highlights the importance of collaborations at all stages, from problem identification to the data collection to the analysis of that data. Research finds that CBPR can produce important learning outcomes that contribute over time to participants' skills and civic engagement. (Seblewongel Yigletu 1, 2021)
- **Design Thinking:** User needs need to be understood through empathy alone, and experimentation during a process of iterating. By sessioning stakeholders in the process of brainstorming or prototyping, designers can imagine and develop solutions to which the community will respond.
- **Post-Occupancy Evaluation (POE):** Following build, POE estimates the degree to which a designed space meets user needs. Feedback gathered from occupants can inform future projects fine-tuned by real world experiences. (Sharmin, 2021)

Benefits of Participatory Design:

There are numerous benefits in this like the feeling of **satisfaction** throughout the community. Projects that get developed using PD do **align better with the community needs**, so that leads to increased feeling of satisfaction between the stakeholders. When the different opinions are heard the support on the outcomes of a project is more possible than when people are neglected.

Another key benefit is the **empowerment of community** members and stakeholders through the engagement to the design process. This gives a sense of ownership to the participants that in general leads to greater acceptance of the solution proposed and co-created for the project.

It is worth mentioning that through this process we can **build a Social Capital**, meaning the process strengthens social ties within the communities and stakeholders and collaboration and shared goals are met. This can lead to better designed future projects through the use of this capital.

Finally, in general there is an **improved design quality overall** through incorporating diverse opinions and proposals. This leads to innovative solutions that are also effective for everyone involved. (Valerie Barker, 2014)

Challenges in Participatory Design

Despite all the benefits PD faces several challenges. These can either be **due to existing power structures** in communities that already have a word in what is to be done and what is not. This leads to some voices having a louder impact to the process of discussion and others can be silenced. (Sharmin, 2021)

Another constraint is the **resource** one. Effective participation will require mostly time and funding and these might be limited in low-income communities. The sustaining of engagement to the whole process will be a factor to consider as well.

In one of the recent papers on this subject, the following where found which contribute to our research presented above.

Key points of the paper:

a. **Public Disagreement in Urban projects**: Many recent projects do seem to have a public pushback, suggesting that the **methods used to promote plans are outdated**
b. **Digital tools for participation**: Digital media and digital tools offer great potential for large scale participation but are really **underutilized**

This paper examined hundreds of studies and identified key issues as well as methods and tools. Case studies were conducted in Germany, France and Netherlands giving inside information on the challenges of large urban projects

Prototyping was used to create tools, for example, sentiment analysis tools to capture the public feedback on the subject

Main challenges in digital participation were found to be:

1. **Low engagement of public**, insufficient participation
2. **Bias:** The participants are not always what we expect them to be and do not express the general public opinion
3. **Complexity of communicating** complex plans concepts to non-experts

Some approaches that are worth mentioning are:

a. **Gamification**: Use game like elements to increase motivation in participating
b. **VR/AR**: Visualizing plans is the best way of communicating them
c. **Sentiment analysis**: Used to analyze public feedback in a large scale so we have a better grasp on the public opinion

Summarizing:

In this study we will explore on how these tools can be used, in order to involve the general public in urban design and development process. The main highlights will be the **challenges** for engagement of public, bias and complexity of communication overall. We will provide solutions implemented to deal with these like gamification, sentiment analysis and also, immersive technology tools, that really boost participation and transparent planning. (Sander Münster, 2017)

Conclusion

Participatory design is able to give a **fresh and transformative approach** to the process of urban planning together with community engagement and sustainable development. By prioritizing stakeholder engagement and participation in the process of design and planning from start to finish, using collaboration and community feedback with digital tools, enhances satisfaction and gives empowerment to the communities. This way the environments and buildings in urban areas are shaped and built in a more sustainable way.

There are many different challenges in the process and also important limitations in resources, but despite all, there are **many successful case studies that show the great potential** in this methodology, for creating innovative solutions that are created in accordance with community needs. As cities continue to evolve, they face more and more complex challenges but with using methods like Participatory Design, all stakeholders and community members can create **more inclusive and sustainable projects** and solutions for improved health and well-being in the city. (Ben, 2020) (Marzia Mortati, 2022)

2.3 Digital Solutions in Urban Planning

Digital solutions are fundamental for the transformation of urban planning, through the provision of new and very innovative tools, that give **enhanced collaboration** and **better visualization** this way **boosting decision-making process**. These technologies include Building Information Modeling (BIM), Digital Twins and Geographic Information Systems (GIS) contribute to the process of urban renovation, with providing better, more integrated and more efficient solutions. Here we will discuss these technologies and how these are implemented and used in urban renovation process.

Building Information Modeling (BIM)

BIM is a technology used to **facilitate the design and management of building renovations**, helping with **creating a detailed 3D model** that **includes data from many different variables**. These include **material types, costs and life cycle analysis** for each building we use BIM for. (Volk, et al., 2014) BIM helps professionals like architects and engineers, planners to be able to **work together** in designs. It is recommended for help in the upgrading process of existing structures, especially the ones with historic value, because it can help to meet the necessary regulations for improvements while maintaining certain design aesthetics (Dore & Murphy, 2012).

Effectiveness of BIM in Renovation Processes

BIM can be used to **enhance efficiency and accuracy**, and also help **in collaboration** during the processes of planning, design and execution stages. It provides a range of benefits to the project:

1. **Visualization:** BIM offers detailed 3D models that represent real life conditions for a building. This way it gives the stakeholders a more understandable view of what the state of the building really is. These models help in identifying problems and issues early, before the project goes in construction phase. (Saeed, 2011)

2. **Collaboration**: BIM helps in better understanding between project stakeholders, because it provides a shared database and platform that has all data included. This ensures that information is well coordinated in order to help in more efficient decision making, leading to better results in the renovation process. (Azhar, 2011)
3. **Cost and Time efficiency:** BIM is really effective and accurate in cost estimation and scheduling. It provides much detailed insights on what is needed from materials to labor and helps doing comparisons with project timeline. This combination of crucial information reduces greatly the possibility of budget overruns and delays, which are really common in most projects dealing with constructions and renovations (Ji & Chen, 2020).
4. **Accuracy and Precision:** BIM models include and use data that is precise regarding building components and systems. This makes them ideal for renovations. Minimized omissions and inconsistencies comes from this attribute since all stakeholders use current and correct information. (Khaddaj & Srour, 2016)
5. **Compliance and documentation:** Using BIM we can ensure that all codes, regulations, standards and permits are monitored during construction or renovation of structures. With using BIM, we ensure that all regulatory codes necessary, all standards and all permits are strictly monitored especially during construction or renovation of structures. This makes it easier to actually deal with legal requirements of each project, like local standards, laws etc. for the construction process. (Volk, et al., 2014)
6. **Sustainability:** BIM can also be used to simulate the performance of each building, on energy consumption. This way it can help in identifying areas where this can be enhanced and improved with renovation process. It can also help in integrating sustainable practices with recommendations on design and even materials used that can actually improve building performance and also reduce the building's environmental impact. (Carvalho, 2020)

BIM is one essential tool for successful renovation process, that can **help in optimizing a projects outcome.** It can help us **reduce risks** and ensure that the process can **lead to high quality results**. Using BIM in renovation projects can help in achieving enhanced efficiency, more effective designs and better sustainability for all stages of the project.

Digital Twin Technology

DT technology, is a cutting-edge innovative tool in digital transformation of urban buildings and area renovation projects. It is **a virtual model, of a physical object, an engineered system or a process, that is built from real time data** that comes from various sensors and IoT devices that provide us with this data. With this virtual model, we can **emulate, evaluate and enhance the real-life system**, in a virtual space, this way **taking back feedback and data, for better support of decision making** on how to enhance the performance of the real system. DT can be used for urban renovation projects to offer us great potential for better design, management and sustainability of the project outcome.

Optimizing renovation planning and design:

Digital twin technology gives many advantages and benefits in the design, monitoring, management and also sustainability of the built environment we deal with. In urban building renovations DT helps the architects and planners to **create 3D models** of existing buildings that offer a detailed description of the physical attributes and characteristics of the building,

including spatial relationships of the components, the structural performance and also the performance of the mechanical subsystems, which can all aid and be used to model the different renovation options and experiment with the changes to the design before the actual construction. With this approach **we can identify any possible problems at the early planning** stage this way avoiding delays and also enhancing the quality of the renovation projects results. (Lu, et al., 2020)

Digital Twins can also simulate the **impact of environmental factors**, such as weather conditions and temperature changes, and also assess phenomena like urban heat islands, water floods etc. With this function it can help in building more energy efficient constructions. Accurate modeling and **using extensive data from IoT** can help the designers to actually see how these affect the buildings design and performance and adapt to these accordingly.

Real time monitoring: IoT sensors and devices embedded in the building or construction can be used by DT technology during the construction phase and after that for real time monitoring. Data is gathered continuously and gives valuable performance indicators on different parameters like energy use, temperature, humidity, air quality, waste. Using all this data Digital Twin can do predictive analytics and identify potential issues, before these issues expand and turn to system failures. (Piras, 2024) With continuous monitoring of these variables **predictive maintenance** can be performed in the various different systems, ensuring most problems can be dealt with in advance in a more **proactive way**. This is how we can achieve reduced downtime, expand life of the systems of a building, and also minimize costs in the long run. A case study in a recent paper by (Lu & Xie, 2020) provide us with such a scenario with pumps of an HVAC system in a building. Using a DT model, they created an anomaly detection system that was used to monitor data from the system working in real time. Using this data and a Bayesian change point detection method, the system could identify and filter anomalies, thus enhancing the efficiency and the automation of system monitoring for the building, helping in the facilitation of preventive maintenance.

Enhanced Sustainability and Energy efficiency: Two of the most important **benefits** of DT technology in urban building renovations is **energy optimization and enhanced sustainability**. Because it uses IoT to continuously collect and analyze data on energy consumption, DT can be used to simulate the different results we will get, if we change building materials, insulation methods, use energy efficient systems for heating/cooling, giving us extensive information about the most cost effective and sustainable solutions for each project. These **simulations helping managers and building tenants to make better and more well-informed decisions** on many aspects of the renovation, especially in the sector of using renewable energy sources and how to integrate these in order to improve overall energy efficiency in a building. (Belik & Rubanenko, 2023) DT models can be used to predict how different building designs and settings will do under various scenarios and conditions, this way helping to design more resilient and energy efficient buildings that can be better in adapting to climate change and problems of urban environment like heatwaves. Also really important is the additional function of DT to actually aid in power grid stability in peak consumption hour scenarios. By adding renewable energy sources to the buildings, these can be used to add more stability to the grid and help the city demands for power by helping in creating a more stable and sustainable energy grid. (Belik & Rubanenko, 2023)

Improved Stakeholder Collaboration: DT fosters **better collaboration** among various stakeholders taking part in urban building/area renovations. Creating a digital representation of the building or area allows all stakeholders to be able to access a unified platform. This way

it is ensuring that everyone can work with and see the same information that is up to date. This way problems in miscommunication are dealt with and ensures that decision making process taking place is based on accurate data. (Tripathi, et al., 2024) Also, stakeholders can visualize the renovations that are possible in a simulated environment, this way enhancing their ability to assess the outcomes of different options and choices. These can be material choices, design choices, modification in the structure of the building etc. This way more precise and data driven decisions can be made. This approach is more holistic and gives better transparency while reducing problems and errors and gives a boost to the renovation procedure completion time.

Smart Urban area renovation: DT can be used for urban area renovations as well. Using data from multiple sources, like different buildings and urban infrastructure, DT can create a **dynamic and interconnected model of the entire urban system**. This way urban planners and stakeholders can simulate and optimize renovation projects in neighborhood or district level. They can actually simulate many different variables like traffic, public services, environmental impact, and also social dynamics. With this wider aspect approach, we have a boost in overall livability and sustainability of urban environments. As an example, we can simulate the effects of improving a districts energy grid infrastructure with renewable sources and the effect this will have on energy savings of individual buildings. Or we can model the actual impact of new green spaces in urban environment and livability. With this holistic and data driven approach we can achieve more sustainable results.

Digital Twin technology is simply **changing how cities plan, build, maintain, and sustain their buildings and areas.** It makes physical and digital models work together in harmony and make better decisions, manage resources better and work better as a team. This is because as cities expand and meet critical environmental and operational needs, Digital Twin technology will act as a blueprint in determining the future of how buildings and cities can be designed to be sustainable, resilient and capable of responding to future requirements.

Geographic Information Systems (GIS)

GIS is foundational in urban renovation. These are used for **spatial analysis and visualization**. We can integrate spatial and non-spatial data to them in order to create layered maps that help us to inform the decision-making process in a proper and inclusive way. (Batty, et al., 2012)
GIS can be used to enable the **identification process of unused or underused areas**, mapping of social and environmental dynamics and also the simulation of proposed interventions impacts in the urban environment. Many studies have demonstrated the effectiveness of GIS in planning infrastructure interventions and also assessing risks related to climate change or climate phenomena like flooding or even urban heat islands. (GIS, 2024)
A good example of using GIS and BIM tools for smart City planning is studied and analyzed in the paper “Assessment of Urban Energy performance through integration of BIM and GIS for Smart City Planning” by S. Yamamura, where it focused on the communities surrounding the JR Yamanote Line in Tokyo, Japan. This area comprises twelve transit-oriented development (TOD) communities, which cover all the 29 stations of the Yamanote Line. The research focuses on about 150000 buildings within a 1000m proximity to these stations. The researchers used a **GIS-BIM based urban energy planning framework to assess and provide specific energy strategies appropriate for each community**. The results show that although large scales of development models are useful in areas with many large buildings, the long tail

approach, which focuses on the application of energy saving measures in small buildings, can bring more significant energy saving effects to the whole city.

Internet of Things (IoT):

IoT is pivotal for urban building renovations, because it **enhances efficiency**, **sustainability and allows for better decision making** since it does extensive data gathering. With the data gathering analytics are performed to improve all aspects of a building and its performance.
IoT provides real time data monitoring and management of urban spaces during the process of construction or renovation projects. Sensors and also connected devices are used to measure multiple environmental factors, such as, air quality traffic patterns, water pollution, noise pollution etc. (Eleonora Riva Sanseverino, 2017). A good example is smart lighting and energy management systems used to optimize resource consumption during the project and also after the project, this was contributing to smarter and greener solutions for smart city objectives. (Caragliu, 2011)

IoT can be used in:

- Smart lighting systems
- Energy Management
- Indoor air quality monitoring
- Security and surveillance
- Water Management
- Waste Management
- Predictive Maintenance

IoT is transforming the way urban renovations are done, giving us benefits of better energy efficiency, better security, and most importantly sustainability of the environment. With IoT integration, smarter and more resilient urban infrastructure can be created to serve the needs of urban populations. (Maltseva & Tkachuk, 2020)

Virtual Reality:

VR is a powerful tool in participatory urban planning, because it **provides immersive experiences and allows users to engage with 3D models** of the proposed developments in their area/building thus giving a realistic view on the development itself and how this will affect them in their own perspective.

The research has shown that VR can really **increase public participation** because participants will be able to use VR to interact and experience other design options or ideas and **see how these actually affect their environment.** This find was based on a study conducted in The Hague where VR headsets were proven to deliver information to citizens during the process of making a decision when redesigning a public park. VR use was reported to result in higher levels of engagement and more vivid memory of designs than either traditional display methods, such as 2D images or physical models. VR attracts more participants and is more likely to be actively used. (Jos P. van Leeuwen, n.d.)

VR enables **co-design activities** where community members can **collaborate** with architects and planners to negotiate on design decisions and find solutions to possible problems that both parties might have missed in the initial design of the projects. This collaboration

empowers the citizens by giving them a voice and an active role in shaping their environment. The study highlights that VR gives the means for better communication between the experts, the stakeholders and the public, but also will help in building consensus among the diverse groups allowing them to visualize the competing designs therefore helping everyone make better decisions. (Jos P. van Leeuwen, n.d.)

Augmented Reality (AR):

Augmented Reality offers another innovative approach to participatory design by **overlaying digital information onto the real world**. This tech offers citizens a way to visualize **how the proposed developments will fit in the existing environment**, thus enhancing their ability for comprehending these complex urban changes. From a recent study we found that AR significantly improve public understanding of choices in the different city/area plans compared to the traditional visualization methods like static images and designs. (Boos, 2022)

AR applications are also **effective during public meetings/community consultations** because the ones participating can use their smartphones or tablets to view 3D models of planned buildings, parks, urban areas from where they stand. This capability allows users to assess the various aspects of the project, such as scale, aesthetics, practicality, accessibility and also how this integrates with the surrounding area and structures under different environmental conditions like different lighting. Such interactive engagement increases transparency and also encourages well informed discussions about urban development. (Boos, 2022)

Artificial Intelligence (AI):

AI is transforming urban renovation projects by giving us **enhanced decision-making capabilities, optimizing resource allocation and improving overall efficiency** of each project. The use of AI in the analysis of the urban renovation is the integration of data analysis techniques used in the **prediction of trends, optimization of operations and assessment of the sustainability** of the renovated spaces.

1. **Predictive Analytics and Trend Forecasting**: AI-based analysis can analyze big data from various domains including population of cities, economic indicators and shifts in the environment. Some of the most powerful tools in machine learning are used to detect patterns and tendencies for the future. With the help of such parameters as population dynamics, changes in employment, transportation requirements, and climatic conditions, AI allows urban planners to predict future load on infrastructure and service. This predictive power is important in the crafting of renovations that are scalable and suitable for the changing demographics of the population. (Szpilko, et al., 2023) For instance, it can predict which regions may require such improvements as population density changes or changes in business and residential patterns.

2. **Optimizing Resource Allocation**: AI models help cities to make better resource allocation and do it in a more effective way by analyzing trends. These can be energy consumption, traffic patterns and also building use trends. AI for example can identify any underutilized spaces and give recommendations that help in maximizing space efficiency, this way reducing expenses and waste of resources. AI can help in energy saving strategies and

measures for example in heating or cooling systems operation based on usage patterns, this way leading to reduced renovation and operation costs (Moghimi & Gulliver, 2024)

3. **Sustainability and Environmental Impact**: AI can help in reshaping urban renovation and transformation in a more environmentally friendly way, by considering energy consumption and also environmental effects of the process. Sensors can provide real time data and weather forecasts can be used to help optimize heating, cooling but also lighting conditions for each building in a dynamic manner. This way we can achieve a minimization of energy use and reduce the cost of operation, and carbon emissions to the environment. AI can assist with decision making in the material choice and green building renovation techniques that is compliant with environmental policies and can assist cities with climate change challenges. (Lim, et al., 2021)
4. **Enhanced Decision-Making**: Decision making during planning and design phases of urban development and renovation can be enhanced with AI. It can be used to analyze big data to suggest the best renovation solutions, while taking into account cost, environment and also society. It makes it possible to create a number of renovation alternatives and actually suggest best strategy to be used. Helps with assessment of risks and evaluates the possible dangers while minimizing them before they can create complications to the project
5. **Supporting Predictive Maintenance:** The support of predictive maintenance with AI is one of the most important uses of AI in urban renovation. All the data, maintenance records, system performance etc. can be used by AI in order to better determine when repairs are needed this way, we achieve better building functionality and safety. AI for example can predict probable roof leakages or HVAC system failures based on past occurrences and data gathered so that it can do preventive maintenance and avoid bigger implications and system failures. (Hu, 2024)

In conclusion AI driven analytics can offer **great benefits** for urban renovation projects and increase a **buildings performance and safety**. From predicting trends and optimizing resource use, to **predictive maintenance** we can achieve better performance and sustainability. Modern cities using AI can improve all the processed involved in construction and renovation, starting from planning to the execution phase, this way achieving long term goals for performance, better efficiency and sustainability, while in the same time being really cost effective and prepared to tackle any future challenges ahead.

2.4 Scenario Modeling Techniques

Life Cycle Assessment and Energy Demand Modeling, are important tools that help us in evaluating urban building renovations. Both are used in modern smart building renovations and give us very important benefits.

Life Cycle Assessment (LCA)

Life Cycle Assessment helps in **identifying the environmental impacts of building materials** and also **construction processes**. Also identifies the operational energy consumption levels throughout the building's life cycle. LCA counts for factors like energy used while in construction phase, known as embodied energy, and also how much carbon would be released into the atmosphere during that. Can also provide us with the amount of waste that would be generated and the rate at which the natural resources are being consumed in the process on a renovation project. This way helps in advice on the most sustainable methods of renovating a building. (Fahlstedt, et al., 2024)

Energy Demand Modeling

This tool focuses more on the part of **predicting the energy consumption** of a building under various different scenarios. Various **different variables are taken into account**, such as climate **conditions**, **design** of the actual building and **technological factors** and interventions used like HVAC systems and **insulation** used. It can **simulate different approaches** and gives energy demand models that allow us for optimizing energy efficiency of a building, this way providing designers with the means to create buildings that are efficient, sustainable and cost effective. (Verwiebe, et al., 2021)

Using these models the designers can e**valuate the actual benefits of the different energy interventions and modifications**, see the results and test the possibility of using and adding renewable energy sources to the mix. LCA and energy demand modelling together can help us create an integrated approach that can lead to better data driven decision making in urban building renovation projects, creating low carbon emission projects that are also very energy efficient.

2.5 Stakeholder Engagement in Urban Renovation

One of the most **critical aspects** of successful urban renovation projects is the actual participation of the local community in the project. Using advanced technologies and tools with the help of data gathered with IoT, tools are created so that **all stakeholders can be involved in the process of design for a project**, that way making it more **inclusive and sustainable** and also the project in in accordance **with the needs and desires** of the community. Stakeholders' engagement can be divided into steps:

1. **Stakeholders Definition**: stakeholders can be many different parties, expanding from government to residents. Every group has its own goals and perspectives on each project. For example, the residents who are directly affected by the project's outcome, while the government tries to be within regulations. (Ehwi, et al., 2018)
2. **Engagement methods**: Structured methods are needed to facilitate collaboration between different stakeholders. Participatory planning models like co-design and co-production must be used so that we can involve as many stakeholders as possible. This way the project will be using the input and knowledge of the many having many benefits. A sense of ownership created to the stakeholders, and also the creation of

more sustainable solutions, that are accepted and approved by local citizens. (Ehwi, et al., 2022)

3. **Role of digital tools in Engagement**: Very important for the success are the digital tools used for facilitation of stakeholder engagement. These can vary from digital twins to VR and AR or GIS or even combination between them. This enables stakeholders to better visualize the proposed design for the project and make their opinion in a better and more informed way. These tools achieve a really high level of communication, better transparency and support of well-informed decision making. (Jr., 2024)
4. **Addressing of conflicts**: In many projects it is common to see conflicts of interest between the stakeholders, that need to be addressed. Power dynamics together with this is really important for the success of the project and leading it to acceptable by all parties' solutions. Making the projects more inclusive and engaging parties that are otherwise marginalized, so that we can achieve minimizing of inequalities between the stakeholders, and also avoid boosting the gap between them. The processes used for participation must be able to seek diverse interests and balance them and the needs, in order to foster a more collaborative environment for everyone to be part of. (Ju & Binwei, 2021) Frameworks for effective governance and collaboration are also needed. Coordination is required between public and private sector and is considered critical. Integration must be made at different tiers of government and private domain.

   General coordination between the public and private sector since the two are critical. It has to be made at the various layers of government and between the public and the civil society and the business. It is also necessary that the smart city initiatives span across a number of regulatory domains; it will therefore be necessary to clarify the governance structure in order to define and describe the roles and responsibilities and the communication channels between the various entities involved. (Commission, 2020)
5. **Evaluation and feedback mechanisms**: Evaluation and feedback as well are critical. This way we can ensure that stakeholders engagement stays effective in the projects. Conversations, questionnaires and research helps to determine at what extend are the stakeholders concerns. With these mechanisms we can make adjustments and guarantee that the process is in the right direction and in line with the stakeholders involved. Using participatory approaches and embracing use of technology, managing conflicts, using collaboration in governance and providing stakeholders with feedback mechanisms, urban renovation projects can be made a success, while being inclusive and in line with more sustainable solutions. (Ehwi, et al., 2022)

Figure 1 Stakeholders in urban development projects (UrbanLearning.eu, 2024)

Public Participation and Collaborative Design

Both public participation and collaborative design are considered **essential components** for successful urban renovation projects and planning. They help in community engagement and make sure that the process is inclusive throughout the decision making and planning process. With the integration of digital technologies, enhanced participatory approaches have emerged, enabling for better interactions and communication between the planning team and the citizens. In this section we will explore the various methods used.

Importance of public participation

Public participation is crucial to the **success of planning process of the projects**, because with it we can **ensure that the needs and requirements** of the local community are considered and implemented in the design. Relevant research shows that involving citizens in the planning process can help us in achieving **greater acceptance levels** and also **enhances the quality** of the actual urban renovation projects. (Diaz, 2016)

Through effective participation, **citizens are empowered and transparency is boosted** about the design decisions and accountability of actions in the process. As urban areas grow and the problems of rapid urbanization become a reality, a need for more inclusive practices and methods used to the planning process becomes paramount, in order to address the diversity of needs and requirements of all stakeholders that are involved.

Digital technologies enhance participation

Using technological means, has **advanced and revolutionised the traditional methods** and approaches, and makes stakeholders **more active and creative**. Using tools like Public Participation Geographic Information Systems (PPGIS) in combination with online forums gives the means for people to offer their feedback on the project in real time. (Bugs, et al., 2010)

Using these technologies make possible to **visualize the planning proposals**, this way helping the public to understand complex urban issues and **give back informed feedback** on the projects. A good example of using **Web 2.0 technologies**, this way enhancing urban planning practices in Canela Brazil proves the above statement. (Bugs, et al., 2010).

Collaborative Design models

An example of a collaborative design model is proposed in a paper by (Marsal-Llacuna & Rosa-Esteva, 2013), and is called **Representation for All Model**. This model uses agent-based systems in order to enhance citizen participation in urban planning process, and emphasizes on the importance of incorporating the citizens feedback before and during the development of urban projects. This way it ensures that the **proposed changes and possible interventions are in accordance with the community needs, and reflect the feedback they provided**. Using recommender systems, the planning team can predict citizens reactions to the solutions they proposed, this way increasing acceptance rates and provide more sustainable solutions.

Challenges in Public Participation and Collaborative Design

Despite the many successful applications of participatory urban planning, many challenges remain. Most important of these is the **digital divide**. That **can limit access to these tools for certain minority groups**, **this way creating inequalities in the process**. Some people input their opinion and needs and others do not even know how to use the tools. (Nahhas & Kharitonov, 2024)

Another factor we need to consider is the **effectiveness of public participation**, **is not always the same**. It can vary depending on what **methods** are being used, and the **willingness** of the planning team to use citizen feedback to the decision-making process. We need a more focused approach in the development of better and more inclusive participation, with the use of technology and AI, we can enhance participatory design and project development processes. (Prodanovic, et al., 2024)

Governance Tools for Citizen Involvement

These tools are important in the process of participatory design in urban renovations. Using these we can **facilitate communication and collaboration** between different stakeholders, and have feedback between them, ensuring that the opinion of the citizens is taken into account in the decision-making process. Their success depends on the following important **factors: Technological innovation, organizational structure and also the actual desire** of the stakeholders to be involved and participate in the process.

Digital Platforms for Public Participation

Using digital technology has become important part of civil engagement in the planning of urban renovation projects. These include **public participation GIS and other Web-based participatory decision-support tools**, that help and enable citizens to give their input and preferences regarding a project. (Diaz, 2016) As an example, in this paper Diaz have created a web based PPGIS for environmental reporting, with its citizens could give their opinions on urban plans and this way a **bottom-up decision-making process was facilitated**. These tools are ideal to **enhance** the participatory planning process, and also the **quality of projects** by incorporating all the diverse opinions and perspectives.

Collaborative Governance Frameworks

Frameworks are essential for integrating citizen input into urban planning process. A good example in included in (Jutraz & Moine, 2016) study where they discuss the **co-governance model used in Lahore**, at which **local governments and NGOS collaborate with the citizens**, in order to **manage green spaces**. The model can make different stakeholders work together, this way achieving common goals and enhancing the effectiveness of the outcomes for everyone involved. Citizen's involvement can lead to more innovative practices and policies that **really reflect the needs of the local communities and lead to sustainable designs**.

Challenges to Participation

There are many challenges in participation and effective use of the input. A recent paper by (Wang, et al., 2023) shows that the main challenges spotted are:

- **Insufficient communication channels**: Traditional methods fail to meet public demands
- Limited resonance media: Lack of effective platforms for multi-stakeholder's dialogue

- **Weak Objective planning**: Poor planning and objectives are not clear
- **Realistic Deviations**: Disconnect between public expectation and outcomes

In this paper the author states the acceptability of the planning decisions depends very much on the implementation of the public involvement procedures (Chen, et al., 2022).

There are **factors that might limit the participation and can be from organizational constraints, bureaucratic procedures or maybe lack of resources**. Public attitude against the process of engaging may take some time to change as well because in many cases people doubt that their input is being used.

Future Direction

Though many new and innovating technologies give better and more effective ways to participate we still have a lot to do. **AI and blockchain can be great tools** if utilized correctly to boost the efficiency and effectiveness of the process of participation. Better **transparency and efficiency** can be achieved, while better collaboration is implemented between the stakeholders. For example, blockchain can be used to facilitate more secure and transparent communications, **ensuring that all contributions and opinions are used, recorder, processed in the decision-making procedure**. (Shang, 2023)

AI could play a role in analysing public feedback and give predictions on acceptance and response to the proposed changes and solutions for urban development and renovation. AI can really improve planning process and quickly and effectively analyse citizens' input. (Yigitcanlar, et al., 2020)

Conclusion

Governance tools for citizen participation and involvement in urban renovation projects are essential in order to create inclusive and participatory friendly urban planning processes. Digital platforms and all other tools enhance citizen engagement and make sure that all diverse opinions are being integrated into decision making process and in final designs of the project. Many challenges remain but future technologies hold great promise for better solutions and more inclusive and sustainable solutions for everyone to be involved in.

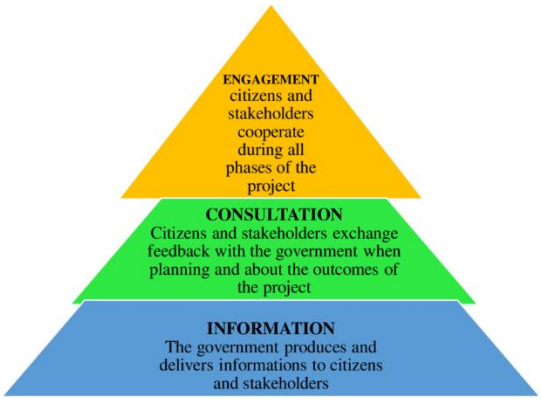

Figure 2 The three levels of citizens' participation in governance (Boulbazine & kebiche, 2023)

2.6 Summary of Key Findings

In this chapter, we provide a detailed background on sustainable urban renewal with a focus on the need for urban centers to address issues of the growing and aging urban fabric. This pointed out that sustainable renovation entails the improvement of existing structures to match current best practice for efficient use of resources and the general well-being of occupants. Some of the strategies used include policy in field of energy conservation, usage of LEED and BREEAM certifications, and eco-preferable products which also help in assessing the company's environmental footprint. In addition, the paper focuses on the role of participatory design in the context of urban planning and finding that stakeholder involvement should occur throughout the design process. They are not only important as they improve the contributions and performance of urban solutions but also as they help communities to embrace the solutions. Organization communication with its stakeholders, involvement of stakeholders in the decision-making process, opportunities for them to share opinions, ideas and visions, is also stressed through the involving of collaborative workshops and implementation of VR/AR technologies which are virtual and augmented reality. Together with the results of working out the idea, it is possible to state that the combination of the aspects of sustainability with the principles of participatory design enhance the potential of improving the urban environment as the environment becomes more sustainable and adjusted to the requirements of people living in cities.

Chapter 3: Methodology

This study adopts a multiple case study analysis combined with a literature review of projects and solutions that are implemented in real world, in other relevant research in order to explore real life applications of the practices and compare between our research findings with the ones we studied. In this chapter we will explain the approach and methods used. The criteria and reasons for selecting these case studies, how we gathered our data and why, and also the steps we take to analyze the data from the selected case studies.

3.1 Research Design

Type of Research

This research employs a multiple case study design in order to investigate the application of digital solutions in participatory design and planning of urban projects. A multiple case study design allows for a more in-depth exploration of multiple different cases, this way enabling a better understanding of the case under study. The cases were selected based on certain criteria and are analyzed on many different factors like the use of digital technologies, citizen engagement and urban development impact. Similar studies were also taken into account and their methods of assessment were combined with other important factors so that we could derive a subjective grading system that would help our investigation on how really effective the solutions studied where and how we can possibly divide them according to the area these cover.

A comparison with the theoretical findings from other studies and papers, and the practical ones will lead us to combined conclusions on effectiveness and sustainability of the solutions that actually stand out between the two categories we studied and we will try to prove if the existing theory is proving correct in all the different projects we reviewed.

Research approach

In this research we will combine methods of literature review and comparative study as we will try to gather information about successful implementations of projects on urban renovation of areas and buildings using digital tools and participative design. We will gather data from both areas and compare the results with the existing theory and between them in terms of goals, benefits, barriers etc. This way we will explore how impactful these are to the transformation process of the smart cities and which ones stand out in terms of sustainability and impact.

Theoretical Frameworks:

This research is based in several theoretical frameworks that provide us with a structured approach to analyzing the implementation and also the impact of smart city renovation projects. The frameworks that are most commonly used are: systems theory, sustainability models, innovation diffusion theory, stakeholders' theory and also Technology acceptance Model (TAM). These enable multidimensional evaluation of the different projects and case studies and will guide this research in better understanding the interplay between technology, stakeholders' involvement and urban environment while using the theory to try and interpret the results and findings of it.

Systems Theory: Introduced by Bertalanffy in 1968, it conceptualizes different complex entities as interdependent and interconnected systems. In smart cities this theory views cities as interconnected elements, where each element does influence others and is influenced by other elements. It's a more holistic perspective that emphasizes on how important is to understand the interactions to achieve the goals of sustainable and resilient urban environment. Using this kind of thinking we can identify patterns, synergies, and deal with challenges in a more holistic way, thus leading to better and more effective solutions. In the case studies we analyzed such as MetroTaifun and LORIOT demonstrated how system integration can enhance efficiency and also cases like AmbiAir show how important feedback loops for optimizing real-time decision-making process. This proves how interconnected systems can lead to benefits, such as improved management of resources. (Meadows, 2008)

Sustainability Models: Sustainability models, taking as an example Triple Bottom Line by Elkington 1997, give an emphasis on balancing economic, environmental and also social outcomes. In this study we identified that solutions like Arqlite SPC is an ideal example of circular economy's principles, while Encompass Blue for example combines energy efficiency and carbon reduction for overall better health for occupants of the buildings. These both show the importance of aligned smart city project goals with long term sustainability goals.

Innovation Diffusion Theory: Innovation diffusion theory by Rogers (1962) helps in understanding how the technologies are adopted in societies. Examples like GreenPocket can show us how early users can really influence the adoption of tools for energy management. Examples like MetroTaifun show the challenges of scaling and the barriers that can exist from financial limitations. Talking wastebins on the other hand show how social influence can really accelerate the adoption process.

Stakeholder Theory: Stakeholders Theory by Freeman (1984), has a focus on balancing the needs of all different stakeholders involved in a project. In projects like Sustainaccount, this alignment of goals between the stakeholders enhances the success of the project. In other solution like Omnicarbon there is a highlight of the value of transparency in the collaboration for better environmental results.

Technology Acceptance Model: TAM framework introduced by Davis in 1989, assesses the perceived usefulness and ease of use in technology adoption. Cobundu case implements user friendly systems, this way reducing the actual complexity and others like Greenpocket show how actionable insights can enhance the perceived value.

Resilience Theory: This emphasizes adaptability and also robustness while facing disruptions (Walker, et al., 2003). Case like Urbanistic Planning Platform show how useful and enhancing predictive analytics can be, this way enhancing urban resilience.

Integrating all the above frameworks, this thesis evaluates urban building and area renovations in a more holistic way. We will try to assess the different case studies in areas of sustainability, adoption dynamics, economic viability, environmental impact. Using these theoretical perspectives to ensure a robust analysis of how these digital solutions can deal with urban challenges and how these help in the goal of more sustainable solutions.

Justification:

Case studies were chosen as the primary method for this study because these provide in depth, contextualized insights to more complex phenomena. The complexity and the continuous evolution of smart cities, require an approach to the analysis of the projects that can actually encompass this complexity and interrelations. Case studies are ideal to this context for many reasons. These include:

A. Rich contextual Insights
B. Suitable for exploring Complex systems
C. Give comparative analysis opportunities
D. Flexible in addressing many diverse objectives
E. Bridge the gap between theory and practice

Case Study Selection

The selection of the case studies is of critical importance for shaping the depth, the scope and also relevance of the research results. This section will cover the criteria used for selection of the projects that align with the research objectives. Also important is to ensure the diversity of the cases, and ensure we can get data required from these. Choosing the right set of case studies can give us a better understanding of how urban renovations operate in different environments, and also lay down the foundation for comparative analysis and thus leading to generalizable solutions.

Criteria for selection:

Primary criterion was the **relevance** with the objectives. A focus on key urban challenges of sustainability, efficiency, health and well-being was performed. Innovation was also an important factor in choosing these case studies and projects.

Diversity was also really important for the case studies from Beesmart.city where multiple solutions were chosen. These were diverse solutions from many different geographic contexts and different regions. This way we can achieve exploring how geographical factors will influence the actual project and implementation of it. Moreover, an important factor was technological innovations. A wide range of technologies was used in the projects from IoT to AI driven systems, behavioral tools etc. in order to assess how different technological solutions can address the different urban challenges.

Accessibility to actual data and examples of implementations was also important. Having reliable and well documented solutions was prioritized. Some of the solutions had detailed reports on actual assessments of climate risk, like for example Sustainaccount solution.

Selection Process: The process of selection involved an initial pool of 465 projects. From these we chose the projects about Smart Environment, Environmental Impact and finally Smart building projects using the filters provided in Beesmart.city webpage. The initial pool was refined to our needs and selection criteria. An analytic case study for each project was performed for relevance to the research objectives, their diverse environments and technological contexts and also availability of data relevant to the projects. For example, we can take AmbiAir which was selected due to its main focus on air quality monitoring and optimization, this way aligning with both environmental and also technological oriented research objectives. The final mix of case studies was chosen so that it includes a balanced mix of solutions that help in answering our research questions and ensuring an extensive and comprehensive analysis.

Case Study profiles: Selected case studies include a variety of innovative solutions from smart cities and smart buildings that address a variety of urban challenges. Some examples are:

- Greenpocket Energy Management: Mainly focused on energy optimization and integration of renewable energy sources in urban environments
- Arqlite SPC: Circular economy solution that promote recycling, converting plastics into construction materials
- Metrotaifun: Innovative waste collection system using pneumatic technology, addresses both management and also reduces traffic congestion from garbage trucks
- bGRID: Modular IoT platform that enables smart building optimization, using interconnected sensors.
- Talking Wastebins: More of a behavioral tool, helping in proper waste disposal, thus reducing urban littering

Link to research Questions:

Selected case studies and the methodological approach are in direct alignment with the research questions, providing us with a structured path for exploring integration, impact, and also implications of using immersive technologies in urban building and area renovation projects. Each question addresses a part of how these digital solutions add to sustainable urban development, and also the case study analysis is designed in such a way to provide more comprehensive answers to all these questions by giving us the ways these projects deal with the problems of urban sustainability.

RQ1: How can immersive technologies, such as VR/AR be effectively integrated into participative design and scenario modelling, for urban building renovations to enhance sustainable energy solutions, health outcomes and socio-economic impact assessments?
The following case studies offer a good foundation to help us explore the role of immersive technologies in participative design and scenario modelling. These are:

A. Sustainaccount Climate Resilience suite: This project demonstrates how using digital tools can enable participative planning, involving stakeholders in the process of assessing climate risks and then planning more sustainable renovations. This is in alignment with participative design focus mentioned in RQ1.
B. AmbiAir: It focuses mainly air quality, but offers us with data on how real time digital tools can really help in enhancing health and well-being in urban renovations
C. Virtual energy audit: Gives us a good example of the potential of virtual models in showing us energy inefficiencies and simulation of renovation projects with different scenarios and outcomes. This relates to scenario modelling for sustainable energy solutions.
D. Cobundu: This gives an emphasis on user-centric approaches to create virtual models for optimizing building layouts, using occupancy patterns and space layouts. Helps in enhanced well-being and health outcomes, improves spatial efficiency of buildings.

These case studies, help us explore integration strategies, and how these immersive technologies are tailored to each project. They provide us good examples on how these engage with stakeholders to achieve goals for well-being, health, energy efficiency and socio-economic balance.

Theory Context that these can be analyzed with includes:

Systems theory, Sustainability models and Innovation Diffusion Theory

RQ2: What are the impacts of immersive digital solutions on energy efficiency, health outcomes, and socio-economic factors in urban renovation projects?
Impacts of the immersive technologies are analyzed in all case studies that provide documented measurable outcomes, and some examples are:

A. GreenPocket energy Management Software: This project provides quantitative data on the energy efficiency achieved with digital interventions. Provides measurable optimization of energy use in renovation projects.
B. Talking Wastebins: Helps in contributing insights in health and well-being by using technology-driven behavioral solutions that improve quality of life in urban areas.
C. Arqlite SPC offers us an innovative perspective on socio economic point of view, showing us, how circular economy solutions can really add value to renovation projects and reduce environmental impact too.

All of the above cases analyze the direct and indirect effects of different immersive digital solutions, showing us their potential in transforming urban renovation projects in many different ways.

Theory Context that these can be analyzed with includes:

Technology Acceptance Model, Stakeholders Theory

RQ3: What are the benefits and challenges of these digital solutions?

During this research we explore both the potential of the solutions and also the challenges that come with them. For example, we will analyze some case studies benefits and challenges respectively:

A. Virtual Energy Audit: Helps to simplify renovation process, with providing the stakeholders with actionable insights remotely without even visiting the building. Reduces the on-site costs that relate with this assessment.
B. Omnicarbon: Showcases the ability of carbon tracking platforms to provide us with accurate metrics on the environment, aiding transparency and accountability for renovation projects.

Challenges:

A. Talking Wastebins and other solutions on behavioral aspects, struggle with public acceptance and require educational and also engagement efforts from the planning team
B. Sustainaccount gives emphasis on the complexity of integrating immersive tools with older legacy systems already existing in cities, that can really create difficult to surpass technical but also logistical problems.

Theory Context that these can be analyzed with includes:

Innovation Diffusion Theory

Concluding with integration of case studies such as Virtual Energy Audit, Sustainaccount and bGrid with theory such as Systems Theory, TAM, this thesis tries to directly address the three research questions. The examples we used above give a highlight to the transformative

potential of the digital solutions and also identify the challenges that come with these. This way a more balanced analysis on how these really contribute to the various sectors of urban renovation benefits is presented and the general patterns used in the solutions are revealed.

Data collection and sources:

Since the primary data methods are restricted due to the bibliographic analysis of the case studies, using their websites and data from these.

Primary data can be taken from direct content analysis of the websites of the actual projects and also analysis of the data provided in beesmart. City website. This leads us to extraction of relevant, self-reported information that comes directly from the websites and online documentation provided on the case studies. These can be from technical specifications and descriptions of how the tools works and also outcome reports and performance metrics included and shared on the websites.

Data collected can include metrics on energy efficiency, emissions reduction impact, user engagement, benefits, barriers, challenges etc. Also, some data can be gathered by virtual observations from online media provided like videos, case study websites, interviews, project implementation demo etc. We will also create a subjective ranking of the solutions table presented in a separate excel file where all different scenarios will be ranked accordingly to their performance and impacts on various different variables that we chose, after extensive research on similar studies doing rankings of similar type to smart city projects. These ranks are based on theory and our observations and 37nderstandding on the solutions presented and studied. We will explain how these case studies where ranked and which variables we used to rank them with and why in this chapter.

Secondary data: Secondary data comes from case studies, reports and papers, academic and industry also. From these we will extract performance metrics, stakeholder engagement strategies, socio economic benefits. Also, we can extract independent evaluation methods of the actual tools used, their effectiveness, scalability and also the challenges these met. Very effective is to study the solutions websites also to get information on the evaluations of the cost effectiveness, usability and scalability for example of the projects.

Through bibliographic analysis of the data, from projects in beesmart and also the ones we found on other papers that are relative, we can create a comprehensive dataset with combination of the different information can lead to a robust understanding of each case study. This way we can address the RQ's:
RQ1-Integration: Using the available documentation and analyzing how these tools and technologies are integrated in scenario modelling and participative design.
RQ2-Impacts: Find metrics and qualitative outcomes, from media and reports, and try to evaluate the different metrics such as energy efficiency, health and well-being, and socio-economic benefits. We will also use our own metrics based on relevant rankings of smart city solutions. (Shi & Shi, 2023) (Gazzeh, 2023)
RQ3-Benefits and challenges: We will try to identify the benefits and challenges associated with each projects using the data available.

Using this approach our research stays grounded with verifiable data, even though our limited access to the projects themselves, with the combo of the above we will lead this research to meaningful insights.

Data Quality and Reliability: Ensuring that the data has quality and is reliable is critical for this thesis, since primary data is limited and we have to rely mostly on bibliographic analysis and case study websites to gather it. High quality and reliable data can contribute for more valid results and the creation of robust conclusions. Data in general must be accurate, relevant with the project, up to date, comprehensive and complete, and finally credible.

How can we achieve that the data is reliable?

- Cross reference sources
- Use multiple sources
- Evaluate sources
- Have transparent limitations

Challenges:

- Limited data
- Secondary data might be biased
- Incomplete data

Maintain consistency and rigor will help in the process of data collection. A standardized data collection framework will be used. Uniformity across all case studies will be applied. Using key variables such as community engagement, effectiveness of solution, sustainability, scalability, innovation, interoperability, cost effectiveness, carbon emissions reduction and TRL. Also Benefits, barriers, environmental impact, Economic Viability are taken into consideration and analysed as well for each scenario. (Shi & Shi, 2023) (Gazzeh, 2023)

Data analysis

This process was designed in order to interpret the information gathered from the case studies and bibliographic case studies in a systematic way, this way trying to ensure the alignment with the RQ's and theoretical frameworks. A structured approach was used in order to help us identify patterns, rank the impacts and this will lead us to answering the research questions of the study. **Analytical Framework:** This provided the foundation for organizing the data, doing interpretation on what the data meant and also synthesizing results. Analytical framework provides the theoretical and also methodological basis for interpreting the data. It combines both qualitative and quantitative approaches so that it can deal with the multidimensional nature that the RQ's have.

Thematic analysis: This way employed to identify patterns and themes in the data, for example descriptions from case studies and bibliographic sources. This way common stuff was revealed on how the technologies are integrated, their impacts and also the challenges in implementing them in the projects studied. For example, themes such as: participative design, stakeholders' engagement, energy efficiency can be met in quite a few case studies i.e. Virtual Energy Audit

Comparative study analysis: This enabled us to evaluate similar areas and differences between the different case studies. This way we could rank the spot the best solutions,

identify variations between them and also find common challenges and barriers. For example, Metrotaifun project vs Greenpocket shows differences in area of application, waste vs energy, showed differences in scalability of these and different adoption levels.

Impact assessment framework: In order to evaluate the outcomes of these technologies, we use and impact framework. Three dimensions where used, energy efficiency, health and well-being, and socio-economic factors. These were integrated into one metric called Effectiveness of solution and is presented in both matrices for Beesmart projects and Literature review case studies.

Integration with the theory: The findings were structured in accordance with the theoretical frameworks to ensure these align with academic principles and guides. For example, systems theory was applied to help analyzing systems that are interconnected using IoT, like bGrid and how these can play an important role in urban renovation projects and their outcomes. Stakeholders' theory can help in giving insights on how collaborative tools like Sustainaccount as an example use participative decision making.

Steps in analysis

All the data gathered was structured in the same format, that was created in order to help us make a systematic analysis. We then did an initial review of the data in order to identify themes and patterns. An initial observation of similarities in benefits and challenges in many projects was performed. Then a thematic coding was carried out, based on what these projects were about and what aspect these were trying to improve. We identified where each project could fit and we did a separation of areas of interest according to the project's objectives. A comparative analysis was then performed against one another in order to clarify which ones had better results in areas like scalability, sustainability, innovation, interoperability, community engagement and effectiveness of solutions. Quantitative analysis was then performed where data was available for example carbon footprint reduction by Omnicarbon was summarized and interpreted accordingly that is why this solution was ranked subjectively in a high rank placing it second overall. Synthesis was after, where all insights are combined to help us answer the RQs and identify the trends that are seen more times than others. Key themes and trends were identified this way, and last was validation of the results using secondary resources, for example articles on the actual technology used in the project and evaluations that are independent to the actual project team.

Comparative analysis

Comparative analysis is vital for this thesis, since it enables the evaluation and comparison of different case studies, and tries to find similarities, differences and also spot the best practices in the integration of immersive technologies in urban renovation projects. CA offer an understanding of the factors that determine the effectiveness of an implementation and shows differences in the effects of various technologies, different areas and also different applications. The purpose of comparative analysis can be summarized as:

- Evaluation of the effectiveness across different dimensions
- Identification of patterns and trends
- Uncover challenges and also enablers for certain cases

In our analysis we will use a structured framework for comparing the case studies focusing on the following dimensions:

Metrics and evaluation

Extensive documentary analysis on project reports, media articles and project websites gave us a better understanding on each project's aim and how each project managed to complete certain goals.

There was extensive research in every single one of the 28 projects in many different areas. These were:

- **Community engagement:** How actively are stakeholders involved in the design and decision process? (Highly important)
- **Effectiveness of solution:** Does the solution give an effective outcome? (Highly important)
- **Sustainability of solution:** How does the solution cope with environmental impact? Is it viable long term? (Highly important)
- **Scalability of solution:** Can the solution be adapted and implemented easily? (Medium importance)
- **Innovation:** Is it innovative as a solution? (Medium importance)
- **Interoperability:** Does it integrate with existing systems easily? (Medium importance)
- **Cost Effectiveness:** Is it value for money as a solution? (Medium importance)
- **Carbon Emissions Reduction:** How much does it impact reduction of carbon emissions? (Highly important)
- **TRL-Technology Readiness Level:** Is it mature and ready for deployment? (Medium importance)

  After studying the projects from beesmart city website and also their webpage we came to the results presented on the excel sheet presented at table 1.

  These rankings were developed using MCDA method with variable weighting. The variables were chosen in accordance with the significance these meant for the projects we studied.

MCDA provides us with a structured approach, helping to evaluate and prioritize urban solutions based on diverse criteria. The framework enables us to compare the alternative solutions with the help of assigned weights and scoring for each of the variables against the different metrics. The metrics and weights we have chosen are shown in Figure 3.

Variables	Weight
Community Engagement	20%
Effectiveness of Solution	20%
Sustainability	20%
Scalability	15%
Innovation	10%
Interoperability	10%
Cost effectiveness	10%
Carbon Emissions Reduction	20%
TRL	5%

Figure 3- Variable Weights

Rationale for weighting

Community engagement is one of the most important factors. As theory showed multiple times, projects that actually involve as many stakeholders as possible and throughout the whole design process actually lead in more successful and sustainable projects that are actually accepted by local communities.

Effectiveness of solution: In our perspective and compared to other similar projects how effective the actual solution proposed is.

Sustainability: One of the key factors and intended outcomes for successful smart city solutions. Sustainable and liveable solutions are the main aim for the project planners and stakeholders.

Carbon Emissions Reduction: This is also really important for long term sustainability and ecological friendly solutions

Scalability: Solutions that have good scalability tend to expand and be applied more rapidly than others. Especially when its relatively low cost and low complexity solutions that can be used in many scenarios.

Innovation: Innovation is also important for the different solutions. Very innovative solutions usually give us ways and perspectives that are not very common and provide us with radical results.

Interoperability: Very important as an aspect as the required effort to make a solution work with existing infrastructure is important also for the extend of the application of this solution. If its easily integrated then it is used extensively and applied with ease. If it requires a lot of modifications and changes usually it expands but less quickly.

Cost Effectiveness: This was clearly used to try and add an economic cost perspective to each scenario we ranked. High cost means it is harder for tight budget scenarios to use the solutions. It is sometimes better to use less expensive solutions in a bigger extend that will have a better impact, rather than one way more expensive that will not have the same impact.

TRL: This was used to give us an estimation of the maturity of the technology used in each solution we studied. Can be used to enable consistent and uniform discussions of technical maturity (Wikipedia, 2024) across the different types of technology used in each of the scenarios.

How these metrics answer the Research Questions?

The metrics we used in the comparative analysis, provide us with a structured approach to address the Research Questions. Here we will present the logic behind choosing these variables and how these fit with their relative Research Questions.

RQ1 How can immersive technologies, such as virtual and augmented reality, be effectively integrated into participative design and scenario modelling for urban building renovations to enhance sustainable energy solutions, health outcomes, and socio-economic impact assessments?

The following variables are contributing to answer RQ1 by addressing the variables of integration, participative potential, and also performance in design and modelling:

a. **Community Engagement:** Measures the actual level of stakeholder's engagement in Participative Design and Scenario Modeling. i.e. **Talking Wastebins** has high value in this variable because of its nature and the interaction this project fosters with the citizens.
b. **Interoperability:** This evaluates how well the immersive technologies integrate with the existing systems and other tools. i.e. **bGrid** offers open APIs to achieve seamless integration to existing building systems
c. **Innovation:** Indicates how technologies like VR/AR enable new methods for participative design process. i.e. in **Virtual Energy Audit** virtual simulations are used to engage stakeholders
d. **Technology Readiness Level:** This shows if the technology is mature enough and is deployed. i.e. Sustainaccount example show great level of readiness for adoption in collaborative urban renovation projects

RQ2: What are the impacts of immersive digital solutions on energy efficiency, health outcomes, and socio-economic factors in urban renovation projects?

The metrics we consider to address RQ2 by evaluation of the outcomes of the solutions in terms of energy savings, improving health and well-being and also socio-economic benefits are:

a. **Effectiveness of solution:** Measures the success of the actual technology in achieving higher energy savings, giving better well-being and health levels and also providing socio economic benefits. i.e. **Greenpocket** shows really high energy savings while **AmbiAir** provides better health and well-being status.
b. **Carbon emissions Reduction:** This is a more long-term quantified evaluation of the environmental impact of the technology. I.e. Decarbonization as a Service shows reduction that can be measured and add to more sustainable solutions.
c. **Sustainability:** Gives an evaluation of long term environmental, social and also economic impacts of the solution we study. i.e. Arqlite SPC provides socio economic benefits while promoting circular economy with recycling of plastics and using these as construction materials.
d. **Cost-effectiveness:** This variable shows whether the financial benefits of the technology used, are outperforming the cost for implementing the technology. i.e. Virtual energy Audit has high-cost effectiveness because it achieves socio economic outcomes that outperform the cost of implementation of the solution.

e. **Extra variables used in secondary analysis:** Environmental Impact, Energy Efficiency, Health and Well-being

RQ3: What are the benefits and challenges of using these digital solutions?

The metrics used to address RQ3 are:

a. **Scalability:** The ability of the technology to expand and also adapt to diverse needs and contexts. Shows opportunities and challenges in any implementation
b. **Cost effectiveness:** Balances benefits and respective costs, thus giving the affordability of the solution
c. **Innovation:** High end features can give advantage over other solutions
d. **Community engagement:** How the technology address community engagement to the projects, involving as many stakeholders as possible.
e. **Interoperability:** Addresses challenges of integration on existing systems
f. **TRL:** identifies the true maturity of the technology. If it's a low TRL, this indicates technology might need further development.
g. **Extra variables used in secondary analysis:** Barriers, Economic viability, Socio Economic Effects.

Conclusion

All the above metrics provide us with an extended framework in order to address all the Research Questions. We will evaluate all the above variables with this structured approach we can derive actionable insights into the possibilities and true potential of the solutions and also have a clear idea on their limitations. This enables us to contribute to both academic understanding and also use the above study for practical application of the solutions.

Limitations of the study

This research tries to provide an in-depth analysis of the process of integration, the impacts and the actual challenges of using immersive technologies in urban renovation projects, and several limitations must be acknowledged. These come from the scope, the methods used and also the availability of the actual data. These must be analyzed and identified in this section of our study in order to help in identifying areas for future research.

Starting with **Data availability and Quality**, we can state that the data both primary and secondary were limited and was sourced from bibliographical analyses, official websites of the case studies, publicly available data from reports, videos etc. These sources provide valuable insights but also posed several challenges. These include:

- **Incomplete data:** in many case studies there was lack of information on many key metrics such as precise energy savings achieved, detailed outcomes of socio-economic nature and specific data on health impacts achieved for example. For instance, we can use Metrotaifun case where it clearly states it reduces emissions but doesn't give a clear view on long term impacts.
- **Absence of long-term performance data:** This limited our ability to assess the sustainability and scalability factors over time. Take Virtual Energy Audit as an example it gives instant benefits but its true dynamic long term in not clearly defined.

- **Potential bias in data:** Since we used information that came from promotional material and official webpages of the projects, these usually promote and emphasize on the positive side and outcomes while not showing a lot of the negative ones. These can be challenges met, limitations and also negative results, that are left out intentionally or are reported in a really limited way.

The **methodological approach used** comes second in the limitations, since the methodology chosen limits the data collection from sources like interviews, testing, field observations of the actual projects. This has limitations on our research in the following areas:

- **Limited stakeholders' views**: There was no direct engaging of the actual stakeholders, to validate the findings or have better insights in to user experience and how these perceived the whole process. For example, in Sustainaccount project user feedback was used from secondary sources and not directly from users. This may lead to results not reflecting the actual performance of the project or how it impacts the stakeholders while being developed and then while implemented and working.
- **No real-world testing**: The study mainly relies on documented case studies and there were no hands on with the technology in use in the different projects studied. This limits our ability to evaluate the practical challenges associated with its use, like maybe existing technological issues or resistance to implementation which are usually left out of the material we used to extract our data.
- **Comparative analysis limitations**: Although this approach has its advantages and gives really valuable insights, it depends on the availability of data to compare between the different case studies and technologies. If the data is not always complete or available to us the comparison might be wrong or inconsistent.

Scope of Metrics that we chose to evaluate the different projects plays an important role too. Community engagement, scalability, cost effectiveness and others provide for a more structured way of comparison but these also introduce limitations to our study. These can be either from **subjectivity side** of the metrics, for example community engagement and also innovation is subjective and do depend on how the case studies actually define and also measure the concepts.

Very important also is the **generalizability of the actual findings**. Our findings are derived from a limited and selected set of case studies, that represent specific case study contexts, technologies used and also different environments of implementation. This gives us some limitations with the generatability of the findings including:

- Results are context specific: in projects like Arqlite SPC the project deals with recycling aspect only and might not be ideal to use in other contexts
- Regional bias: Many of the projects come from developed regions with advanced infrastructure and also better resources. This does not reflect challenges we have to deal with in developing regions or maybe in areas that the funds for such projects are not available.
- **No cross-section analysis** of immersive technologies was performed, as many might have broader applications in other sections, but that was beyond our scope of this study.

There are also some **limitations on impact assessment**, with challenges in accurate capturing of the full range of possible impacts of the projects. These can vary from **indirect impacts**, secondary effects, such as health outcomes of tools like AmbiAir. This tool can really play a

role on productivity in workplaces and also community well-being, but this was not counted for in this study as it wasn't clear on how impactful that was and we had no clear data. Also, the study was **based on short term impacts** for the projects since that was available to us, and does **not include long term considerations** on the various variables we used. There is a **reliance on proxy sources** that we used since in many cases there was not direct data on the impacts. The complex level of impacts from each case in many projects was derived from aggregate data and not only project specific measurements.

An important aspect also is the **evaluation of scalability** which was critical for our study and posed some unique challenges. These mainly came from infrastructure dependency of some projects, like MetroTaifun for example, was really depended on infrastructure upgrading and new installations making the scalability part really context dependent. There are also important regulatory and policy barriers in some projects that influence the scalability of them, and we had no data on how these affected the projects in each case and might have prevented a wider adoption of these. As an example, bGrid depends heavily on policy in order to be adopted in a wider way. Worth mentioning also are the **metrics of TRL and Innovation**, that revealed insights on the projects and also created some new challenges for us. For example, emerging technologies like AR, are still under development and this limits our ability to actually see how these perform in full deployment since little to none of the projects actually used that technology. Another factor is **how fast these technologies are being developed and used**. The rapid pace of innovation in them actually leads us to raise concerns, on how long these will be used for and which ones may become outdated in the near future.

All the above limitations show the constraints of our study that relies on certain data sets for the case study analyses performed. There is a great level of contribution from this study to the integration, the impacts and also the challenges we usually meet in urban renovation projects. It also underscores the areas where more research is needed in order to close the existing gaps of knowledge and to better assess case studies with more data available to do this. Despite these constraints, a solid foundation is set for advancing the knowledge in the field and also many insights are offered for future projects to use.

Chapter 4: Results from literature review

This chapter presents our findings from the literature review. Focusing on case studies and empirical data related to the themes we identified and used in chapter 2. Results are organized according to the key areas of urban building renovation, participative design, digital solutions, scenario modeling techniques and stakeholder engagement.

4.1 Overview of Urban Building Renovation

In this part we will analyze examples of successful renovation projects that have used sustainable practices, giving highlight to the methods used and the outcomes these achieved to get.

Case Studies on Urban Renovation Practices examples in literature

We will analyze a paper from (Guerrero, et al., 2016) showing how social media can be used in order to inform urban green infrastructure planning process. In a case study in Copenhagen #sharingcph initiative used sharing of geo-referenced images of urban nature using Instagram. A more detailed analysis of these images also showed certain spatial patterns and 'hotspots' that can be useful in understanding the way in which the public uses and engages with green zones. Although the study does not present a case of any particular urban building renovation project, it shows how such data can be useful in urban planning and management by identifying and fulfilling community needs.
Another example of successful urban building renovation has taken place in Portland, Oregon in Portland Building. (Siry, 2021) This was designed and completed in 1982 by Graves and has faced many challenges over the years. Starting 2017 and for 3 years the building had extensive renovation done by DLR Group. The projects main aim was to preserve the iconic design while addressing some of the most critical issues like water problems and seismic reinforcement of the frame. The project enhanced the building and made it more sustainable with the aid of participative design, mainly workshops and feedback gathering, and had community engagement throughout the process. Sustainable practices like energy efficient building envelope, use of sustainable materials, window upgrades, seismic resilience, enhanced HVAC systems and water management improvement were used to make the building as resilient as possible to today's standards.

4.2 Theoretical Frameworks in Participative Design

In this part we will expand on the theoretical frameworks that guide participative design processes, also including collaborative governance models.

Frameworks supporting Participative Design examples in literature

A study from (Maziashvili, et al., 2022) explores how digital communication tools achieve participative design in urban planning process. This research focuses on two cities in Poland and Georgia, and examines frameworks that support citizens engagement using digital tools. The **key frameworks** identified are:

- **Digital Platforms for citizen engagement**: Online platforms were used in both that allowed citizen to participate in urban planning process. Through these platforms the users were able to give feedback, suggest their ideas, and stay informed about ongoing projects, this way promoting a better collaboration between all stakeholders.
- **Social media use**: social media was actively used in order to disseminate information and better engage with citizens. Social media can be ideal tools for real time communication,

by allowing immediate feedback and discussion of urban development projects and not only on those.

- **E-Government Services**: With the use of e-government services that give access to administrative functions online, citizens are more participative in many different ways. It provides a way for better services and also encourages more active participation since it can be done from anywhere using online platforms.
- **Mobile applications**: Mobile applications are developed and used in both cities to help in participative design. These allow the citizens to report problems, take surveys, and learn about updates on urban projects. These apps help in making participation and active engagement more accessible for everyone and also more convenient.
- **GIS:** Using GIS and also interactive maps enables citizens to visualize the projects in the urban environment. Using these tools helps a lot in understanding the design better and how this will be in real world. It is a crucial tool for planning decisions and well-informed feedback.

The study concludes that with integrating all these tools, we can achieve an **enhanced participative design process**, making everything **more inclusive and efficient**. It also notes there are challenges that need to be addressed in order to get the full potential of these practices, like digital divide.

One more study by (Horgan & Dimitrijević, 2019) where the authors elaborate on various frameworks that facilitate participative design, with a more structured and guided way for citizen engagement in the process of urban planning. These frameworks give an emphasis on **collaboration, inclusiveness and technologically advanced approaches** to make sure that all stakeholders opinions are taken into account in the process of urban planning. Some of the frameworks analyzed in this paper are:

- **Scotland's Place Standard Framework:** This is more conversational based, to assess the quality of places. Uses structured prompts to gather insights on different aspects (accessibility, housing, green spaces etc.) Empowers communities to express priorities and help in urban design in a systematic manner.
- **BREEAM Communities Assessment Tool:** A tool more sustainability focused. Assesses social, economic, environmental aspects. Integrates citizens participation as core component. Community needs come first. Involves stakeholders on early stages. Helps in more transparency and accountability of actions and choices.
- **Smart City Co-Production Tools**: GIS, Digital Twins, Online platforms for participation. Enable real time engagement, feedback, active participation in urban planning process. Help to make more inclusive and sustainable solutions.
- **Social Innovation Frameworks**: Use both co design and co creation principles. Promote innovative solutions to urban challenges.

A practical application of one framework showcased in this study was in Glasgow, where **SPSF was used to guide the community input,** in order to create greener and more inclusive neighborhoods. This way it gave results that ensured that the needs and priorities of the local community was reflected in the final design.

All the above frameworks **collectively support Participative design**, in a better, more structured and more inclusive way. These ensure that the outcome of the planning process will be meeting the needs and desires of the local communities. All **show the evolution from traditional methods of participation to a smarter, more technological oriented way**, **actively**

engaging more stakeholders to the process, making the urban renovation process more sustainable and efficient.

4.3 Digital Solutions in Urban Planning

In this section we will present case studies of digital solutions that show the use of BIM, Digital Twins, GIS and VR/AR, AI, IoT successfully in real world scenarios.

Building Information Modeling BIM examples in literature

In the paper by (Omar Doukari, 2023) the authors present a case study about the renovation of a residential building in Denmark. The project exemplifies the **use** and successful **application of BIM tools** in order to assess and **implement effective renovation strategies** to the building. BIM tool used various data sources, such as architectural plans, structural information, energy performance metrics of the building and combined these into a unified digital model. Then it was used to **simulate energy performance** in order to evaluate the initial energy consumption levels and predict the possible outcomes from the different renovation proposals and measures. Multiple renovation scenarios were modeled, giving stakeholders many outcomes to compare and evaluate in terms of energy savings, total cost, sustainability and environmental impact for each scenario. Finally, the tool **provided visualizations** and **quantitative analyses** to better support informed decision-making process among the different stakeholders. The tool provided the decision makers **with three outcomes**:

- **Energy efficiency evaluation**
- **Cost effectiveness evaluation**
- **Better stakeholder collaboration**

The above case study proves the value of BIM tools in evaluating and implementing building renovation, this way leading to more sustainable and efficient solutions for urban renovation.

One more case study showcasing the importance of BIM tools is one from (Guo, et al., 2021). In this case BIM was used for a green building evaluation in Singapore. The main objective was to **optimize energy efficiency, indoor environment quality, and resource utilization** in order to **meet green building standards**. Again, in this case a **unified model was created** combining data from architectural, structural, mechanical perspectives in order to achieve a more comprehensive analysis. **Energy simulations were performed** to identify problems and **possible solutions, and sustainability assessment** was conducted to evaluate the buildings compliance with green standards. System optimization was then done for improved HVAC, lighting and sustainable material to achieve better energy performance of the structure and reduced resource consumption. The outcomes of the study showed **reduced energy consumption, improved indoor environment quality and better resource efficiency,** proving once more BIM's ability to integrate sustainability into green building design, and evaluation process.

Digital Twins examples in literature

In the paper of (Francisco, et al., 2019) they explore the application of DT technology **in urban energy management.** One of the studied case studies demonstrates how a digital twin was created for Chicago, with an **emphasis on energy management within the buildings**. This digital replica **contained current energy consumption data** from various sources, so that the **energy performance could be constantly assessed**, and maintenance strategies planned. The study revealed that the implementation resulted in **energy conservation and increased performance** thus proving the use of digital twins in enhancing the urban energy management systems.
Another successful case study studied in (Dembski, et al., 2020) showcases the use of DT technology in order to **enhance urban planning and citizen engagement in Herrenberg**, Germany. A **3D model of the town was used** and integrated key features such as detailed models of the buildings, streets layout, wind flow simulation and also urban mobility analysis. In addition, the model used and **incorporated Volunteered Geographical Information** (VGI) from residents giving enriched data with more inclusive local insights. This was used for participatory urban planning process where the citizens could visualize proposed interventions and give feedback on those, this way promoting **collaboration, inclusivity, transparency and sustainability to each project**. VR was used to allow for immersive experiences for stakeholders, this way boosting collaboration and co-working on the projects even more. Scenario testing allows for the simulation of the effects of urban development on mobility, environment, and urban dynamics in order to inform decision making. Digital twin has therefore been useful in improving the urban planning of Herrenberg town, traffic management, and environmental management. This project shows how digital twins can be used for better and sustainable urban development through modeling integrated with citizens.

Geographical Information Systems examples in literature

A case study worth mentioning is the one from S. Sisman. In this case study they explore the use of Geographic Information Systems (GIS) with **Multi Criteria Decision Analysis (MCDA)** for computationally complex urban planning challenges in smart cities. The study mostly emphasizes that **a rush of diverse data flows from the rapid urbanization and technological advancements**, **requiring the sophisticated tools for the effective decision making.**

Various methods of MCDA such as the Analytic Hierarchy Process (AHP), Technique for Order Preference to Ideal Solution (TOPSIS) and Weighted Linear Combination (WLC) are discussed in this study. AHP is very useful when structuring the decision of a complex problem, but it is time consuming while TOPSIS on the other hand is quite simple but can be oversimplifying in some cases.

In order to demonstrate practical applications, the study presents case studies for the Pendik district of Istanbul. It mainly focuses on:

- Land suitability evaluation
- Land Value mapping
- Parking area Selection
- Prioritizing parking alternatives

By combining GIS and MCDA provides the opportunity to visually and analytically examine the spatial data to inform on urban planning decision making process. The authors suggest that using a **hybrid approach**, **comprising several MCDA techniques taking advantage of their own strengths and diminishing any shortcomings**.

The results in Sisman's research emphasize the use of **GIS based MCDA in the development of smart cities.** Urban planning process can become a more transparent, accountable and also sustainable process by systematically examining completely different criteria and visualizing spatial data. (Şişman, 2020)

A study by (Theodoridou, et al., 2012) analyzes **energy retrofitting and solar energy potential** in Thessaloniki using GIS. GIS was used to give detailed building classification, according to construction type, materials used, energy consumption of the building, this was enabling **spatial analysis of power consumption and energy performance in the city**. Some of the main findings include the delineation of buildings with high energy needs that can benefit from specific retrofit measures such as insulation and window replacement. GIS also identified the rooftop solar potential taking into account the orientation, tilt and the shading of the roof and identified the areas suitable for Photo Voltaic installation. Socioeconomic data was incorporated into the GIS platform to determine the financial viability of the interventions by checking whether they were implements physically and could be afforded. **The methodology delivered:**

- **Energy consumption maps**
- **Strategic plans for interventions**
- **Recommendations for rooftop PV installations**

This case study proves **GIS's ability to integrate diverse data, optimize resource allocation, support renewable energy sources adoption**, this way demonstrating the critical role of GIS in sustainable urban planning process.

Integration of VR/AR, AI and IoT examples in literature

VR case study

The study by (Li & Li, 2024) focuses on the **renovation** of Tangzixiang district in Wuhu China, using VR to **engage the citizens in the process of planning and design**. Two renovation plans where created, one using traditional architectural styles and one more using more modern elements. **Both plans were modelled in VR**, allowing users to **actually experience and evaluate** each design while interacting with it. Sixty-two residents and two architects participated in the VR sessions and **provided feedback using surveys and discussions**. The results showed a higher preference for the first plan that was prioritizing cultural preservation and maintained the historical essence of the area. All participants admitted that **VR enhanced their engagement in a significant way** and 90% of them were really satisfied with the immersive experience it offered. VR enabled real time feedback, this way leading to design adjustments in order to align better with community needs and preferences. This participatory approach ensured that the renovation will preserve local heritage, and would address environmental sustainability issues. This project proves that VR has great potential as a new and innovative tool for community driven urban renovation in smart city projects.

AR case study

One more study by (Jun Wang, 2014) features a case study involving the **renovation of a historic building** in Chongqing, China. The project aimed to preserve the cultural heritage of the building while modernizing the actual functionality. It **uses BIM and AR**, to develop an interactive visualization system that allowed stakeholders to **overlay the digital renovation models, onto the existing structure** during the on-site assessments of the intervention. With this approach real time visualization of the changes was achieved, this way **enabling instant feedback and better-informed decision making in the process**. With using AR enhanced communication was achieved among the different stakeholders, this way ensuring that the renovation would respect the buildings historical heritage and significance, and also meets the needs of the local community for sustainability. The successful use of BIM and AR proves the **true potential of these technologies have to improve and expand collaboration** and lead to more efficient and sustainable renovation projects.

4.4 Scenario Modeling Techniques

In this section we will study and discuss on LCA and energy demand modeling successful implementations that we found in recent papers.

Life Cycle Assessment examples in literature

In a recent study by (Mastrucci, et al., 2020) the authors examine the environmental impacts of urban building renovations using a detailed framework. The study is performed in Luxembourg, and the framework **integrates GIS, energy demand modeling and LCA to evaluate the carbon footprint, and how that can be affected from using different renovation techniques and strategies.**

There are two renovation standards being assessed. A conventional one called S1 and an advanced called S2, and two renovation rates Current R1 and accelerated R2. When the combination was S2+R2, advanced standard and accelerated pace, the researchers noted greater emissions reduction up to 28% by 2030. The analysis showed that the **renovation process as is contributes to 4% to 16% of lifetime emissions in total**. Time adjusted calculations showed offsets up to 9% due to the renovation impacts. This highlighted therefore the **need to look at the operational and embodied emissions** when developing a renovation plan.

The case study demonstrates how **spatio-temporal LCA** can help **guide urban energy planning** by guiding policymakers to the most effective approaches to energy efficiency, while also factoring in the environmental impacts. This approach enables **better decision-making** at the **urban level in terms of design and management of urban space**.

Another recent and really good study by (Fahlstedt, et al., 2024) the authors examine various studies that **apply LCA to building renovation projects**. One notable case study in renovation projects was the renovation of a multi-family residential building in Sweden, which utilized LCA in order to **evaluate the environmental impacts** from different **proposed solutions and strategies.**

The objective was to assess the **environmental performance of different energy renovation techniques and measures**, starting with insulation upgrades, windows upgrades, installation of energy efficient HVAC systems etc. The study used **LCA to analyze the entire life cycle** for the building, **starting from material production and processes used to construct and operate up to end-of-life stages of it.** With this approach the authors tried to give a more complete approach to the process and stages, and identify **which of them are the most impactful** to the

environment. This way they could try to reduce the impact on these ones by using specific renovation strategies and measures.
The LCA showed that implementing a **mix of upgrades**, from insulation to more energy efficient windows could really have a big impact on a building's operational energy use, this way leading **to big reductions in greenhouse emissions over the lifespan of it**. The study also noted the importance of **considering the embodied energy and emissions**, associated with producing and installing these new materials. We need a **balanced approach that weighs environmental impacts in renovation planning.**
Concluding the case study showed that the LCA is really effective as a tool for sustainable urban renovations, its biggest advantage is the provision of a holistic view of environmental impacts of the building within its lifecycle. LCA enables stakeholders to make better and more informed decisions that help in optimizing energy performance and also boost sustainability in urban renovation projects.

Energy Demand Modeling examples in literature

Energy demand modeling is also really important for urban building renovation modeling. Authors Yu Qian and Z.M. Berzolla in (Ang, et al., 2020) examine different applications of **Urban Building Energy Modeling (UBEM)** in urban renovation projects and analyze their findings from these. A significant case study discussed in this paper is about the energy upgrade of a residential district in the city of Geneva in Switzerland, where UBEM was used to **evaluate and optimize the different renovation strategies**. The **aim was to reduce energy consumption** of the buildings and also **reduce carbon emissions across the district**. How did they do that? Using UBEM **detailed energy models for the buildings of the district** where created. These **models had various data** about these buildings, including construction materials, building design, occupancy patterns and also existing energy systems. Simulations where then performed to **assess the impact of various different solutions** and upgrades to see the effect that these had on energy efficiency. What the study found was that UBEM analysis can **help with an up to 50% energy consumption reduction** for the basic needs of heating and cooling. The interventions that really stand out were insulation of building envelopes and using high performance glazing windows.
The modeling also provided with a **cost benefit analysis** of the different options and solutions, this way giving the stakeholders a way to **actually prioritize the interventions needed** based on their **actual effect in energy savings**. One more notable result was the **scalability** of the practice of using UBEM in district level and higher, providing really valuable insights for urban planning teams and policy making. Concluding the study shows the practical application of UBEM, and how it can add to better and data driven decisions that can enhance energy efficiency and provide more sustainable solutions to the urban renovation strategies we use. UBEM is a really powerful tool for urban renovation.
Another important paper on "Building energy simulation and its application for building performance optimization" by (Pan, et al., 2023) discusses the various methods and tools, highlights a case study in Italy. In that case **CitySim, an urban scale energy modeling tool**, was used to **perform optimization of energy performance** while a **residential district renovation** was underway. The projects aim was to identify the most effective measures to use in order to achieve maximum energy efficiency and sustainability. CitySim was used to **model energy performance of buildings including multiple sourced data**. Trials were performed to test different materials in insulation, different window types, integrating renewable energy sources and other interventions in order to study their effect on the actual project. The findings showed an up to **30% energy consumption reduction**, again with **a combination of**

measures, consisting of insulation and high-performance windows. The only downside to this study was the financial part where it was **high-cost solution and needed support mechanisms** to actually encourage these interventions taking place. Concluding the study shows the importance of tools like CitySim for evaluation and optimization of urban building renovation scenarios in bigger scale. Using it can provide detailed insights in energy saving practices and techniques and also giving cost effectiveness value for each intervention, helping this way in a more data-based and driven decision-making process. This way better, more sustainable and efficient solutions can be achieved.

4.5 Stakeholder Engagement in Urban Renovation

Public participation, has played a very critical role in facilitating urban renovations or buildings or urban areas. In this section we will study some successful case studies presented in recent papers of this subject.

Public Participation and Collaborative Design examples in literature

Public participation and collaboration are considered of great importance in many studies about urban renovation projects. In particular in a recent study by (Li, et al., 2020) about use of **collaborative workshop for community participation** the authors find the following. Collaborative design and public participation can drive urban renovation in an effective and more sustainable way. The project aim was to **revitalize the village of Shenjing** in Guangzhou, while **preserving the cultural identity** of it and also addressing the needs and desires of the residents, while **balancing the goals of stakeholders**. The approach used collaborative workshops, where all **stakeholders engaged in open discussions**, in order to **identify and give priority to needs and resolve problems arising**. This way through the workshops the residents actively participated to the process of planning and design sharing their opinions and needs for the future of their village. Using participative method also helped in **creating a sense of ownership and accountability in the community**, enhancing their connection to the actual project. Major renovation measures were planned in cooperation to maintain cultural considerations at the same time as fulfilling the objectives of urban growth.
The following were realized as project outcomes; **enhanced community participation**, **conflict resolution among various interest groups, and the integration of sustainable development principles.** The involvement process made sure that all the strategies of renovation consider the cultural heritage of the area and at the same time meet the current urban context. The staking of the Shenjing Village case shows how community design and involvement in the regeneration of the urban process can lead to inclusive, culturally sensitive, and sustainable results.
One more good case study is demonstrated in (Poplin, 2012) where the author shows how **gamification** can be used to enhance citizen engagement in urban planning. The research in this paper focuses in developing a **serious game to involve residents** in the process of designing a new marketplace in Hamburg, Germany. The goal of this was creating a platform that **made urban planning more accessible**, with **more engagement** and also more **inclusive using playful interaction**. This game allowed the participants to actually **visualize and modify the proposed layout design of the marketplace**, letting them use different design elements and different configurations, aesthetic features etc. Users could **collaborate in real time** and provide feedback with a good support of interactive simulations and storytelling in order to enhance understanding of the process. This approach seems that it has appealed to a bigger audience, including many that have never participated in the past with traditional participative methods. The outcomes of this show that **increased community engagement,**

and better collaboration can be achieved with improved planning results. All the feedback gathered was used for the final design, ensuring that the community needs and preferences were taken into account. Concluding this showed and proved the true potential of gamification in conjunction with collaborative design and public participation, can actually make urban planning process more inclusive and sustainable for all stakeholders.

Governance Tools for citizen involvement examples in literature

In a paper by (Dawes & Helbig, 2010) they examine how **government information can be utilized in order to engage citizens in urban planning and renovation process**. A key case study used focuses on using the public accessible land records in order to facilitate better citizen involvement and interaction with urban development projects. This paper presents the analysis of the case study to understand the potential and the risks of employing the government transparency as a means of increasing the public engagement. **Land records** that are supposed to be available to the public were discovered to be **hard to comprehend**, not updated, and mostly provided in **formats that are not easily understandable** by the citizens. This way they were unable to contribute effectively to the issues concerning urban planning and renovation.

The authors stress that the **potential of government data to engage citizens cannot be realized if the data is of poor quality, inaccurate or late.** They suggest that governments and organizations should **create understandable tools and applications** that will help people use the data. These tools may include map-based applications, reduced complexity data visualization, and channels for citizens' direct input.

The study therefore adds to the literature on the **value of open government strategies** in urban governance. This paper argues that **through increasing data usability, transparency interventions can foster citizen participation, create trust, and result in better and inclusive urban renewal projects.** This paper describes how the effective use of specific information management techniques can help to turn government information into an effective instrument for collaborative urban planning.

One more paper studied is (Horgan & Dimitrijević, 2019) explores tools and frameworks that enhance citizen participation in urban planning. A case study used in this is use of **Scotland's place Standard tool to guide urban renovation projects**. This tool enables residents to **evaluate their neighborhood in a structured way using 14 key themes**, **like public transport, housing quality etc.**

People were engaged through **community workshops** where they assessed the areas they lived in, using a simple scoring system, and **discussed problems and possible solutions**. This approach enabled the generation of good conversations between the residents, planners, and the local authorities.

By using this tool and adopting it they saw a greatly enhanced public participation as it helped people to promote their ideas for their desired community. It helped to show local government what was important and where the difficulties were found. This way the strategies of urban renovation were more focused to these difficulties and needs and provided more inclusive and sustainable results. Using SPS tool can help boost engagement compared to more traditional methods this way leading to more data driven decision making and better outcomes. It helps ensure that public input can make these projects **more inclusive and focused on the actual needs of the stakeholders**.

4.6 Synthesis of Literature Insights

Several interconnected themes are revealed from the insights, that underscore the importance of sustainable practices, participative design and digital engagement in urban planning process. A very significant finding is the **emphasis on practices that promote sustainability** as shown in the project of Portland Building. The main aim was to preserve the iconic design, while in the same time **addressing critical issues** of the building. Using systems that are energy efficient and also sustainable materials, it proved there is a trend towards more environmentally friendly and responsible urban designs and projects.

Use of **participative design** is also important **for achieving community engagement** in these projects. All the studies show that PD frameworks including from workshops to mechanisms of feedback, can **really enhance the process of urban renovation**, making sure that all voices are equally heard and every stakeholder's opinion is taken into account equally. Again, this was illustrated in Portland Building case study. **Inclusion gives a great advantage** of sense of ownership to the citizens, together with accountability and transparency on the project's decisions.

Very effective is the use of **social media together with citizen input**, and can really lead to better results in urban projects that are also more sustainable. Digital engagement tools help to achieve better quality of communication and higher participation that results in better outcomes in urban projects. Integrating these digital tools into participative design frameworks can improve collaboration and the final outcomes of the projects.

In summary, literature review shows that to achieve successful projects in urban renovation, we **need to implement a multifaceted approach to the process**. **That combines sustainable practices, participative design, digital engaging of the stakeholders**. By using all these tools and practices planners can create **more resilient** and **community-oriented solutions** and projects that are designed and built to **meet the requirements and needs of local populations**.

The case studies we analyzed and studied span in a wide range of application domains.

Areas of use:

- Urban sustainability and renovation
- Energy optimization
- Participatory Planning
- Green infrastructure and Environmental planning
- Decision Support for Smart Cities

Methods used:

- Data Driven Decision Support
- Participatory and collaborative Tools
- Life Cycle and Impact assessment
- Simulation and optimization

Aims:

- Sustainability and carbon emission reduction
- Citizen centric Urban development and renovation
- Optimizing use of resources
- Enhanced decision making
- Innovation in the way that we interact and engage to projects

All projects aim for **more sustainable and resilient designs** aiming for **sustainability goals**, leading to **more environmentally friendly solutions**. **Increased participation** was also a target on almost all projects **leading to better decisions and outcomes** for the projects. **Frameworks like BIM, GIS based MCDA showed great potential for scalability**, **with being able to adapt to different urban contexts. Integrating diverse datasets** and also **adapting to the needs** of each case, these **provided flexible solution for urban planning projects**. Their **modular nature** allows planning team to **replicate successful strategies** used in other projects, and this way it helps promoting consistent improvements in sustainability and efficiency of the projects. Multi criteria frameworks are also useful in order to achieve a more balanced decision-making process. Using a range of factors from technical feasibility to social impact and sustainability. By incorporating all these metrics, these make sure that the **decisions made will align** with stakeholders' **needs and requirements**, while addressing the complexity of the nature of urban renovation process and creating more sustainable solutions.

4.7 Summary of Case Studies

Below in table 1 we show all the case studies found in the literature and analyze them. The table is also included with the excel file, that comes with this thesis.

Scenario Name	Main Objective	Application Domain	Administration Level	Technology	Benefits	Barriers	Used in	Environmental Impact	Impact Explanation	What it does
Rotterdam LCA Renovation	Life Cycle Assessment (LCA)	Urban building renovation and sustainability assessment.	Municipal	LCA, GIS combination	Identification of renovation that balance energy savings and environmental impact, detailed insights of benefits, support for informed decisions to policymakers	complexity of data collection, integration, expertise for LCA studies, cost	urban planning, policy development	reduction of greenhouse emissions, resource consumption reduction	LCA helps in evaluation of environmental impacts of different scenarios.	Environmental impact analysis, operational vs embodied emissions, material sustainability
Geneva Energy Modeling	Energy Demand Modeling (CitySim)	Urban Building Energy Modeling (UBEM)	Municipal	UBEM frameworks	Identification of carbon reduction ways, support for policymaking, drives data driven decision making process	complexity of data collection, calibration of model, resources to maintain UBEM, expertise to use and interpret result	develop carbon reduction policies	reduction of carbon emissions	UBEM helps simulate energy scenarios and assess how effective these are	Energy simulations, retrofit scenario optimization, district-level energy planning
Thessaloniki Solar Mapping	Geographic Information Systems (GIS)	Urban energy planning, renewable energy integration	Municipal	GIS	Identification of optimal positions for PV, Support for renewable energy use, Provides data driven insights	complexity of data collection, accuracy, requirements of resources to make and maintain the map, need public engagement	strategic plan for using renewable energy sources	reduction of greenhouse emissions, resource consumption reduction	can lead to better and more targeted PV system investments.	Spatial solar potential mapping, rooftop analysis, shading and orientation factors
Shenjing Village Collaborative Planning	Collaborative Workshops with GIS	Urban regeneration, Participatory Design	Municipal, local government	GIS, collaborative workshops	Boost in community engagement, ensures results align with needs, Sustainable solutions	Balance priorities, Resources needed for analysis of feedback, Tools needed	Planning and implementation of sustainable solutions.	Provides sustainable urban growth	Shows the value of participatory approaches, and community driven decision making.	Stakeholder engagement, participatory planning, community-driven decision-making
Hamburg Serious Games	Online Serious Games	Urban planning, Citizen engagement	Municipal	Serious Games, feedback mechanisms	Boost citizen participation, engaging way to do it, gives precious feedback on planning decisions	Accessibility to tools, Digital Divide, Balance of the game, Maybe biased feedback	Design and planning of urban spaces	Project gives value because citizens interact actively with the project design.	Gamification enables experimentation from participants	Gamified participation, design visualization, collaborative engagement
Scotland Place Standard	Place Standard Tool	Urban planning	Local authorities	Structured assessment framework-14 themes encompassed	Encourages inclusivity in planning process, identifies areas for improvement, enables evidence based decision making	Requires participation from all, Reaching common ground, Resources needed to analyze assesments	Planning and implementation of sustainable solutions.	Promotes sustainable development	Comprehensive frameworks to assess different aspects	Citizen scoring of public spaces, structured engagement, actionable feedback
Copenhagen's #sharingcph Instagram Initiative	Social Media Volunteered Geographic Information (VGI) via Instagram	Urban planning, Citizen engagement	Municipal	Social media platform, Instagram	Helps in active citizen participation, Provides real time data, Fosters community work	Bias due to various levels of instagram use, challenges in data collected, data management needed.	informing green space planning decisions.	Supports preservance and enhancment of green spaces	Collect valuable insights using SM on how residents interact with green spaces and nature	Collection of geo-referenced images tagged with #sharingcph, Categorization of images based on content related to urban nature, Spatial analysis of image distribution patterns
Digital Communication and Citizen Engagement in Kutaisi and Poznań	Digital Communication Platforms (e.g., social media, official websites)	Digital communication and participatory governance	Local authorities	Digital platforms, SM channels, official government websites	Improves transparency, Encourages participation	Digital divide, challenges to maintain engagement	Enhancing Citizen Participation	Not direct focus, can be considered as a way to more sustainable planning	Digital communication tools, enhance relationship with citizens, and adds to public involvement in decision making	Assessment of digital tool usage intensity among citizens, Evaluation of perceived usefulness of social media for civic participation, Analysis of the relationship between digital engagement and trust in local governments
BIM-Based Evaluation of Building Renovation Strategies	Building Information Modeling (BIM)	Building renovation	Local authorities	BIM	Enables multi criteria assesment of renovations, Improves accuracy in costs, energy, environmental impact. Improves collaboration	Training Required, High cost, data universalization challenges	EU countries for renovation projects	Reduced energy consumption and carbon emissions	BIM tool provides a robust framework for comparing renovation scenarios	Automated assessment of renovation scenarios, Evaluation metrics: duration, cost, labor requirements, and disruption potential, Application to diverse building types and locations

1	BIM-Based Green Building Evaluation and Optimization	Building Information Modeling (BIM)	Green building design, Sustainability	More focused on Designers, architects, engineers	BIM	Enables evalutaion of energy performance, helps in decision making with simulations, optimizes designs to comply with standards	Complexity, High cost, challenges in balance of performance with budget	Design and assesment of sustainable buildings	Enhances energy efficiency and reduces carbon footprint	BIM tool provides a robust framework for comparing renovation scenarios and simulate, identifying best options	Integration of green building standards into the BIM process, Automated evaluation of environmental performance metrics, Optimization of design elements to improve sustainability
2	Digital Twin-Enabled Urban Energy Management	Smart City Digital Twin	Urban energy management, optimization	Municipal and private stakeholders	Digital Twin, Real time energy monitoring systems	Enables real time energy performance benchmarking, Support proactive management with simulations, Identifies problems in performance	Cost, Data integration challenges, Expertise required to manage	Citywide energy optimization, urban planning	Reduces energy consumption and carbon footprint	DT Holistic and real time view of urban systems. Enable targeted interventions to improve sustainability and efficiency	Real-time monitoring of building energy consumption, Dynamic energy benchmarking across urban building portfolios, Identification of energy inefficiencies and optimization opportunities
3	Herronberg Urban Digital Twin	Urban Digital Twin	Urban planning, Citizen engagement	Municipal	3D modeling, space syntax analysis, urban mobility, wind flow sims, VGI. Digital twin technology	Enables better collaboration with use of comprehensive digital model, Enchances public participation, Supports informed decision making	High resources, technical expertise, data accuracy and integration	Urban development, citizen engagement and scenario testing	Promotes sustainable development	DT Holistic and real time view of urban systems. Enable visualization and evaluation of potential outcomes.	3D modeling of the built environment, integration of street network analysis using space syntax, Simulation of urban mobility and wind flow, incorporation of empirical data from citizen input
4	GIS-Based MCDA for Smart City Planning	Geographic Information Systems (GIS) integrated with Multi-Criteria Decision Analysis (MCDA)	Urban planning, Decision Making	Municipal	GIS and MCDA techniques	Supports data driven decision making, improves resource allocation, enhances transparency	Requires high quality data, Complex, Technical expertise needed	Urban planning, mobility planning	Promotes sustainable development	GIS MCDA provides a structured and transparent framework for evaluation priorities in urban planning	Evaluation of land suitability for urban development, Generation of land value maps for real estate management, Selection and prioritization of parking areas for sustainable transportation planning
5	Tengxixiang Historic District VR Renovation	Virtual Reality (VR)	Urban Planning, renovation	Local authorities, stakeholders	VR technologies	Enhanced public participation, Improved and informed decision making	Accessibility to tools, Digital Divide, Required high quality VR environment needs resources, tools to interpret feedback	Design and planning of urban spaces	Promotes sustainable development and renovation	Using VR project did a bottom up decision making approach, enabling active participation of citizens to the process of renovation	Development of two renovation schemes: one with a traditional architectural style and another with a modern style, Creation of immersive VR environments for both schemes, allowing residents to experience and evaluate the designs, Implementation of smooth movement and node-based movement modes within the VR environments
6	BIM and AR Integration for Architectural Visualization	Building Information Modeling (BIM) combined with Augmented Reality (AR)	Visualization of architecture and construction planning	Stakeholders of project, architects, engineers, managers	BIM and AR to overlay virtual models onto physical environment	Improves understanding of design, facilitates real time modifications and feedback, enhances collaboration	High cost, Technical Expertise, Challenges to achieve high quality	Design and planning of urban spaces	Reduces material waste and identifies design problems early	BIM and AR enhances the process of design. Reduces errors, optimizes resource use and collaboration.	Integration of BIM models with AR to overlay virtual building elements onto physical environments, Interactive visualization allowing stakeholders to experience and modify designs in real-time, Application across various stages of the building lifecycle, including design, construction, and
7	LCA Framework for Urban Building Renovations	Integration of Geographic Information Systems (GIS) and Life Cycle Assessment (LCA)	Urban scale building renovations, Sustainability assesment	Municipal	LCA, GIS combination	Identification of renovation that balance energy savings and environmental impact, detailed insights of benefits, support for informed decisions to policymakers	complexity of data collection, integration, expertise for LCA studies, cost	Evaluating renovation strategies for urban housing projects	Promotes sustainable development and renovation	LCA helps in evaluation of environmental impacts of different scenarios.	Development of a geospatial building-by-building stock model to assess energy demand and material flows, incorporation of time-adjusted emission accounting to evaluate environmental impacts over the renovation timeline, Scenario generation to explore various renovation strategies and their potential outcomes
18	Scoping Literature Review on LCA in Building Renovations	Life Cycle Assessment (LCA)	Building renovation sustainability assessment	Project level and Regional renovations	LCA	Identifies key areas for renovations, Provides guidance for sustainable solutions	Inconsistencies in scopes of LCA, challenges in complex material flows and end-of-life scenarios, limited integration of social factors	Sustainability assesments and policy recommendations	Reduction in lifecycle emissions	Shows the value of LCA in sustainable building renovations by identifying gaps in current practices	Analysis of 54 scientific articles published between 2005 and 2022, Identification of trends and methodologies in LCA application to building renovations, Evaluation of challenges in setting environmental benchmarks due to variability in scope and functional units
19	Open Government Information Strategies	Open Government Data (OGD)	Government transparency, Public participation	National, Regional, Local	OGD platforms	Improves transparency, Encourages participation, supports innovation using government data	Complex data, need quality accuracy and accessibility, challenges to foster trust and engagement with gov data. High cost and resource demands for data management	Land records, Urban planning, Citizen feedback systems	Indirect, Support sustainability in governance, data driven decision making	Fosters transparency, build public trust, enhances capacity for collaboration, essential for addressing complex urban and environmental challenges arising	Analysis of public use of land records to understand complexities in government information utilization, Examination of factors influencing effective information use, including data quality, accessibility, and user capabilities, Recommendations for improving information-based open government strategies

Table 1 Literature review summary of case studies

Key outcome and Feature analysis for each scenario

L	M	N
Key Outcomes	**Feature analysis**	**Scenario Name**
Optimized renovation strategies, reduced lifecycle emissions, enhanced sustainability	- Evaluates life cycle emissions and energy savings - Supports optimized retrofitting strategies	Rotterdam LCA Renovation
Up to 50% energy reduction, cost-benefit analysis of retrofits, district-wide insights	- Models energy demand reduction and renewables integration - Analyzes retrofit feasibility and scalability - Reduces carbon emissions across urban areas	Geneva Energy Modeling
High-potential areas for solar energy, targeted resource allocation, increased renewables adoption	- Maps solar irradiance and rooftop suitability - Guides PV system installations - Promotes renewable energy adoption	Thessaloniki Solar Mapping
Inclusive planning, culturally sensitive designs, long-term sustainability	- Preserves cultural heritage via participatory design - Engages stakeholders through workshops - Aligns renovation with community preferences	Shenjing Village Collaborative Planning
Enhanced community engagement, user-informed designs, participatory urban planning	- Encourages citizen input via gamified platforms - Facilitates feedback for urban design	Hamburg Serious Games
Improved urban regeneration strategies, inclusive design outcomes, policy alignment	- Assesses urban environments across 14 themes - Encourages public engagement in planning - Identifies actionable improvements	Scotland Place Standard
Identification of urban nature hotspots based on user-shared images, Enhanced understanding of public perceptions and uses of green spaces, Informed urban green infrastructure planning through citizen-generated data	- Uses Instagram for green space engagement - Collects geo-referenced social data - Informs urban green infrastructure	Copenhagen's #sharingcph Instagram Initiative
In both cities, higher intensity of digital tool usage correlates with stronger relationships between citizens and local authorities, Perceived usefulness of social media significantly enhances citizen engagement and trust in local governance, The study underscores the importance of effective digital communication strategies to foster active citizen participation in urban governance.	- Enhances public engagement via digital tools - Builds trust between citizens and governments - Facilitates efficient feedback and information flow	Digital Communication and Citizen Engagement in Ku
Enhanced decision-making through comparative analysis of renovation options, Identification of optimal strategies tailored to specific building contexts, Demonstrated applicability across different European countries	- Compares renovation scenarios for efficiency and cost - Facilitates decision-making with data visualization - Optimizes sustainability in building retrofits	BIM-Based Evaluation of Building Renovation Strateg
Streamlined assessment of green building criteria, Enhanced decision-making through data-driven insights, Improved environmental performance of building designs	- Evaluates green building performance using BIM - Simulates environmental impacts and energy efficiency - Optimizes design for sustainability compliance	BIM-Based Green Building Evaluation and Optimizati

L	M	N
Improved accuracy in energy performance assessments, Enhanced decision-making for energy retrofits and policy implementations, Facilitation of near real-time energy management at the city scale	- Monitors urban energy systems with digital twins - Provides real-time benchmarking for buildings - Supports energy efficiency retrofits and planning	Digital Twin–Enabled Urban Energy Management
Enhanced participatory urban planning processes, Improved collaboration among stakeholders, Data-driven decision support for sustainable urban development	- Simulates urban mobility and environmental impacts - Enhances participatory urban planning - Provides real-time data for decision-making	Herrenberg Urban Digital Twin
Effective identification of optimal urban development zones, Enhanced management of urban real estate through detailed land value assessments, Improved planning of parking facilities, contributing to sustainable urban mobility	- Identifies optimal urban land use - Balances environmental and infrastructure factors - Supports sustainable city planning	GIS-Based MCDA for Smart City Planning
Enhanced resident engagement in the design process, leading to more informed decision-making, Preference for the traditional architectural style, highlighting the importance of cultural preservation, Improved social sustainability through increased community interaction and participation, Environmental benefits achieved by reducing the use of printed materials for design reviews	- Preserves historic districts using VR technology - Collects resident feedback for design validation - Ensures alignment with cultural values	Tangzixiang Historic District VR Renovation
Enhanced communication among stakeholders through immersive and interactive design presentations, Improved decision-making by enabling real-time modifications and immediate visualization of design changes, Increased efficiency in identifying and resolving design issues before construction	- Enhances architectural visualization with AR - Facilitates collaborative real-time design - Reduces errors and material waste	BIM and AR Integration for Architectural Visualization
Identification of optimal renovation strategies that balance energy savings with environmental impacts, Provision of detailed insights into the spatial distribution of environmental benefits and burdens within urban areas, Support for policymakers and urban planners in making informed decisions to promote sustainable urban development	- Evaluates environmental impacts across renovations - Integrates spatial and lifecycle data - Supports policy and sustainability goals	LCA Framework for Urban Building Renovations
Recognition of limitations imposed by original design decisions on renovation options, Highlighting the complexity in establishing consistent environmental benchmarks across studies, Recommendations for future research to address granularity issues, improve communication of environmental impacts, and incorporate economic and social considerations	- Analyzes LCA methods in building renovations - Identifies gaps in current sustainability practices - Proposes standardization for better outcomes	Scoping Literature Review on LCA in Building Renovat
Identification of challenges in making government data "fit for use" by diverse external users, Insights into the importance of data quality and user engagement for successful OGD initiatives, Practical recommendations for enhancing public value through improved information strategies	- Promotes transparency through open data platforms - Enhances citizen involvement in urban planning - Supports data-driven governance strategies	Open Government Information Strategies

Table 2 Key outcomes of case studies

4.8 Implications for future Research and Practice

Implications for future research and practice are important, so that we can ensure better level of knowledge in the field. A promising area for research could be the **integration of sustainable practices in urban renovation projects**, and how will the **long-term impacts** of this will affect urban resilience and well-being of the community.

Participative frameworks and improvement of these is also important. Since we distinguished participations crucial impact on all projects, we need to further dive in the study of these frameworks and **how these can be improved**. A more extensive study on the **impact of inclusivity on final designs** in also important area to be examined. Finally, the examining of digital engagement tools that show promising like social media must be investigated further. Since #sharingcph in Copenhagen reveals how social media can be used to gather data and involve the public in the planning of cities. And these and widely used and available we must consider using them more.

Further works should also examine the possibility of new technologies in the future so as to enhance the participation of communities and enhanced results of the projects. This is similar to cases of other disciplines, whose incorporation of technology has been viewed as a way of improving the conduct of research and practice. (Pasca, et al., 2021)

In practice urban planners must **prioritize the integration of more sustainable practices**, **participative design and digital engagement** in renovation projects. With a more holistic approach that will enhance the resilience but also will foster the creating of a sense of ownership and actual engagement in the planning process of each project.

In conclusion the future must lead to a more **synergetic approach** that combines sustainability, community engagement and technological innovation together in order to achieve more resilient, inclusive and sustainable solutions for the urban environment.

Chapter 5: Case Study Analysis-Projects from Beesmart website

5.1 Overview of Selected Case Studies

The case studies were chosen from beesmart City webpage under the solutions section. We applied the filters for Indicator->Smart Environment,
Key Benefit->Environmental Impact and finally Spatial Level->Smart building.
These gave us 28 case studies that fit our thesis perspective and sample goal, and we will do an analytical study on these so we can derive some results on how much these will affect the project implementation we study if these are implemented. These provide us with a wide range of geographical diversity, project objectives, technological interventions and also unique challenges each one met. This section of our study provides an extensive analysis of each case, key features and all the important information on the projects for a better understanding of the solutions. After the extensive analysis we provide a summarizing table that shows the case studies and their respective data in a more compact version, and also a ranking using MCDA method and respective weights for the variables used for that purpose.

Case Study 1 Instant Bin Audit

In this case study we see the use of AI technology to analyze waste by identifying and categorizing waste categories. AI Identifies, categorizes and assesses waste providing instant analysis and compliance insights. This way there is an efficient and accurate Identification of non-compliance with regulatory standards.
What it does: Assessing the level of contamination in a bin used to be cumbersome, costly, messy and slow.
Aim: To create an instant contamination report within 3 seconds, allowing facilities, cleaning contractors and Waste Cos to see how contaminated the bin is (in percentage terms) together with a list of the items that need to be removed to make it 100% compliant. Instant Bin Audit™ can be configured for any bin type.
Key features:

- It uses AI to analyze waste contamination
- How it works: By taking a photo of the bin, with AI there is an instant analysis that leads to identifying waste categories and if there is any contamination
- How is it used: Gives out reports about contamination levels, detailed insights for the application areas
- Has various subscription levels based on audits/month it does on each bin
- Main benefits: Accurate, Central reporting, Compliance with rules and also customizable

Key Benefits according to BeeSmart:

- Easy Replication
- Efficiency Gains
- Connectivity
- Knowledge Sharing
- Cost Savings
- Environmental Impact

Spatial Level- Smart City, Smart Building

Project Webpage: **https://instantbinaudit.co.uk/**

Main Objective: Bin Contamination analysis

Application Domain: Waste management, Smart City, Building

TRL: 8 since it demonstrated in real world environment and deployed

Admin Level: Municipal or administration level

Barriers: Cost, Privacy, Integration on existing systems, Public Adoption, Maintenance

Technology of implementation: AI Based image analysis system

Case Study 2 Preoptima Concept

Preoptima is a company which provides software solutions to help buildings assess and manage their whole life carbon impact. It highlights two of their products:1. A tool for industry professionals to quickly compare design options and make strategic, carbon informed decisions, PREOPTIMA CONCEPT. It enables real time carbon optioneering, rapid whole life carbon assessment, and enhanced building modeling and carbon assessment accuracy. 2. Preoptima PACER - a solution for local planning authorities to efficiently deliver whole life carbon assessments within planning applications to encourage sustainable policy. The document also features endorsements from industry professionals and partners, and the benefits and capabilities of Preoptima's solutions. With Preoptima, it offers a centralized portal for assessment submissions, ensures accurate submissions that fit in relevant standards and policies, and tracks comprehensive carbon profiling to deliver during the planning process.

Key features:

- Preoptima offers software solutions for carbon assessment in building design
- CONCEPT: This tool helps industry professionals quickly compare design options for carbon reduction and real-time optimization of decisions.
- PACER: This helps local authorities to review carbon assessments this way ensuring compliance with policies
- Its highly recognized solution-Awarded for innovation in sustainable solutions
- Future goal: To integrate these two tools, Concept and Pacer for giving carbon compliance from the stage of design to the stage of approval

Key Benefits according to BeeSmart:

- Efficiency Gains
- Citizen engagement
- Cost Savings
- Environmental Impact
- Interoperability

Spatial Level- Smart Home, Smart Building

Project Webpage: **https://www.preoptima.com/**

Main Objective: Sustainability

Application Domain: Sustainability, Environmental Impact

TRL: 9 developed system and deployed

Admin Level: Municipal or administration level

Barriers: Data Requirements, Cost, Complexity, Regulations

Technology of implementation: Software solutions

Case Study 3 Talking Wastebins

The talking Wastebin project involves using sound modules, integrated to waste bins, so that audio messages can be played when thrash is thrown inside. This has an aim to reduce litter around the bins and actually increase usage efficiency.

Key features:

- This project encourages users to properly dispose waste by using audio cues
- Waste bins will give audio feedback, aiming at better waste disposal and also reduction of garbage
- Its compatible with BigBelly bins or new ones
- It is available as an extra accessory as well
- It has proven value of cleanliness around the waste bins
- It has good media coverage so it's already a well-known solution

Key Benefits according to BeeSmart:

- Efficiency Gains
- Citizen engagement
- Cost Savings
- Environmental Impact
- Interoperability

Spatial Level- Smart City, Smart Building

Project Webpage:**https://www.smartcityinventions.com/homepage/talking-wastebin/**

Main Objective: Sustainability

Application Domain: Waste Management, Smart City

TRL: 9 developed system deployed

Admin Level: Municipal or local level

Barriers: Cost, Maintenance, Acceptance, Integration

Technology of implementation: Hardware-Sound modules

Case Study 4 Sustainaccount Climate Resilience Suite

This project aims on providing a service for Climate. This will help business and organizations to understand and address the climate risks that affect their operations and assets.
Purpose of the project: To give actionable climate risk info for buildings
Benefits: Better resilience, effectiveness, reduction of climate risks and finally a certification to prove this process completion
It is a Software as a Service solution that is combining both data and climate models and it will result in more resilient buildings and a proven up to 90% reduction in climate related risks.
Key features:

- It provides digital solution for the assessment of climate risks
- It helps in implementation of resilience strategies and solutions for buildings and their environments
- Offers many different services in compliance with many standards
- It works by suggesting adaptive measures with aim to enhance the asset value and resilience
- It's widely used by global companies and real estate developers
- Helps in risk management and achieving sustainability goals for the project
- Has a good reputation plus its high-quality and precise risk assessments with the help of visualizations

Key Benefits according to BeeSmart:

- Efficiency Gains
- Life Quality
- Cost Savings
- Environmental Impact
- Knowledge sharing

Spatial Level- Smart City, Smart Building

Project Webpage: **https://sustainaccount.com/**

Main Objective: Sustainability

Application Domain: Climate analysis, Sustainability

TRL: 9 developed system, deployed

Admin Level: Municipal or corporate level

Barriers: Cost, Data integration is complex, Regulations

Technology of implementation: Software platform

Case Study 5 Preflet

This project is about and Energy AI platform that is helping managers to build more efficiently and with a reduced energy and environmental cost. It is about public and commercial buildings and it uses smart meters that process the buildings climate and also its energy data, and gives easy to do actions to improve that.
Problem it aims for is that buildings have a significant carbon footprint due to poor energy management practices. As energy prices go up and new strict regulations being applied, the building managers struggle to achieve those goals due to outdated techniques and technologies being used. This leads to a massive number of 165 million insufficient buildings that have a cost of 100 billion euros.
The Aim is to empower optimization of energy usage and decarbonising the buildings. Huge energy costs can be achieved by using the energy AI platform that this project offers making a great impact on our environment.
It has a cost of 1.5 euros/sqm per year but the investment is returned within the first year.
This results in a saving of up to 25%.
Focused on efficiency improvements through analytics and carbon reduction strategies.
The Goal is to contribute to energy-efficient, and environmentally friendly buildings.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency Gains
- Cost Savings
- Environmental Impact

Spatial Level- Smart City, Smart Building

Project Webpage: **https://www.preflet.com/**

Main Objective: Sustainability

Application Domain: Energy efficiency, Carbon footprint reduction, Sustainability

TRL: 9 tested system, deployed

Admin Level: Building managers, City planners

Barriers: Cost, Integration with existing systems, Energy usage data tricky

Technology of implementation: AI driven technology-software platform

Case Study 6 Data-Driven air purification system

Aura Air is an innovative air management platform, that cleanses indoor air while it also monitors its quality in real time. It has an award-winning design and patented technology in the filters it uses for disinfecting indoor air with its simple plug and play solution. It removes VOCs, bacteria, allergens, mold and viruses like SARS-COV-2 and influenza in 60 minutes time. Its main problem is the indoor air quality and it aims on monitoring, filtering, disinfection of air. Based on an easy to use and connected system. It provides real time data on air quality. Has own awards on its innovative product.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Citizen engagement
- Life Quality
- Connectivity
- Cost Savings
- Environmental Impact

Spatial Level- Smart District, Smart Building

Project Webpage: **https://auraair.io/**

Main Objective: Sustainability

Application Domain: Air quality monitoring/purification, Health, Smart building management

TRL: 9 deployed system, used in real world

Admin Level: Building managers

Barriers: Cost, Integration with existing systems

Technology of implementation: AI and sensors with software platform and hardware

Case Study 7 EMF Supervision

This project uses a network of communicating sensors that are deployed in an area and periodically measure exposure to electromagnetic fields. A secure platform for supervision is available to the city municipality. Allows for monitoring, storing, organizing and display of measurements. The info provided exclusively for technical services. Also, a free public website is provided so that citizens can view all measured data adding to transparency.
The main problem is that deployment of new communication equipment creates emf and exposes people to them. The Aim is to shed light on the environmental concerns and health concerns due to the increasing EMF in urban areas. With this project it's easy to monitor over time the levels of exposure so citizens are properly informed and everything is transparent.

Main benefit is the independent measurement of data by a specialized laboratory, thus ensuring neutrality and objectivity about electromagnetic waves used in networks. Also, the public access of the data is easy by using an interactive map. Big Cities are becoming part of the network like Paris and Brussels.

Key Benefits according to BeeSmart:

- Citizen engagement
- Life Quality
- Connectivity
- Knowledge Sharing
- Environmental Impact

Spatial Level- Smart City, Smart Building

Project Webpage: **https://www.observatoiredesondes.com/fr/**

Main Objective: Sustainability, Health, Environment

Application Domain: Air quality monitoring/purification, Health, Smart building management

TRL: 9 deployed system, used in real world providing data

Admin Level: Municipal

Barriers: Public trust, Cost, Integration with existing systems

Technology of implementation: Sensors Network-uses platform to show results

Case Study 8 Urbanistic planning platform

This project is about a digital solution aimed at supporting city planners in designing smarter and sustainable cities. It includes tools for 3D city modelling, real time data analysis and also citizen engagement tools to make the planning process participative. Enhancing the collaboration between the different stakeholders it optimizes land use and integrates environmental data for better decision making while designing the required area. This way more efficient and livable urban spaces will be created with the aid of advanced technology.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency gains
- Citizen engagement
- Life Quality
- Cost Savings
- Environmental Impact
- Interoperability

Project Webpage: **https://www.urbanistic.de/**

Main Objective: Sustainability, Environment

Application Domain: Urban Planning, Development, Architecture

TRL: 9 deployed system, used in real world, still scaling up

Admin Level: Municipal, Urban developers

Barriers: Cost, Integration with existing tools, Adoption by stakeholders

Technology of implementation: Software platform

Case Study 9 Arqlite SPC

This project is about a smart material company that produces lightweight eco-friendly gravel for 100% recycled plastics. Used mainly in construction and landscape project Arqlite gravel will provide better insulation and drainage if we compare it to other traditional materials. This way the product helps in reducing plastic waste, thus contributing to a more sustainable and circular economy. Its main advantages is that its highly durable, lightweight and cost effective material with a positive impact on the environment.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency gains
- Environmental Impact

Project Webpage: **https://arqlite.com/**

Main Objective: Sustainability, Environment, Reduce Plastic waste

Application Domain: Recycling, Sustainability

TRL: 7

Admin Level: Municipal, Construction

Barriers: Cost, Adoption

Technology of implementation: Material transformation-Hardware

Case Study 10 H2OE-Guard

This project is about a smart water monitoring system that provides real time alerts for leaks, pipe problems and out of normal water usage. Key features include automated water shutoff, remote monitoring and very detailed analytics to optimize water consumption. It is an ideal solution for property managers and municipalities or even home owners that aim in reduced water consumption and prevention of damages. It mainly helps is saving water and reducing operational costs and at the same time prevents and protects from water related damages to the property.

Key Benefits according to BeeSmart:

- Efficiency gains
- Citizen Engagement
- Life Quality
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.techsoil.in/**

Main Objective: Sustainability, Environment, Reduce Water waste, Use IoT

Application Domain: Public Infrastructure, Sustainability, Environmental Monitoring, Smart City

TRL: 7, tested/used in real world, still scaling

Admin Level: Municipal

Barriers: Cost, Adoption, Integration challenges

Technology of implementation: IoT Network. Hardware and Software platform

Case Study 11 AmbiAir

This project is a about a smart ventilation system that monitors and controls indoor air quality. It uses sensors to track CO2 levels, temperature, humidity and particulate matter thus ensuring optimal air quality. It is energy efficient and automatically adjusts air flow to reduce energy consumption while it maintains the quality of air for a healthy environment. It is an ideal solution for offices, schools and hospitals where the air quality is critical for the people inside. In general, it gives comfort by improving air quality, reduces energy costs and is compliant with regulations.

Key Benefits according to BeeSmart:

- Efficiency gains
- Life Quality
- Cost Savings
- Environmental Impact

Project Webpage: **https://ambisense.net/indoor-air-quality/**

Main Objective: Sustainability, Environment, Public Health

Application Domain: Sustainability, Environmental Monitoring, Building Management

TRL: 9, used in real world

Admin Level: Facility/Building Managers, Urban planners

Barriers: Cost, Awareness, Adoption, Integration challenges

Technology of implementation: IoT hardware and Software Platform

Case Study 12 Encompass Blue

This project is about a comprehensive digital platform for managing smart city operations and data. Key features include real time monitoring, data analytics, integration of urban services like water, energy, transport and public safety.
Key benefits are efficiency, sustainability, quality of life for the citizens and also automation. Mainly to be used by Municipalities and urban planners for automating city management by using smart infrastructure.

Key Benefits according to BeeSmart:

- Efficiency gains
- Life Quality
- Connectivity
- Knowledge sharing
- Cost Savings

- Environmental Impact

Project Webpage: **https://www.blueiot.com.au/**

Main Objective: Sustainability, Environment, optimize energy usage, Reduce carbon footprint

Application Domain: Sustainability, Environmental Monitoring, Building Management, Energy management

TRL: 9, used in real world, operational

Admin Level: Facility/Building Managers, Municipal

Barriers: Cost, Adoption, Integration challenges, Data Security

Technology of implementation: IoT hardware and Software Platform

Case Study 13 DeCarbonization as a Service

This project offers tailored solutions to help cities and organizations reduce their carbon emissions. It includes comprehensive tools for assessing and tracking carbon footprints, optimizing energy use and doing so while integrating renewable energy sources. This way it supports long term decarbonization strategies aligned with global climate goals and its target group includes municipalities, businesses or industries that need to meet specific targets in carbon reductions so that these will enhance their sustainability efforts.

Key Benefits according to BeeSmart:

- Easy Replication
- Efficiency gains
- Citizen Engagement
- Life Quality
- Connectivity
- Knowledge sharing
- Cost Savings
- Environmental Impact
- Inclusion and Equality
- Interoperability

Project Webpage: **https://www.dynamhex.com/**

Main Objective: Sustainability, Environment, optimize energy usage, Reduce carbon footprint

Application Domain: Sustainability, Environmental Monitoring, Building Management, Energy management, Carbon management

TRL: 9, used in real world, operational

Admin Level: Facility/Building Managers, Municipal

Barriers: Cost, Adoption, Data Integration challenges, Regulations

Technology of implementation: Software Platform, AI use

Case Study 14 Virtual Energy Audit

This project is about a tool that assesses energy efficiency of a building without the need for on-site visits. Its main features include identification of energy inefficiencies and offers tailored recommendation this helping in reducing operational costs. Supports Energy optimization, lowers carbon footprint and so it enhances sustainability. It's a solution ideal for property managers/building owners.

Key Benefits according to BeeSmart:

- Easy Replication
- Efficiency gains
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.btrlyf.com/**

Main Objective: Sustainability, Environment, optimize energy usage, Reduce carbon footprint

Application Domain: Sustainability, Environmental Monitoring, Building Management, Energy management, Carbon management

TRL: 9, used in real world

Admin Level: Facility/Building Managers, Municipal

Barriers: Cost, Adoption, Awareness

Technology of implementation: Software Platform using AI

Case Study 15 MetroTaifun Automatic Waste Collection System

This project is about a smart solution for waste management using a vacuum based network to transport waste. Key benefits include minimal traffic congestion caused by waste collection vehicles, improves cleanliness in urban environments and lowers overall operational costs.
It's a solution suitable for urban areas, big residential complexes and public spaces. It promotes sustainability by optimizing waste collection logistics and also redacting carbon emissions from the waste collection vehicles.

Key Benefits according to BeeSmart:

- Efficiency gains
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.metrotaifun.com/**

Main Objective: Sustainability, Environment, Automated Waste Collection System, Reduce carbon footprint

Application Domain: Sustainability, Waste Management

TRL: 9, used in real world, fully operational

Admin Level: Municipal

Barriers: High Cost, Infrastructure integration, Adoption

Technology of implementation: Hardware, Pneumatic technology

Case Study 16 Omnicarbon

This project is about a carbon management platform designed to help cities and various organizations to track and reduce carbon emissions. It features real time monitoring, footprint analysis and many reporting tools to support decarbonization efforts. It basically gives insights for sustainable decision making and helps to meet regulatory rules for carbon reduction. Suitable for municipalities and large organizations and aims to implement sustainability initiatives so that climate goals can be achieved.

Key Benefits according to BeeSmart:

- Citizen Engagement
- Life Quality
- Knowledge Sharing
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.omnicarbon.co/**

Main Objective: Sustainability, Environment, Tracking, Reduction of carbon footprint

Application Domain: Sustainability, Carbon management, Climate Change

TRL: 6, Development, Demonstration of technology

Admin Level: Municipal, Corporate

Barriers: High Cost, Data Integration, Regulations

Technology of implementation: Software Platform using AI

Case Study 17 Ambient Air Quality Monitoring System

This project is about an Ambient Air Quality monitoring system. It tracks air quality in real time and measures pollutants that are most important like CO2, PM2.5 and PM10. Key features include continuous monitoring and data analytics allowing for proactive management of environment. Main benefits include improving of air quality in cities and also alignment with regulatory standards this way promoting public health with provisioning of actionable insights on air quality.
It's an ideal solution for urban environments and generally in regions with high pollution levels.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Citizen engagement
- Life Quality
- Knowledge Sharing
- Cost Savings
- Environmental Impact

Project Webpage: **https://oizom.com/product/polludrone-air-pollution-monitoring/**

Main Objective: Sustainability, Environment, Tracking, Reduction of carbon footprint

Application Domain: Sustainability, Carbon management, Climate Change

TRL: 9, used in real world, deployed

Admin Level: Municipal, Corporate

Barriers: High Cost, Data Integration, Regulations

Technology of implementation: IoT hardware and Software Platform

Case Study 18 Smart Pipe sewage rat trap

This project is about an automated solution for controlling rat populations is sewage systems. Its function is to detect rat activity and trigger mechanical traps to eliminate them humanely. This way the system reduces the need for chemicals used for pest control and is environmentally friendly, thus improving public health while controlling rat populations in urban areas. It is ideal solution for city sewage systems so that rats are managed effectively and infestations are reduced.

Key Benefits according to BeeSmart:

- Connectivity
- Environmental Impact

Project Webpage: **https://www.anticimex.nl/smart/**

Main Objective: Eco friendly pest control, Sustainability, Environment, Tracking, Reduction of infestations

Application Domain: Pest Management

TRL: 9, used in real world, deployed

Admin Level: Municipal, Health agencies

Barriers: High Cost, Infrastructure, Data Integration

Technology of implementation: IoT, Hardware, Software

Case Study 19 GreenPocket Energy Management Software

This project is about a platform designed to optimize energy consumption through advanced data analytics and visualization. Core features include real time monitoring, details on energy usage and also predictive analytics to enhance energy efficiency. Main benefits are reduced energy costs, lower carbon footprint and also achieving sustainability targets.
Can be used by municipalities or businesses to implement energy saving strategies.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.greenpocket.com/**

Main Objective: Energy management software, Sustainability, Environment, Tracking

Application Domain: Energy Management

TRL: 9, used in real world, deployed widely

Admin Level: Municipal, Corporate

Barriers: High Cost, Adoption, Data Integration

Technology of implementation: Software platform

Case Study 20 Smart Sensors MQTT Gateway

This project provides a solution that allows for seamless integration and communication between various smart sensors and also IoT systems using MQTT protocol. Its key features are that it facilitates real time data transfer with low latency and is also energy efficient for communication between the various devices. Its benefits are its ideal fit for smart city applications, the solution enhances data collection from multiple sources this giving us the opportunity for better decision making and better system management.
Its suitable for smart infrastructure, monitoring of the environment and also building monitoring.

Key Benefits according to BeeSmart:

- Easy Replication
- Citizen Engagement
- Connectivity
- Environmental Impact

Project Webpage: **http://airepuertoreal.sinapseenergia.com/**
Main Objective: IoT Sensor Management, Sustainability, Environment, Tracking

Application Domain: Smart City Solutions, Environmental Monitoring, IoT infrastructure communications

TRL: 8, used in real world, deployed

Admin Level: Municipal, Corporate, Urban infrastructures

Barriers: High Cost, Complex, Adoption, Data Integration, Data Security

Technology of implementation: Software-Communication Protocol

Case Study 21 Independent Homes

This project is about a smart housing solution that is focused on improving home autonomy and energy efficiency so increasing comfort as well. Its key features include integration of smart technology for energy, security management and also home automation to support living.
It's designed for elderly individuals or people with special needs and enables a safer more comfortable and self-sufficient living environment for them.
Benefits are that it promotes sustainability and independence by using smart home innovations and this improves overall quality of life for those in need.

Key Benefits according to BeeSmart:

- Easy Replication
- Citizen Engagement
- Connectivity
- Environmental Impact

Project Webpage: https://www.gridx.ai/use-cases/home-energy-management-system

Main Objective: Energy/Security Management, Sustainability, Environment, Managing renewable energy consumption

Application Domain: Smart Homes, Energy efficiency

TRL: 8, used in real world, deployed widely

Admin Level: Municipal, Corporate, Local

Barriers: High Cost, Complex, Adoption, Awareness

Technology of implementation: Software Platform, IoT Hardware

Case Study 22 Ubiik Weightless LPWAN Advanced Metering Infrastructure-Electricity

This project is about a smart metering solution for electricity that is using Low Power Wide Area Network (LPWAN) technology. It provides real time data collection, and features like remote meter reading this way providing better communication efficiency with utility providers.
Benefits is that it improves grid management, it reduces operational costs and supports more efficient energy administering.
It's ideal for utility companies so that these can improve their energy distribution and monitoring.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency Gains
- Life Quality
- Connectivity
- Knowledge Sharing
- Cost Savings
- Environmental Impact

Project Webpage: https://www.ubiik.com/smartmetering

Main Objective: Energy Management-Large scale, Sustainability, Environment, Managing energy consumption/efficiency in large scale.

Application Domain: Smart Grid, Energy efficiency

TRL: 8, used in real world, deployed

Admin Level: Municipal, Utility providers

Barriers: High Cost, Complex, Data privacy

Technology of implementation: Software Platform and Hardware IoT

Case Study 23 Loriot-LoRaWAN Network Server

This project is about a scalable solution for managing LoRaWAN networks and it enables communication between various IoT devices. It's secure and flexible and supports large scale deployment with important low energy consumption. It's ideal for smart city applications from environmental monitoring and energy management to infrastructure automation offering a reliable data transfer. It's designed for network operators and municipalities or corporate use for deploying IoT networks.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency Gains
- Life Quality
- Connectivity
- Cost Savings
- Environmental Impact

Project Webpage: **https://loriot.io/**

Main Objective: IoT Management-Large scale, Sustainability, Environment

Application Domain: IoT infrastructure, smart cities, utility, industrial

TRL: 8, used in real world, deployed

Admin Level: Municipal, Utility providers, large corporations

Barriers: High Cost, Complex, Data security

Technology of implementation: Software Platform, Network Server

Case Study 24 Energy efficiency building automation with energy self-sufficient devices

This project is about wireless, battery free and energy self-sufficient devices for automating building systems. Key features are that it enables real time monitoring and control of energy usage thus enhancing sustainability and also reducing energy waste. Main benefit is that it increases operational efficiency, and also minimizes environmental impact and that is done with its battery free technology that reduces the maintenance part by a lot. It's ideal solution for modern smart buildings and is mainly focused on maximizing energy savings and automation.

Key Benefits according to BeeSmart:

- Easy replication
- Efficiency Gains
- Citizen engagement
- Life Quality
- Knowledge Sharing
- Cost Savings
- Environmental Impact

Project Webpage: **https://envuco.com/**

Main Objective: Optimize building energy use, Sustainability, Environment, Main advantage not using batteries

Application Domain: IoT infrastructure, smart buildings

TRL: 9, used in real world, deployed and used

Admin Level: Municipal, Building Managers

Barriers: High Cost, Complex, Integration on existing systems, Scalability

Technology of implementation: Software Platform and hardware Solution

Case Study 25 bGrid

This project is about a smart building solution providing a sensor network in order to optimize indoor environments. Its key features include real time data collection for temperature, light, motion, air quality and also occupancy this way enabling energy efficiency and enhances comfort for its occupants.
It improves building management by adjusting systems based on environmental data and this way it results in lower energy use and better working environments. It's ideal for offices or commercial buildings and also smart infrastructure projects that are focused on sustainability and efficiency.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Life Quality
- Cost Savings
- Environmental Impact

Project Webpage: **https://bgrid.com/**

Main Objective: Optimize building energy use, Sustainability, Environment

Application Domain: Smart buildings, Energy optimization, Sustainability

TRL: 9, used in real world, deployed in many buildings in EU

Admin Level: Building Managers, Facility operators

Barriers: High Cost, Complex, Integration on existing systems, Scalability, Data Security

Technology of implementation: Software Platform and hardware Solution

Case Study 26 Cobundu

This project is about a smart building platform to improve space utilization and workplace efficiency. Its key features are that it collects and analyzes data on occupancy, environment and user behavior so that it can optimize workspaces. This way it enabled businesses to manage resources in a more effective way, it reduces energy costs and enhances employee well-being by creating responsive and more adaptable work environments.
Its suitable for offices, commercial buildings that need to improve operational efficiency and user experience.

Key Benefits according to BeeSmart:

- Easy Replication
- Efficiency Gains
- Life Quality
- Cost Savings
- Environmental Impact

Project Webpage: **https://www.spacewell.com/**

Main Objective: Optimize building, Sustainability, Environment

Application Domain: Smart buildings, Energy optimization, Sustainability

TRL: 9, used in real world, deployed in many buildings

Admin Level: Building Managers, Facility operators

Barriers: High Cost, Complex, Integration on existing systems, Scalability

Technology of implementation: Software Platform

Case Study 27 Virtual Intelligent Smart Automation

This project is about a platform offering advanced automation for building systems. Its core features include integration of AI for real time monitoring, does predictive maintenance and automated control of lighting, Heating Ventilation Air Conditioning systems. Its benefits include reduced energy consumption, it optimizes building performance and enhances comfort of occupants by using smart automation. It is ideal for smart buildings and commercial uses or large-scale infrastructure projects that need to be more efficient and use more automation.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Life Quality
- Connectivity
- Cost Savings
- Environmental Impact

Project Webpage: **http://blueiot.com.au/**

Main Objective: Optimize building, Sustainability, Environment, Comfort

Application Domain: Smart buildings, Energy optimization, Sustainability

TRL: 9, used in real world, deployed

Admin Level: Building Managers, Facility operators, Municipal

Barriers: High Cost, Complex, Integration on existing systems, Scalability, Data Privacy

Technology of implementation: Software Platform

Case Study 28 PreQurs Certificate for heat system LPEC

This project is about a certification solution that ensures compliance and energy efficiency for heating systems. Its main key feature is that it provides a certification process for optimizing heating systems performance and this way achieves lowering carbon emissions. Benefits owners and managers to ensure compliance with regulations and also improving sustainability of their systems.
Designed mainly for residential or commercial properties.

Key Benefits according to BeeSmart:

- Efficiency Gains
- Environmental Impact

Project Webpage: **https://platform.beesmart.city/solutions/prequrs-certificate-for-heat-system-lpec**

Main Objective: Certification for buildings, Sustainability, Environment

Application Domain: Heating Systems, Energy optimization, Sustainability

TRL: 9, used in real world, already certifying

Admin Level: Building Managers, Facility operators, Municipal

Barriers: Cost, Regulations, Awareness

Technology of implementation: Certification solution

TRL: 9

5.2 Application of Digital Solutions in Case Studies

The integration of digital tools in the projects we analyzed earlier shows there is a wide spectrum of solutions that use the digital solutions. We will do a small analysis based on the actual tools using each technology and try and split the projects according to their main focus. Later in this chapter we do a more in detail analysis of the projects we studied in beesmart cases. The following table provides a clear view on the technologies used by the different projects and also their environmental impact.

Scenario Name	Technology Used	Environmental Impact
Waste Management, Circular Economy Projects		
Instant Bin Audit	AI Based image analysis system, AI,IoT	Medium
Talking Wastebins	Hardware-Sound modules,IoT	Medium
Arqlite SPC	Material transformation-Hardware,IoT	High
Metrotaifun-Automatic Waste Collection System	Hardware, Pneumatic technology,IoT, Sensors	High
Smart Pipe Sewage rat trap	IoT, Hardware, Software Platform	Medium
Urban Planning, sustainability		
Preoptima Concept	Software solutions,BIM, Digital Twin	High
Sustainaccount Climate Resilience Suite	Software platform, BIM, Digital Twin	High
Urbanistic Planning Platform	Software platform,BIM IoT	High
DeCarbonization as a Service	Software Platform, AI, IoT, BIM	High
Energy Efficiency and Automation		
Preflet	AI driven technology-software platform, IoT	High
Encompass Blue	AI, IoT, hardware and Software Platform	High
Virtual Energy Audit	Software Platform, AI use, IoT,BIM	High
Greenpocket Energy Management Software	Software platform,IoT	High
Energy Efficiency building automation with energy	Software Platform and hardware Solution, IoT	High
bGRID	Software Platform and hardware Solution,IoT	High
Cobundu	Software Platform,IoT,Digital Twins	High
Air quality, environment, health		
Data Driven Air purification System-AuraAir	AI,IoT and sensors with software platform and hardware	Medium
EMF Supervision	AI, IoT and Sensors Network-uses platform to show results	Medium
H2OE Guard	IoT, Sensors Network. Hardware and Software platform	Medium
AmbiAir	IoT, sensors, hardware and Software Platform	High
Omnicarbon	Software Platform, AI use	High
Ambient Air Quality Monitoring System	IoT hardware and Software Platform	High
Independent Homes	Software Platform, IoT Hardware	Medium
Automation-Data driven projects, certificates		
Virtual Intelligent Smart Automation	IoT, Software Platform	High
Ubiik LPWAN Advance Metering Infrastructure	IoT, Software Platform and Hardware	High
Loriot-LoRaWAN network Server	IoT, Software Platform, Network Server	Medium
Smart Sensors MQTT Gateway	IoT, Software-Communication Protocol	Medium
Prequrs Certificate for heat systems LPEC	Certification solution, uses BIM,Digital Twin tech	High

Table 3 Scenario_Tech used

Key outcomes from table 3

Some observations we have derived from this table is that IoT is the most widely used technology between all the cases we studied. Its versatile and enables real time monitoring and data gathering so that it can automate many different functions. Some of the cases show the true benefits of IoT, such as MetroTaifun Project where the automated waste collection system results in great reductions in waste and also operational costs. AI is also rising as a useful means to help this process of data gathering and decision-making combination. In projects like AuraAir and Preflet, AI use helps in predictive analytics improving air quality and also energy efficiency respectively. The only downside with use of AI is a higher cost and need of more technical expertise, limiting the scalability of such solutions.

BIM and DT technologies are mostly used in urban planning and sustainability projects. Projects like Preoptima and Urbanistic demonstrate the capabilities of such tools that lead to

higher levels of achieved environmental impact. Implementing these is also resource depended since they require quite a few to be used, and also need technical expertise.

5.3 Data results we gathered from the study of the Projects in Beesmart.city

In this part we present the data gathered from all the projects we studied

Table 4 Objectives, domain, admin level, technology of case studies from Beesmart.city

Scenario Name	Main Objective	Application Domain	Administration Level	Technology	Benefits	Barriers
Instant Bin Audit	Bin Contamination analysis	Waste management, Smart City, Building	Municipal, administration	AI Based image analysis system	Easy Replication, Efficiency Gains, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Cost, Privacy, Integration on existing systems, Public Adoption, Maintenance
Preoptima Concept	Sustainability	Sustainability, Environmental Impact	Municipal, administration	Software solutions	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Cost, Complexity, Regulations
Talking Wastebins	Sustainability	Waste management, Smart City, Building	Municipal or local level	Hardware-Sound modules	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Cost, Maintenance, Acceptance, Integration
Sustainaccount Climate Resilience Suite	Sustainability	Climate analysis, Sustainability	Municipal or corporate level	Software platform	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact, Knowledge sharing	Cost, Data Integration complexity, Regulations
Preflet	Sustainability, Energy Conservation	Energy efficiency, Carbon footprint reduction, Sustainability	Building managers, City planners	AI driven technology-software platform	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Cost, Integration with existing systems, Energy useage data is tricky
Data Driven Air purification System-AuraAir	Sustainability	Air quality monitoring/purification, Health, Smart building management	Building managers	AI and sensors with software platform and hardware	Efficiency Gains, Citizen engagement, Life Quality, Connectivity, Cost Savings, Environmental Impact	Cost, Integration with existing systems
EMF Supervision	Sustainability, Health, Environment	Air quality monitoring/purification, Health, Smart building management	Municipal, administration	Sensors Network-uses platform to show results	Citizen engagement, Life quality, Connectivity, Knowledge Sharing, Environmental Impact	Public trust, Cost, Integration with existing systems
Urbanistic Planning Platform	Sustainability, Environment	Urban Planning, Development, Architecture	Municipal, Urban developers	Software platform	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Cost Savings, Environmental Impact, Interoperability	Cost, Integration with existing tools, Adoption by stakeholders
Arqite SPC	Sustainability, Environment, Reduce Plastic waste	Recycling, Sustainability	Municipal, Construction	Material transformation-Hardware	Easy Replication, Efficiency Gains, Environmental Impact	Cost, adoption
H2OE Guard	Sustainability, Environment, Reduce Water waste, Use IoT	Public Infrastructure, Sustainability, Environmental Monitoring, Smart City	Municipal, Urban developers	IoT Network. Hardware and Software platform	Efficiency Gains, Citizen engagement, Life Quality, Cost Savings, Environmental Impact	Cost, adoption, Integration challenges
AmbiAir	Sustainability, Health, Environment	Sustainability, Environmental Monitoring, Building Management	Facility/Building Managers, Urban planners	IoT hardware and Software Platform	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	Cost, Awareness, Adoption, Integration Challenges
Encompass Blue	Sustainability, Environment, optimize energy usage, Reduce carbon footprint	Sustainability, Environmental Monitoring, Building Management, Energy management	Facility/Building Managers, Municipal	IoT hardware and Software Platform	Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Cost. Adoption, Integration Challenges, Data security
DeCarbonization as a Service	Sustainability, Environment, optimize energy usage, Reduce carbon footprint	Sustainability, Environmental Monitoring, Building Management, Energy management, Carbon management	Facility/Building Managers, Municipal	Software Platform, AI use	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	Cost. Adoption, Data Integration Challenges, Regulations
Virtual Energy Audit	Sustainability, Environment, optimize energy usage, Reduce carbon footprint	Sustainability, Environmental Monitoring, Building Management, Energy management, Carbon management	Facility/Building Managers, Municipal	Software Platform, AI use	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Cost, adoption, Awareness
Metrotalfuri-Automatic Waste Collection System	Sustainability, Environment, Automated Waste Collection System, Reduce carbon footprint	Sustainability, Waste Management	Municipal	Hardware, Pneumatic technology	Efficiency Gains, Cost Savings, Environmental Impact	High Cost, Infrastructure integration, Adoption
Omnicarbon	Sustainability, Environment, Tracking, Reduction of carbon footprint	Sustainability, Carbon management, Climate Change	Municipal, Corporate	Software Platform, AI use	Citizen engagement, Life quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Data Integration, Regulations
Ambient Air Quality Monitoring System	Sustainability, Environment, Tracking, Reduction of carbon footprint	Sustainability, Carbon management, Climate Change	Municipal, Corporate	IoT hardware and Software Platform	Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Data Integration, Regulations
Smart Pipe Sewage rat trap	Eco friendly pest control, Sustainability, Environment, Tracking, Reduction of infestations	Pest Management	Municipal, Health agencies	IoT, Hardware, Software Platform	Connectivity, Environmental Impact	High Cost, Infrastructure integration, Data Integration
Greenpocket Energy Management Software	Energy management software, Sustainability, Environment, Tracking	Energy Management	Municipal, Corporate	Software platform	Efficiency Gains, Cost Savings, Environmental Impact	High Cost, adoption, Data Integration
Smart Sensors MQTT Gateway	IoT Sensor Management, Sustainability, Environment, Tracking	Smart City Solutions, Environmental Monitoring, IoT infrastructure communications	Municipal, Corporate, Urban infrastructures	Software-Communication Protocol	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	High Cost, adoption, Data Integration, Data Security
Independent Homes	Energy/Security Management, Sustainability, Environment, Managing renewable energy consumption	Smart Homes, Energy efficiency	Municipal, Corporate, Local	Software Platform, IoT Hardware	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	High Cost, Complex, Adoption, Awareness

23	Ubilk LPWAN Advance Metering infrastructure	Energy Management-Large scale, Sustainability, Environment, Managing energy consumption/efficiency in large scale	Smart Grid, Energy efficiency	Municipal, Utility providers	Software Platform and Hardware IoT	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Complex, Data Privacy
24	Loriot-LoRaWAN network Server	IoT Management-Large scale, Sustainability, Environment	IoT infrastructure, smart cities, utility, industrial	Municipal, Utility providers, large corporations	Software Platform, Network Server	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Cost Savings, Environmental Impact	High Cost, Complex, Data Security
25	Energy Efficiency building automation with energy self-sufficient devices	Optimize building energy use, Sustainability, Environment, Main advantage not using batteries	IoT infrastructure, smart buildings	Municipal, Building Managers	Software Platform and hardware Solution	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability
26	bGRID	Optimize building energy use, Sustainability, Environment	Smart buildings, Energy optimization, Sustainability	Building Managers, Facility operators	Software Platform and hardware Solution	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Data Security
27	Cobundu	Optimize building, Sustainability, Environment	Smart buildings, Energy optimization, Sustainability	Building Managers, Facility operators	Software Platform	Easy Replication, Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability
28	Virtual Intelligent Smart Automation	Optimize building, Sustainability, Environment, Comfort	Smart buildings, Energy optimization, Sustainability	Building Managers, Facility operators, Municipal	Software Platform	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability, Data Privacy
29	Frequrs Certificate for heat systems LPEC	Certification for buildings, Sustainability, Environment	Heating Systems, Energy optimization, Sustainability	Building Managers, Facility operators, Municipal	Certification solution	Efficiency Gains, Environmental Impact	Cost, Regulations, Awareness

In the next table, Table 5 we present the benefits, barriers, where the projects are used and a brief feature analysis. We will further discuss on these findings in chapter 6.

	Scenario Name	Benefits	Barriers	Used In	Feature analysis
2	Instant Bin Audit	Easy Replication, Efficiency Gains, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Cost, Privacy, Integration on existing systems, Public Adoption, Maintenance	Some retailers/Some Cities does not define exactly	AI-powered waste contamination detection, Centralized reporting for insights, Fast and accurate analysis
3	Preoptima Concept	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Cost, Complexity, Regulations	Denver/UK cities	Real-time carbon assessments, User-friendly interface for stakeholders, AI-driven design
4	Talking Wastebins	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Cost, Maintenance, Acceptance, Integration	Europe/Japan/UK	Encourages proper waste disposal, Reduces littering in public areas, Interactive and educational
5	Sustainaccount Climate Resilience Suite	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact, Knowledge sharing	Cost, Data Integration complexity, Regulations	Europe	Detailed climate risk assessments, Tailored adaptation strategies, regulatory compliance
6	Preflet	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Cost, Integration with existing systems, Energy useage data is tricky	Portugal	Immediate energy savings via smart meters, Carbon footprint reduction insights, Improves operational energy efficiency
7	Data Driven Air purification System-AuraAir	Efficiency Gains, Citizen engagement, Life Quality, Connectivity, Cost Savings, Environmental Impact	Cost, Integration with existing systems	Hospitals Worldwide	Monitors and purifies air in real-time, Four-stage purification process, Smart integration with
8	EMF Supervision	Citizen engagement, Life quality, Connectivity, Knowledge Sharing, Environmental Impact	Public trust, Cost, Integration with existing systems	France	Real-time EMF monitoring, Regulatory compliance assurance, Enhances public awareness of EMF
9	Urbanistic Planning Platform	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Cost Savings, Environmental Impact, Interoperability	Cost, Integration with existing tools, Adoption by stakeholders	Retailers around the world	3D modeling and GIS integration, Collaboration tools for stakeholders, Scenario analysis
10	Arqlite SPC	Easy Replication, Efficiency Gains, Environmental Impact	Cost, adoption	Didn't find any actual use case. Lot of advertisment	Innovative recycling tech, Sustainable materials for construction, Environmental
11	H2OE Guard	Efficiency Gains, Citizen engagement, Life Quality, Cost Savings, Environmental Impact	Cost, adoption, integration challenges	Under Development.Used in some places but not clearly saying	System protection for pH regulation, Chemical free operation, Proved to be effective
12	AmbiAir	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	Cost, Awareness, Adoption, Integration Challenges	UK/Spain	Indoor Air Quality Monitoring, Predictive Analytics, Ease of Integration
13	Encompass Blue	Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Cost. Adoption, Integration Challenges, Data security	Australia	Energy Savings, Carbon Emission Reductions, Health and Wellness Enhancements
14	DeCarbonization as a Service	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	Cost. Adoption, Data Integration Challenges, Regulations	USA	Carbon Footprint Analysis, Custom Decarbonization Plans, Ongoing Optimization
15	Virtual Energy Audit	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Cost, adoption, Awareness	USA,EU,China,Dubai,Saudi Arabia,Bangkok, Manilla	Comprehensive Energy Analysis, Cost-Efficient Process, Actionable Recommendations
16	Metrotaifun-Automatic Waste Collection System	Efficiency Gains, Cost Savings, Environmental Impact	High Cost, Infrastructure integration, Adoption	Nothern Europe	Efficient Waste Transport, Environmental Benefits, Adaptable Applications
17	Omnicarbon	Citizen engagement, Life quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Data Integration, Regulations	Under Development.Used in some places but not clearly saying	Emission Tracking, Strategic Reduction Plans, Sustainability Monitoring
18	Ambient Air Quality Monitoring System	Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Data Integration, Regulations	Turkey and India	Tracks air quality continuously, Provides actionable data insights, Enhances public awareness of air quality
19	Smart Pipe Sewage rat trap	Connectivity, Environmental Impact	High Cost, Infrastructure integration, Data Integration	USA, EUROPE	Reduces rodent populations effectively, Environmentally friendly and chemical-free, Real-time monitoring for maintenance
20	Greenpocket Energy Management Software	Efficiency Gains, Cost Savings, Environmental Impact	High Cost, adoption, Data Integration	Germany	Energy consumption pattern insights, Ensures regulatory compliance, Improves customer
21	Smart Sensors MQTT Gateway	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	High Cost, adoption, Data Integration, Data Security	Worldwide, Vodafone/huawei uses it	Low-latency data transmission via MQTT, Supports diverse sensor integration, Simple setup and configuration
22	Independent Homes	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	High Cost, Complex, Adoption, Awareness	Germany	Promotes energy self-sufficiency, Optimizes energy consumption, Supports grid stability
23	Ubiik LPWAN Advance Metering Infrastructure	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Complex, Data Privacy	Taiwan	Efficient data collection for AMI, Proven scalability for large deployments, Utilizes high-performance connectivity
24	Loriot-LoRaWAN network Server	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Cost Savings, Environmental Impact	High Cost, Complex, Data Security	USA,Europe,Hong Kong	Scalable to millions of devices, End-to-end data encryption, Compatible with diverse hardware
25	Energy Efficiency building automation with energy self-sufficient devices	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability	EUROPE	Self-powered sensors optimize energy, Minimizes maintenance costs, Promotes sustainability
26	bGRID	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Data Security	USA,EUROPE	Optimizes building performance, Enhances occupant comfort, Future-proof API integration
27	Cobundu	Easy Replication, Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability	USA,EUROPE	Optimizes space utilization, Improves indoor air quality, Enhances operational efficiency
28	Virtual Intelligent Smart Automation	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	High Cost, Complex, Integration with existing systems, Scalability, Data Privacy	Australia	Efficient resource allocation, Predictive maintenance capabilities, Informed decision-making for planners
29	Prequrs Certificate for heat systems LPEC	Efficiency Gains, Environmental Impact	Cost, Regulations, Awarene-	Germany	Ensures heating system efficiency, Compliance with regulations,

Table 5 Benefits/barriers/use/Feature analysis of case studies from Beesmart.city

Results presented in table 5 and table 6 show us the projects and implementations we did exploratory case study research at. As we can see from the tables and the results, we can observe the **similarities and the differences** between the multiple projects and how these effect their environments.

5.4 Evaluation of Renovation Scenarios

In order to evaluate and compare the different scenarios and smart city solutions across diverse domains like we show later in **table 6** we need a **structured and objective approach**. Multi Criteria Decision Analysis (MCDA) can be utilized in this case which offers a robust framework to do so, enabling assessment of various solutions **relying on many different performance indicators.** This methodology does a comprehensive evaluation of the solutions and ensures that the ranking aligns with theory and empirical evidence. MCDA, is handling both quantitative and qualitative data, addresses the diverse impacts of smart city projects across many domains.

MCDA Framework

MCDA is a widely **used framework for complex decision making** due to the ability it has to **integrate diverse views, give different priorities to objectives and do a ranking of the solutions that is comprehensive**. For the smart cities solutions ranking MCDA can be used for their evaluation by combining all the diverse criteria to one unified framework. Methods within MCDA include Analytic Hierarchy Process (AHP) and Technique for Order preference by Similarity to Ideal Solution (TOPSIS) and Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE), and each can cater specific evaluation needs.

Process of MCDA involves specific steps. These are:

- **Criteria Definition and Prioritizing**: First we have to select the criteria that align with smart project objectives. For example, environmental impact, economic benefits etc. According to a study from K. Kourtit the criteria can also involve factors that have to deal with urban quality as well, like competitiveness, sustainability, quality of life which are very crucial to evaluating smart city projects. (Kourtit, et al., 2012)
- **Weight Assignment and Sensitivity Analysis**: Using AHP will help in assigning relative importance to each criterion. This uses hierarchical structure to derive the respective weights based on feedback from the stakeholders. This way we ensure that evaluation process will reflect the values of various stakeholders that are involved in the process of urban planning and designing urban renovations. (Taha & Daim, 2013)
- **Performance Scoring**: Evaluating each project against certain criteria that can be derived from other case studies that deal with similar data and projects. Can also use expert opinion or even pilot data.
- **Aggregation and Ranking:** We will aggregate these weighted scores to generate an overall performance score for the solutions one by one, creating a very transparent way of ranking each of them.

MCDA can be applied to various smart city domains in a very effective way. It can be used for waste management, Energy efficiency, Air quality and urban planning. We can use criteria that is tailored specifically for each domain so we can manage to capture the characteristics of each and objectives we are after.

For example, we can consider the following variables useful for the purposes of our study as we have seen in **similar studies**:

Waste management and Circular Economy

- Criteria: Environmental Impact, Operational efficiency, Social Acceptance (Singagerda, et al., 2024)

Energy efficiency and Automation:

- Criteria: Energy Savings, Cost-efficiency, Scalability (Zhou & Liu, 2024)

Air Quality and Environment:

- Criteria: Coverage Area, Data Accuracy, Health Impact (En Xin Neo, 2023)

Urban Planning and sustainability

- Criteria: Sustainability, Climate Resilience, Adaptability (Lopez & Castro, 2020)

Based on our study of literature and similar projects the variables and scales that we will use and choose so that we will be able to grade our mix of case studies in an efficient way, and rank them according to our perspective on the impact of each solution. **We use Analytic Hierarchy Process in our case** since we assign weights to criteria that is based on their relative importance and we compare with each other to rank the solutions.

The logic we use behind our subjective grading was derived from similar case studies using MCDA method that managed to rank such smart city projects and solutions, using their respective variables that they consider to be important in their case. For example, we will use Preoptima Project. We explain in detail and per variable for the project and why we ranked like we did:

Preoptima is an innovative platform that is designed to integrate real time whole life carbon assessments to early stages of a buildings design. This way enables stakeholders to make informed and also more sustainable solutions.

- Environmental Impact: High. Preoptima helps in significant reductions in embodied carbon emissions, this way helping to optimize design options during the planning phase. A company that used it achieved an impressive 50-70% reduction in embodied carbon by choosing timber solutions versus other more traditional materials.
- Scalability: High. Use of AI generative design and automated material quantity helps in adapting the platform to many different projects and scales. Its user-friendly interface and API integration help in facilitating adoption across many different stakeholders.
- Cost-efficiency: High. Its innovative way to create instant whole life carbon assessments, reduces the time and also resources otherwise needed for traditional detailed analysis. With this efficient way it helps us in comparing options in the design that lead to high-cost savings, in the design phase and also in the whole lifecycle of the building.
- Citizen engagement: High. It can generate data driven reports that help in enhancing communication between the different stakeholders. This way helps in facilitating informed discussions that lead to better decisions and results!

Comparative Analysis and ranking based on Case Studies

MCDA gives us the way to have ranking based on multi-dimensional performance giving us a comprehensive evaluation of smart city projects and solutions across different domains. Empirical studies show that the ranking process many times is fully aligned with theoretical expectations in MCDA. Usually, the **solutions that do well on sustainability, scalability and are accepted by majority of the users tend to rank higher than others due to broader application of these and their positive impact on the environment these are applied to.**

In the case of this thesis we observe that solutions like **Preoptima and Greenpocket rank highly due to the massive effect these have on environmental impact and scalability.** These align with sustainability goals and offer solutions that are both scalable and accepted like it is shown in many other MCDA case studies. (Cohen, et al., 2019)

Moderate scorers like Talking wastebins and Independent Homes have **some points of strength** but rank way lower because these have a **limited impact and limited scope** compared to others.

Concluding MCDA offers a **transparent and evidence-based framework** to help us evaluate and rank smart city projects. By integrating multiple criteria with this approach, we can capture the diversity of the impacts of each project across different dimensions. Case studies show that MCDA rankings align closely with theory, confirming it's a valid method for assessment of complex urban renovation projects. MCDA enables planners to make data-informed decisions that enhance the impact, the sustainability and life quality of smart city projects. A table showing the **subjective grading** we did to all the solutions we studied using the weights for the different variables mentioned and explained in **chapter 3.1.8/9** is showed below. This table is based **on two other similar studies by** (Shi & Shi, 2023) (Gazzeh, 2023) **that used similar variables to the ones used in our analysis to grade the different solutions under study**.

Scenario Name	Community Engagement	Effectiveness of Solution	Sustainability	Scalability	Innovation	Interoperability	Cost effectiveness	Carbon Emissions Reduction	TRL	Total Score	RANK
Instant Bin Audit	1.2	1.6	1.6	1.2	0.7	0.9	0.8	1.2	0.4	9.6	
Preoptima Concept	1.4	1.8	2	1.35	0.9	0.9	1	2	0.45	11.8	1
Talking Wastebins	1.4	1.4	1.4	1.05	0.7	0.7	0.6	1.2	0.45	8.9	
Sustainaccount Climate Resilier	1.2	1.8	2	1.05	0.8	0.7	0.7	1.6	0.45	10.3	
Preflet	1.2	1.8	2	1.2	0.8	0.9	0.8	1.6	0.45	10.75	
Data Driven Air purification Syst	1.6	1.8	1.4	1.2	0.9	0.7	0.7	1.4	0.45	10.15	
EMF Supervision	1.6	1.6	1.4	1.05	0.8	0.7	0.7	1.4	0.45	9.7	
Urbanistic Planning Platform	1.8	1.6	1.8	1.05	0.9	0.8	0.8	1.6	0.45	10.8	
Anqlite SPC	1.2	1.4	1.6	0.9	0.8	0.7	0.7	1.8	0.35	9.45	
H2OE Guard	1.4	1.8	1.8	1.05	0.8	0.7	0.8	1.4	0.45	10.2	
AmbiAir	1	1.8	1.8	1.05	0.8	0.7	0.7	1.4	0.45	9.7	
Encompass Blue	1.4	1.8	1.8	1.05	0.7	0.7	0.7	1.6	0.45	10.2	
DeCarbonization as a Service	1.4	1.8	2	1.05	0.9	0.7	0.8	1.8	0.45	10.9	3
Virtual Energy Audit	0.8	1.8	1.8	1.2	0.8	0.8	0.8	1.4	0.45	9.85	
Metrota/fun-Automatic Waste Co	1.2	1.8	2	1.05	0.9	0.6	0.7	1.8	0.45	10.5	
Omnicarbon	1.4	1.8	2	1.2	0.8	0.8	0.8	1.8	0.3	10.9	2
Ambient Air Quality Monitoring S	1.6	1.8	1.8	1.2	0.8	0.8	0.7	1.6	0.45	10.75	
Smart Pipe Sewage rat trap	1.2	1.6	1.6	1.05	0.8	0.7	0.7	1.4	0.45	9.5	
Greenpocket Energy Managemer	1.4	1.8	1.8	1.2	0.8	0.8	0.8	1.8	0.45	10.85	4
Smart Sensors MQTT Gateway	1	1.6	1.6	1.05	0.7	0.8	0.7	1.4	0.45	9.3	
Independent Homes	1.6	1.8	1.6	1.05	0.8	0.7	0.7	1.4	0.45	10.1	
Ubik LPWAN Advance Metering	1	1.6	1.6	1.2	0.8	0.8	0.7	1.6	0.45	9.75	
Loriot-LoRaWAN network Server	1	1.6	1.6	1.35	0.8	0.8	0.7	1.4	0.4	9.65	
Energy Efficiency building autom	1.2	1.6	2	1.05	1	0.8	0.8	1.6	0.45	10.5	
bGRID	1.2	1.8	2	1.05	0.8	0.8	0.7	1.6	0.45	10.4	
Cobundu	1.2	1.6	1.6	1.05	0.8	0.8	0.8	1.4	0.45	9.7	
Virtual Intelligent Smart Automa	1.4	1.8	1.8	1.05	0.8	0.7	0.7	1.6	0.45	10.3	
Prequis Certificate for heat syste	1	1.4	1.6	1.05	0.8	0.7	0.7	1.6	0.45	9.3	

Variables	Weight
Community Engagement	20%
Effectiveness of Solution	20%
Sustainability	20%
Scalability	15%
Innovation	10%
Interoperability	10%
Cost effectiveness	10%
Carbon Emissions Reducti	20%
TRL	5%

Category	RANKS	
Urban planning, Sustainability	Preoptima Concept	11.8
Air,environment,health	Omnicarbon	10.9
Urban planning, Sustainability	DeCarbonization as a Service	10.9
Energy efficiency, automation	Greenpocket Energy Management Sc	10.85
Urban planning, Sustainability	Urbanistic Planning Platform	10.8

Table 6 Ranking of case studies in Beesmart website

Now in regard to our analysis, the above case studies can be split into categories according to the **area they deal with**. Their **main focus area** will help us to split them accordingly. After grading each case study for every parameter, we have a finalized set shown in table 7. Here the case studies are divided according to the area they mostly deal with and are ranked accordingly.

Waste Management, Circular Economy Projects	**Total Score of solution**
Metrotaifun-Automatic Waste Collection System	**10,5**
Instant Bin Audit	**9,6**
Smart Pipe Sewage rat trap	**9,5**
Arqlite SPC	**9,45**
Talking Wastebins	**8,9**

Energy Efficiency and Automation	**Total Score of solution**
Greenpocket Energy Management Software	**10,85**
Preflet	**10,75**
Energy Efficiency building automation with energy self-sufficient devices	**10,5**
bGRID	**10,4**
Encompass Blue	**10,2**
Virtual Energy Audit	**9,85**
Cobundu	**9,7**

Air quality, environment, health	**Total Score of solution**
Omnicarbon	**10,9**
Ambient Air Quality Monitoring System	**10,75**
H2OE Guard	**10,2**
Data Driven Air Purification System-AuraAir	**10,15**
Independent Homes	**10,1**
AmbiAir	**9,7**
EMF Supervision	**9,7**

Urban Planning, sustainability	**Total Score of solution**
Preoptima Concept	**11,8**
DeCarbonization as a Service	**10,9**
Urbanistic Planning Platform	**10,8**
Sustainaccount Climate Resilience Suite	**10,3**

Automation-Data driven projects, certificates	**Total Score of solution**
Virtual Intelligent Smart Automation	**10,3**
Ubiik LPWAN Advance Metering Infrastructure	**9,75**
Loriot-LoRaWAN network Server	**9,65**
Smart Sensors MQTT Gateway	**9,3**

Prequrs Certificate for heat systems LPEC	**9,3**

Table 7. Final results for each solution

Colours are used to show where each solution belong to and which category we can place it in. The total score is calculated by the summary of the variables we used for ranking the solutions. Total score indicates the evaluated effectiveness of the solution and is based on multiple performance indicators.

Below we will analyse the projects that are included in each category and explain why we rank them like this. What are the factors that give some projects better ranking, what is the TRL of the solution, and where these are implemented.

Category 1-Waste Management, circular economy

Projects included

1. Instant Bin audit
2. Talking Wastebins
3. Smart Pipe Sewage Rat Trap
4. Metrotaifun-Automatic Waste Collection System
5. Arqlite SPC

These are focused on managing waste in a more efficient way and help a lot in urban sustainability. The ones standing out are:

From each of the categories that we divided our solutions we will try to explain why we chose the solution that was ranked higher than others and where does the difference in grades come from.
Starting from the category of Waste management and Circular Economy we have:

1. Automatic Waste collection System (Metrotaifun): This system is ranked higher that others with 10.5 points total.
   Why? It is very effective, sustainable and innovative
   Impact on carbon emissions? Great impact-Reduced traffic from garbage collection trucks
   TRL 9- Already implemented and in use in Finland, Denmark and Moscow areas.
2. Instant Bin Audit: This system ranks second in the category. It gets a total of 9.6 points.
   Why? It is effective, sustainable and interoperable
   Cost effectiveness? Very good cost effectiveness level since its simple to implement with a great impact on the environment. Less contaminants inside the garbage so cleaner environment.
   TRL-8 Already being implemented/developed in Bratislava

Category 2-Energy efficiency and Automation

Projects Included

1. GreenPocket Energy Management Software
2. Energy Efficiency Building Automation with Energy Self Sufficient devices
3. Cobundu
4. bGRID
5. Virtual energy Audit

These projects tackle the optimization of energy consumption problem and automation. Can result in large energy consumption reduction. The project that stands out more are:

1. Greenpocket Energy management software: It ranks first in the category. It gets a total of 10.85 points.
   Why? high effectiveness, high sustainability and very high carbon emissions reduction.
   Impact on Carbon emissions? Very High
   TRL-9 Already being used in Germany and expanding
2. Preflet: It also ranks in top 5 with 10.75 total points
   Why? High effectiveness, high sustainability and also great interoperability.
   TRL-9 Already being used in Lisbon. Used in retail, businesses. Support by EU programs for funding innovation

Category 3-Air quality, environment, health

Projects included

1. Data Drive Air Purification System
2. Ambient Air-AmbiAir
3. Omnicarbon
4. EMF Supervision

These projects mainly deal with air quality and public health, mainly using systems that monitor and improve air quality or deal with monitoring of EMF. The ones that stand out more are:

1. Ambient Air Quality Monitoring System: First in score. Total of 10.75 points.
   Why? Very high sustainability and scalability
   Impact on Carbon emissions? Very High
   TRL-9 Deployed in Turkey and India
2. Omnicarbon: Scoring second in the category. Total of 10.9 points.
   Why? Very high sustainability and also very high carbon emissions reduction
   Impact on Carbon emissions? Very High
   TRL-6 Final stages of development

Category 4-Urban planning, sustainability

1. Preoptima Concept
2. DeCarbonization as a Service
3. Urbanistic Planning Platform
4. Sustainaccount Climate resilience Suite

These projects do aim in planning and resilience and thus give sustainable development. The projects that stand out more are:

1. Preoptima concept: First in score. Total of 11.8 points. This is due to really high effectiveness of the solution, very high sustainability and cost effectiveness.
   Impact on Carbon emissions? Very High
   TRL-9 Deployed in UK, USA
2. Decarbonization as a service: Second in score. Total of 10.9 points. This is due to very high sustainability, carbon emissions and also TRL.

Impact on Carbon emissions? Very High
TRL-9 Deployed in USA

Category 5-Automation-Data Driven projects, Certificates

1. Virtual Intelligent Smart Automation
2. Loriot-LoRaWAN network server
3. Ubiik LPWAN advance metering infrastructure
4. Smart Sensors MQTT Gateway
5. Prequrs Certificate for heat systems LPEC

These projects are considered more technical oriented and are focused more on how things will operate together and more efficiently. Also, we have added a certificate category with this lot. The projects that stand out from these are:

1. Virtual Intelligent Smart Automation: This has high effectiveness and also high sustainability. 10.3 points in total
   Impact on Carbon emissions? Very High
   TRL-9 Deployed in AU
2. Loriot-LoRaWAN network server: This solution ranks second in category with very high effectiveness, sustainability. 9.75 points in total
   Impact on Carbon emissions? High
   TRL-8 Starting to be Deployed in CA, ME, China

Assessment of Environmental Impact

In this part we will do an assessment of the **environmental impact of each solution** according to the data and information gathered on the technology used for each solution. Environmental impact was a key feature for evaluation and the scenarios demonstrated different degrees of effectiveness in **reducing greenhouse emissions**. Some of them stood out for their performance. Cases like:

- Preflet: This project excelled in reduced emissions, through optimization of energy usage at building level. Uses AI and through its platform it enables instant carbon footprint reductions, this way making it one of the best performers in this category.
- Preoptima Concept: Also very promising solution, focusing on whole life carbon assessments, increasing sustainability for the whole lifecycle of each building and the materials used.
- Sustainaccount: Achieved high emissions reduction through use of adaptation strategies combined with climate risk assessments. Its main focus is on identifying vulnerable points and recommending on measures to improve these. This platform aims in helping to align with net zero goals for buildings and cities.
- Instant Bin Audit: Provide with moderate environmental benefit. Generally, improves waste management and leads to cleaner cities, but has indirect effect to emissions reduction that limits the real performance of it.
- Talking Wastebins: Same as above. More focused on waste management. Indirect aid to environmental impact goal.

Efficiency of resources

Many of the projects studied **focused on reduction in energy, water and material conservation and minimizing excess use.** As we see in examples like Preoptima and Preflet had a great impact on resource usage using precise energy and carbon optimization techniques. Sustainaccount promoted resource efficiency and used integration of renewable energy sources, and also promoted optimization of land use through planning that took advantage of climate related information. Instant bin Audit enhanced the recycling process and helped in reduction of landfill use and dependence. All of the above provide for really important efficiency gains in resource use and this way led to more sustainable and efficient solutions.

Economic Viability of Case Study Scenarios

We also performed an assessment using **cost benefit analyses**, evaluating the initial costs, funding sources and long-term savings for the different scenarios and provided with a scoring inside table. Many of the cases we dealt with **needed high upfront costs** but provided us with **much greater long-term savings**. For example, projects like **Preflet and Virtual energy Audit** show really **high economic viability**, providing us with **immediate energy savings that minimize the initial costs needed.** These are ideal for stakeholders and planners that seek a **relatively low budget solution that provides with substantial results** without spending a fortune and seeing results quickly. Sustainaccount project on the other hand needed very high initial cost in order to complete the detailed climate modeling part, but all these upfront expenses are wiped out with the long-term resilience and also cost savings this project has to offer.

A really important factor on economic viability was the scale of the actual implementations. Larger cities with higher budgets could make use and adopt the more expensive solutions like Sustainaccount for example, while lower budget cities faced many challenges in finding financial aid to adopt these tools, that leads us to the need for more accessible funding mechanisms implemented to provide solutions for such problems.

5.5 All case studies comparison and analysis

In this section we combine all the results from the previous chapters and have an analysis on technology used, key benefits and key outcomes. This way we can make observations on the technology patterns and how these give different benefits to the various projects.

Table 8 including all solutions studied and literature review ones and technology used to implement these

All scenarios Combination	Technology Used	Key Benefits	Key Outcomes
Waste Management, Circular Economy Projects			
Instant Bin Audit	AI Based image analysis system, AI, IoT	Easy Replication, Efficiency Gains, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Optimized waste analysis, centralized reports, improved compliance and management of waste
Talking Wastebins	Hardware-Sound modules, IoT	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Encourages proper waste disposal, Reducing litter, educational also
Arqlite SPC	Material transformation-Hardware, IoT	Easy Replication, Efficiency Gains, Environmental Impact	Plastic waste reduction, Sustainability of consructions, lower carbon footprint
Metrotaifun-Automatic Waste Collection System	Hardware, Pneumatic technology, IoT, Sensors	Efficiency Gains, Cost Savings, Environmental Impact	Efficient waste management, Enhancd environmental benefits, Scalabity and versatility
Smart Pipe Sewage rat trap	IoT, Hardware, Software Platform	Connectivity, Environmental Impact	Effective rodent control, Not toxic and environmentally friendly solution, Continuous monitoring
Urban Planning, sustainability			
Preoptima Concept	Software solutions, BIM, Digital Twin	Efficiency Gains, Citizen engagement, Cost Savings, Environmental Impact, Ineroperability	Real time carbon assesments, Ai powered design optimizing, User friendly
Sustainaccount Climate Resilience Suite	Software platform, BIM, Digital Twin	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact, Knowledge sharing	Climate risk assesments, Tailored adaptation strategies, Certification support
Urbanistic Planning Platform	Software platform, BIM IoT	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Cost Savings, Environmental Impact, Interoperability	Enhanced decision making, Improved collaboration, Sustainable development
DeCarbonization as a Service	Software Platform, AI, IoT, BIM	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	Carbon footprint assesment, Tailored decarb strategies, Monitoring and optimization
Rotterdam LCA Renovation	LCA, GIS combination	Easy Replication, Efficiency Gains, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Optimized renovation strategies, reduced lifecycle emissions, enhanced sustainability
Shenjing Village Collaborative Planning	GIS, collaborative workshops	Easy replication, Efficiency gains, Citizen Participation, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperatbility	Inclusive planning, culturally sensitive designs, long-term sustainability
Hamburg Serious Games	Serious Games, feedback mechanisms	Easy replication, Efficiency gains, Citizen Participation, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperatbility	Enhanced community engagement, user-informed designs, participatory urban planning
Scotland Place Standard	Structured assessment framework-14 themes encompassed	Easy replication, Efficiency gains, Citizen Participation, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	Improved urban regeneration strategies, inclusive design outcomes, policy alignment

Copenhagen's #sharingcph Instagram Initiative	Social media platform, Instagram	Easy replication, Efficiency gains, Citizen Participation, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	Identification of urban nature hotspots based on user-shared images, Enhanced understanding of public perceptions and uses of green spaces, Informed urban green infrastructure planning through citizen-generated data
Digital Communication and Citizen Engagement in Kutaisi and Poznań	Digital platforms, SM channels, official government websites	Easy replication, Efficiency gains, Citizen Participation, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Inclusion and Equality, Interoperability	In both cities, higher intensity of digital tool usage correlates with stronger relationships between citizens and local authorities, Perceived usefulness of social media significantly enhances citizen engagement and trust in local governance, The study underscores the importance of effective digital communication strategies to foster active citizen participation in urban governance.
GIS-Based MCDA for Smart City Planning	GIS and MCDA techniques	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Effective identification of optimal urban development zones, Enhanced management of urban real estate through detailed land value assessments, Improved planning of parking facilities, contributing to sustainable urban mobility
Tangzixiang Historic District VR Renovation	VR technologies	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Enhanced resident engagement in the design process, leading to more informed decision-making, Preference for the traditional architectural style, highlighting the importance of cultural preservation, Improved social sustainability through increased community interaction and participation, Environmental benefits achieved by reducing the use of printed materials for design reviews
BIM and AR Integration for Architectural Visualization	BIM and AR to overlay virtual models onto physical environment	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Enhanced communication among stakeholders through immersive and interactive design presentations, Improved decision-making by enabling real-time modifications and immediate visualization of design changes, Increased efficiency in identifying and resolving design issues before construction
BIM-Based Green Building Evaluation and Optimization	BIM	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Streamlined assessment of green building criteria, Enhanced decision-making through data-driven insights, Improved environmental performance of building designs
Energy Efficiency and Automation			
Preflet	AI driven technology-software platform, IoT	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Immediate energy Savings, Carbon footprint reduction, enhanced efficiency

Table 8 part-2

Encompass Blue	AI, IoT, hardware and Software Platform	Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Energy and cost savings, Enhanced sustainability, Improved health and well-being
Virtual Energy Audit	Software Platform, AI use, IoT, BIM	Easy Replication, Efficiency Gains, Cost Savings, Environmental Impact	Energy assesment, Cost effective analysis, recommendations on strategies
Greenpocket Energy Management Software	Software platform, IoT	Efficiency Gains, Cost Savings, Environmental Impact	Enhanced energy efficiency, Regulatory Compliance, Improved engagement with customers.
Energy Efficiency building automation with energy self-sufficient devices	Software Platform and hardware Solution, IoT	Easy Replication, Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	Enhanced energy efficiency, Reduced maintenance costs, Sustainable solution
bGRID	Software Platform and hardware Solution, IoT	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	optimized building performance, Enhanced occupart comfort, Scalable solution
Cobundu	Software Platform, IoT, Digital Twins	Easy Replication, Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	Optimized space utilization, Improved indoor environment quality, Enhanced efficiency
Geneva Energy Modeling	UBEM frameworks	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Up to 50% energy reduction, cost-benefit analysis of retrofits, district-wide insights
Thessaloniki Solar Mapping	GIS	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	High-potential areas for solar energy, targeted resource allocation, increased renewables adoption
Digital Twin–Enabled Urban Energy Management	Digital Twin, Real time energy monitoring systems	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Improved accuracy in energy performance assessments, Enhanced decision-making for energy retrofits and policy implementations, Facilitation of near real-time energy management at the city scale
Herrenberg Urban Digital Twin	3D modeling, space syntax analysis, urban mobility, wind flow sims, VGI. Digital twin technology	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Enhanced participatory urban planning processes, Improved collaboration among stakeholders, Data-driven decision support for sustainable urban development
Air quality, environment, health			
Data Driven Air purification System-AuraAir	AI, IoT and sensors with software platform and hardware	Efficiency Gains, Citizen engagement, Life Quality, Connectivity, Cost Savings, Environmental Impact	Air quality monitoring, Advanced purification tech, Smart integration
EMF Supervision	AI, IoT and Sensors Network-uses platform to show results	Citizen engagement, Life quality, Connectivity, Knowledge Sharing, Environmental Impact	Continuous monitoring, Comply with regulations, Transparency, Public awareness
H2OE Guard	IoT, Sensors Network. Hardware and Software platform	Efficiency Gains, Citizen engagement, Life Quality, Cost Savings, Environmental Impact	Real time water quality monitor, Data driven decision making, Regulation compliance
AmbiAir	IoT, sensors, hardware and Software Platform	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	Real time indoor air quality monitoring, Predictive analytics, User friendly
Omnicarbon	Software Platform, AI use	Citizen engagement, Life quality, Knowledge Sharing, Cost Savings, Environmental Impact	Accurate carbon footprint assesment, Tailored decarb strategies, Monitoring and optimizing
Ambient Air Quality Monitoring System	IoT hardware and Software Platform	Efficiency Gains, Citizen Engagement, Life Quality, Knowledge Sharing, Cost Savings, Environmental Impact	Real time air Quality data, Data driven decision making, Public engagement
Independent Homes	Software Platform, IoT Hardware	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	Enhanced energy production and use, Optimized consumption, Grid stability support

Table 8 part 3

Automation-Data driven projects, certificates			
Virtual Intelligent Smart Automation	IoT, Software Platform	Efficiency Gains, Life Quality, Cost Savings, Environmental Impact	Optimized resource allocation, Predictive maintenance, Improved decision making
Ubiik LPWAN Advance Metering Infrastructure	IoT, Software Platform and Hardware	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact	Efficient data collection, Scalable, Advanced comms technology
Loriot-LoRaWAN network Server	IoT, Software Platform, Network Server	Easy Replication, Efficiency Gains, Life Quality, Connectivity, Cost Savings, Environmental Impact	Scalable, Flexible, Robust security, Seamless integration
Smart Sensors MQTT Gateway	IoT, Software-Communication Protocol	Easy Replication, Citizen Engagement, Connectivity, Environmental Impact	Efficient Data Transmission, Scalable and flexible, Simple integration
Prequrs Certificate for heat systems LPEC	Certification solution, uses BIM, Digital Twin tech	Efficiency Gains, Environmental Impact	Enhanced efficiency, Regulatory compliance, Increased value for properties
BIM-Based Evaluation of Building Renovation Strategies	BIM	Easy replication, Efficiency gains, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Enhanced decision-making through comparative analysis of renovation options, Identification of optimal strategies tailored to specific building contexts, Demonstrated applicability across different European countries
LCA Framework for Urban Building Renovations	LCA, GIS combination	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Identification of optimal renovation strategies that balance energy savings with environmental impacts, Provision of detailed insights into the spatial distribution of environmental benefits and burdens within urban areas, Support for policymakers and urban planners in making informed decisions to promote sustainable urban development
Scoping Literature Review on LCA in Building Renovations	LCA	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Recognition of limitations imposed by original design decisions on renovation options, Highlighting the complexity in establishing consistent environmental benchmarks across studies, Recommendations for future research to address granularity issues, improve communication of environmental impacts, and incorporate economic and social considerations
Open Government Information Strategies	OGD platforms	Easy replication, Efficiency gains, Life Quality, Connectivity, Knowledge Sharing, Cost Savings, Environmental Impact, Interoperability	Identification of challenges in making government data "fit for use" by diverse external users, Insights into the importance of data quality and user engagement for successful OGD initiatives, Practical recommendations for enhancing public value through improved information strategies

Table 8 part 4

The combined table above shows us the diversity we meet in the different approaches that ranges between many technologies used from AI, IoT, DT, BIM, LCA, VR, AR and also digital communications. Each technology **addresses the domains needed in order to achieve the goals of each different project.** We see almost all projects use IoT and sensors in order to get real time monitoring helping in data driven decision making. Good examples we can refer to are Metrotaifun solution and also Smart Sensors MQTT among others. Digital Twins and BIM advanced modeling and simulation tools are also popular among the solutions. Examples that stand out are Herrenberg Urban Digital Twin and Preoptima Concept. These provide us with ideal examples of real-world use of the optimizing capabilities of the DT technology. Citizen engagement tools are also really popular as we observe in the study. Technologies that make use of social media enhance public participation and engagement and really enhance

transparency in public governance. Good examples that show the results of such implementations are Copenhagen's #sharingcph and Scotland Place Standard.

Important also is the use of geographical and functional focusing that we see in some of the projects. The cases of Rotterdam LCA renovation as well as Geneva Energy Modeling show that a good driven for innovation is the strong commitment of some communities for more sustainable solutions, that use LCA and energy simulations, in order to help them optimize their infrastructure and also help in reducing their carbon footprints in the process. Projects like these show us the need for global action towards a more sustainable future that will help us mitigate the climate change impacts, and will address the local problems in a more suitable way.

We also observed projects like Hamburg Serious games case where niche domains are being explored and the solutions proposed enhance aspects that are usually not considered really high or are left a bit behind. Same with the project of Tangzixiang that also showcases how important it is to actually engage people and local communities in projects and how effective this method can prove to be in order to avoid certain problems and constraints that otherwise might cripple the progress of a project. Public engagement and use of immersive technologies like VR/AR is the new go to area for modern projects that want better and more sustainable results. Using harmonization of innovation and public engagement provides for better solutions and ideas for new projects. This multifaceted approach shows how versatile the digital tools can be in the process of addressing a wide range of urban challenges across many different contexts.

5.6 Lessons Learned from Case Studies

In this section we will expand on how these projects helped us in identifying the various best practices, the different barriers and the overall recommendations that are needed so that we can achieve implementing successful solutions.

We will start with the **most commonly used tools** which are in respective number of appearances in the solutions:

1.Internet of Things

Most frequent in appearances in the case studies. Used in energy monitoring, air quality, waste management

Advantages: Scalability, cost-effectiveness, real-time data collection

Challenges: Dependency on infrastructure and also many data privacy concerns need to be dealt with.

2. BIM/Digital Twins

High use in urban renovation and also sustainability focused projects

Used in building renovations, urban planning projects and simulations

Advantages: Improved future planning capabilities, predictive functions

Challenges: High cost and usually data intensive and hard to implement

We also have some tools that are **underutilized** and need much more use because these provide us with impressive results when implemented correctly. These are:

1. VR/AR

Very low use overall, mainly in heritage maintenance projects and Participatory planning projects

Used in immersive visualization for stakeholders

Advantages: Really high engagement potential and enhanced accessibility

Challenges: Has limited scalability and costs are high

2. Social Media

Very low use also, only for some projects and public engagement

Used to enhance citizen participation and feedback process

Advantages: Very broad reach and high levels of inclusivity

Challenges: Limited use until this point, need more projects to actually see the downsides.

There are three main practices that every successful project implements with one way or another and these are also used in combinations between them. These are:

Data Driven Decision Making: Examples such as Preflet and Preoptima demonstrate the potential of data use in urban renovation projects. Using real time analytics to help in optimizing energy, carbon footprint and align the project with sustainability goals. Using data driven tools helps planners to actually simulate different scenarios, compare their different outcomes and impacts, this way helping out in making better- and well-informed decisions that help in balancing cost-efficiency-outcomes.

Stakeholder Engagement: Projects like Sustainaccount Suite really show how important and effective is the inclusion of community into the projects. Involving as many stakeholders as possible, gives us great benefits and provides for more transparency, higher levels of trust and ensures that the actual solutions will meet the needs and requirements of local communities. Using stakeholder workshops and implementing participative design processes, really enhances social acceptance, and most importantly reduces the effects of the phenomenon of resistance to change.

Use of Innovative technologies: Using of AI driven solutions, like we saw in Instant Bin Audit project, exemplifies the role of these into enhancing the efficiency and also the sustainability of these solutions. With the help of these advanced tools and technologies we can achieve better, faster, more sustainable and more resilient solutions for our projects. AI, and technologies like AR/VR can really enhance the whole process. Starting with the design and planning phase, and boosting the community engagement in the process using AR/VR technologies to present and adjust the solutions proposed to the stakeholders. AI can scale up the level of real time data processing and help drastically in decision making process for such projects, and also to the preventive maintenance part of them.

Based on the above information and findings we can propose some recommendations to enhance the effectiveness, scalability and also sustainability in urban renovation projects:

- Improving of policy in order to support these new solutions and projects
- Establishment of new standards for data integration and interoperability must be created
- Investments in robust data governance frameworks is essential
- Engagement strategies must be tailored to local needs

Last part of the evaluation is the **way we design the projects**. **Modular solutions** such as Metrotaifun show that these scalable systems are **better and more adaptable** to different urban environments. Also **really important is the citizen engagement mechanisms** we use. These need to be permanently integrated into all future projects since their impact on them is truly making a difference with the results we get. Another important aspect is the **balance of costs and benefits that we need to achieve**, in order to provide solutions that are actually effective. For this example, we can take the digital twin technology which has a high initial cost but provides with great benefits in long term.

Chapter 6: Discussion

6.1 Synthesis of Theoretical and Practical Findings

Introduction

The synthesis of theoretical and practical findings in urban planning and sustainability, leads to the revelation of **a transformative landscape**, that is shaped by use of modern technologies and participation strategies to achieve better results. This review gives a comprehensive analysis integrating insights from a variety of case studies, showing **how the interplay of theory and practice manages to address many urban challenges, using innovative solutions to do so.**

More and more we see emerging complex challenges being introduced to urban environments, leading to the need of better and more efficient smart city solutions, that give more sustainable, more efficient solutions with use of community engagement. Theory helps in understanding the frameworks of systems and sustainability models while IoT driven innovations help in building foundation for understanding how these transformations actually work. Practical examples and solutions across many different sectors can prove the benefits these solutions have in many areas like, energy management, waste reduction, urban planning and can work as a guide for the approaches needed. This study explores key theoretical areas derived from our study of the relevant literature and also analyzes practical findings derived from real world case studies leading to similar areas of interest on both parts. A focus on importance of data driven decision making, stakeholders' participation and sustainability can be considered as core principles to almost all cases.

Linking Frameworks to Practical Outcomes

The case studies that we analyzed in this thesis, provide us with practical context for evaluation of urban technologies, through the established theoretical frameworks. Linking these frameworks, like TAM, Resilience theory and Sustainability models to the outcomes of the projects, this discussion explains **how these constructs influence the adoption, the use and the outcomes of the digital innovations.** Also, the deviations that occur between theoretical predictions, give a highlight to the areas that need improvement both in theory and practice. In this section we will explore these connections and try to offer a more comprehensive way of understanding the game between theory and the actual practical outcomes. In the following table we can see some examples of projects and the respective theoretical framework these belong to.

Framework	Case Study	Application	Outcome	Insights
Technology Acceptance Model (TAM)	Copenhagen's #sharingcph Initiative	Intuitive design facilitated ease of use and engagement.	Over 70% of users reported the platform encouraged participation.	Validates TAM's focus on ease of use but highlights a need for contextual variables.
Technology Acceptance Model (TAM)	Tangzixiang Historic District VR Renovation	VR adoption hindered by cultural unfamiliarity with immersive tools.	Limited adoption despite high engagement among tech-savvy participants.	Suggests TAM must account for cultural and digital literacy factors.
Resilience Theory	Herrenberg Urban Digital Twin	Real-time monitoring and simulation enhanced urban adaptability.	Reduced traffic congestion by 20% and energy inefficiencies by 15%.	Highlights resilience through adaptability but underscores interoperability challenges.
Resilience Theory	GreenPocket Energy Management	IoT-based decentralized energy monitoring improved grid flexibility.	Reduced energy consumption by 25% during peak hours.	Demonstrates how IoT fosters resilience through decentralized systems.
Sustainability Models	Rotterdam LCA Renovation	LCA quantified environmental impacts, driving sustainable design.	Reduced carbon emissions by 30% and material waste by 25%.	Affirms sustainability models' emphasis on lifecycle impacts.
Sustainability Models	MetroTaifun Automatic Waste Collection	IoT optimized waste collection for environmental and operational efficiency.	Diverted 40% of waste from landfills and cut emissions by 15%.	Integrates IoT within sustainability models for measurable gains.
Participatory Planning Models	Tangzixiang Historic District VR Renovation	VR tools enabled immersive stakeholder engagement, fostering public trust.	Increased public support by 40% due to clear and interactive presentations.	Demonstrates participatory tools' potential for overcoming communication barriers.
Participatory Planning Models	Copenhagen's #sharingcph Initiative	Social media fostered broad public engagement in sustainability discussions.	High engagement due to accessible and transparent communication channels.	Shows participatory tools' effectiveness in inclusive decision-making processes.

Table 9 Frameworks to practical outcomes

As shown in the above table the **alignment between the different cases and the outcomes**, shows the **real value in understanding the different technologies**, and the **differences and misalignments we see do highlight the areas that need better theoretical basis**. The table shows us in a clear and structured way, **how the frameworks relate to the projects and their results.** We only use a few cases to **showcase the best examples from the total of projects**.

Further to analyze the alignment between the frameworks and projects outcomes shows the true practical value in understanding and evaluating urban innovation technologies.

For example, we take **Copenhagen's project, that validates TAM**, showing that ease of use and perceived usefulness actually have results with high public engagement. Similarly, in Herrenberg case where **Resilience theory this time enhances the adaptability of the projects with real time monitoring and simulations**. All these confirm the actual relevance of the frameworks in the process of guiding urban technology project implementations to have real measurable positive outcomes.

There are also **deviations** in these though that need our attention and theoretical adjustments in order to improve. For example, the **Tangzixiang VR project** reveals that there are **cultural barriers to adoption, that TAM does not account for, showing that we need to address these factors** and also digital divide factor is not accounted to the model thus needed to make a new model. Similar case can be considered the Herrenberg project where **resilience theory does not take into account technical and infrastructural constraints** in order to fully adapt. Alignments show and validate the value of the frameworks while the deviations pave the way for refinement of the current projects, this way ensuring the evolving of theories so that these can address newer challenges in the complex world of urban renovations.

Theoretical insights

Data driven decision making

Using and application of technologies like **Digital Twins, BIM and GIS**, shows how important these tools can be, and most importantly how important it is to **have high quality, granular data for effective urban planning**. Theory emphasizes in how critical data flow is in order to create more adaptive urban systems where we can use continuous monitoring in order to enable better and more informed decision making. (Ismagilova E, 2019) As an example, LCA frameworks can be used to give robust methods for the evaluation of long-term sustainability impacts, implemented and used in many urban initiatives. Digital communication platforms can provide enhanced transparency and better trust levels between stakeholders and the planning team, local government. These also lead to fostering a more collaborative environment for urban governance and a sense of ownership to the project by the local population participating.

Multi Criteria Decision Analysis

MCDA frameworks used in various smart city projects, **illustrate the theoretical strength of balancing factors like environmental, socio-economic** in urban planning process. (Tahir & Malek, 2016) Using these can help in **prioritizing inclusivity and sustainability** also, by **incorporating diverse criteria into the decision-making processes**. Participatory frameworks like the one we studied Scotland's Place Standard, shows how structured engagement can really guide us for more equitable strategies and solutions in urban planning process. This participatory approach used more and more in recent projects shows the growing recognition of citizens as co-creators in urban planning, that lead to better solutions, more inclusive, more sustainable and ultimately more effective. (Samarakkody & Amaratunga, 2022)

Stakeholder Participation

One of the most crucial findings was **how important the participation and engaging of local communities in the planning process was**. This was the most effective way to make the planning process develop something better and **in alignment with local needs and values**. Case studies like Shenjing Village and also Hamburg's Serious Games prove the benefits of participatory design methods, that also foster a sense of ownership among all the stakeholders and more especially local citizens. Cases like Copenhagen using social media and VGI in order to collect citizen inputs and perspectives, show us the potential of integrating social media tools and social media input from the citizens to various projects, like in this case from green infrastructure planning. (Guerrero, et al., 2016) Using such tools can enhance even more the creating of environments that are reflecting the needs and desires of different communities.

Practical findings

Scalability and replicability

Tools like BIM and DT demonstrate their **scalability** across many different contexts both in a geographic and demographic way. Projects like Herrenberg Digital Twin, really show us the capabilities of these technologies and how these can be adapted to meet specific problems and challenges. (Dembski, et al., 2020) GIS and MCDA cases we studied show they are **easily replicable** across different urban scenarios, giving solutions that are sustainable and with **many diverse options**. The adaptability of those is crucial in order to address the unique needs of the modern smart cities, and promote the best practices for urban development process.

Optimization of urban resources

Energy modeling projects like the Geneva one (Ang, et al., 2020) give us the benefits of simulation driven retrofits, leading to large energy savings and also carbon reduction. BIM tools on the other hand enhance resource allocation by identifying the most cost-effective solutions and renovation strategies that give us maximized environmental benefits. (Guo, et al., 2021).

These practical applications validate the theory that stated that optimized systems lead us to **higher economic** and **environmental advantages**, this way reinforcing the importance of integrating advanced technologies into urban planning process.

Citizen Centric Approaches

Participatory projects like Hamburg Serious Games and Scotland Place Standard, give us **actionable data into how effective engagement of citizens** leads to solutions that are more inclusive and more sustainable. (Suha Alawadhi, 2012) Using digital tools, as we studied, enhance public engagement by creating an environment with increased transparency and also trust between the stakeholders. These citizen centric approaches not only provide for improved quality of urban life, but also empower the communities to be active and participate in the process of reshaping their environments, with engaging in such projects.

Emerging patterns and challenges

In this section we will identify and analyze the recurring patterns and also the key challenges that we observed and recorded across the various projects. These help us to shed light on how the digital tools and technologies are helping to reshape urban renovation practices while pointing out the barriers that we must overcome to enhance their scalability and enhance their effectiveness.

Patterns

Integrating advanced technologies, such as BIM, GIS, Digital Twins, shows a trend towards a more comprehensive, technology enabled process of urban planning. (Bibri, 2019) Sustainability seems to be the core goal across the projects, with an extra focus on reducing the carbon footprint, achieve enhanced energy efficiency and also try to preserve cultural and environmental assets. Also, a clear shift towards a more collaborative governance underlines the growing need of the citizens to be part of the projects and participate in urban planning process, in order to improve their living environment and cover their needs for more sustainable and livable solutions. (Samarakkody & Amaratunga, 2022)

There is a clear **dominance in IoT** and modular designs and technologies, as we recorded across the different projects, as it provided for real time monitoring and optimizing of the case studies. Two great examples are Metrotaifun- IoT was used to make the waste collection process automatic and reduced the need for garbage trucks so provided a boost in traffic congestion cause by them. This project allows for 40% reduction in landfill waste and minimizes operation inefficiencies. Greenpocket energy management is also using IoT to minimize energy consumption, leading to a reduce of up to 25% in the peak hour of energy usage. The modular design and adaptability of IoT to many different urban environments make it a true necessity for smart city projects that want to be successful. Though the need of robust infrastructure is there, this way limiting the scalability to resource-limited scenarios.

Use of **BIM and DT for predictive analytics is also an emerging pattern**. Most projects that focus on urban planning and sustainability use these to enable predictive analytics and dynamic monitoring of the solutions. Two good examples are Herrenberg Urban DT, that shows a reduction in energy by 15% and also a traffic congestion reduction of 20% using DT. Preoptima concept used BIM to optimize building materials during the design, this way enabling for a 30% reduction in total carbon emissions. The downside is that the **implementation of DT/BIM requires high investing in technical expertise**, creating barriers for lower budgets.

AI is slowly being used for predictive decision making. As we observed in our study many projects using AI mainly for **predictive capabilities and automation**. Projects such as AuraAir demonstrates that AI can be helpful in predicting pollution levels so that air purification can be adjusted in a more dynamic way, providing for better air quality inside. Preflet case used AI driven algorithms to help them analyze energy use patterns and provide suggestions on energy saving methods and measures. AI gives a boost to IoT and other technologies by giving us actionable insights. The downside here is the **need for high quality datasets** and really high computational power that limits the capabilities of adoption on cases where there is little to none digital infrastructure.

Citizen engagement also emerges as an important factor. Projects that use participatory engagement elements have **achieved better and higher levels** of **public acceptance** and also **engagement**. Some really important projects showcasing this side is Copenhagen's #sharighcph that used Instagram and social media to engage directly with the citizens about sustainability projects, increasing participation and citizen awareness on these projects. Tangzixiang VR renovation showed that using VR tools increased the support to the project by

40%. Despite of all the success stories, **we see a big underutilization of these tools**, mainly in projects using BIM or DT technologies. This lack of inclusion of them tools can lead to misalignment with the community needs and can lead to projects failing or not being accepted by local populations.

Challenges

Despite all the advancements we stated earlier, there are **still several problems and challenges** that we need to address in order to achieve a more streamlined and futureproof process of urban planning. As a starting point we find the problem **of data and data collection**. We need solutions that are able to do effective collection, integration and management of all the diverse datasets, especially if we want to use GIS, BIM or Digital Twin solutions. (Bibri, 2019) Because **data is the cornerstone** of realistic and accurate models that are used to derive the results from the simulations. If we don't use the correct data to design the model then the simulations will give results that are not close to real world applications. **Data interoperability is also critical** between the different systems. This challenges needs addressing if we want to make full use of technologies like Digital Twins. For example, in Urbanistic planning platform, the integration of diverse datasets for different sources required custom solutions, this way giving delays and also increased costs for the projects. A solution could derive from **standardization of the various data protocols** and also the use of **open-source platforms**, so that seamless integration across many different technologies can be achieved.

Another important challenge is the **high costs, scalability and technical expertise** that are needed, and pose great barriers to a more widespread adoption and use of modern digital tools. While all tools enable for a better and more transformative potential, the main problem of scalability in still in play, and is considered as a key challenge mostly due to cost and resource limitations that exist in many of the projects. We can take as an example the Herrenberg project that needed a hefty investment in infrastructure in order to achieve better data integration, making it really not replicable for municipalities that have tight budgets. A solution could be provided using more **modular and low-cost designs**, like for example in the Virtual Energy Audit case, which enables great scalability and better accessibility in resource limited scenarios. **Digital Divide and accessibility** in also of great importance. Ensuring equal access to these tools in order to engage multiple demographic groups is also a real challenge. Inclusiveness of as many groups as possible is crucial for success of the projects. (McKenna, 2020) A proposed solution could come from **combination of digital and non-digital methods**, like for example community workshops, that make use of user-friendly digital tools to bridge the gap between the different stakeholders' groups.

One more significant observation was that many technologies can lead to great environmental benefits, but **implementing them can introduce negative trade-offs such as increased energy consumption** while using IoT and AI systems. An example like AuraAir can prove this statement. Air quality is being improved but not without a significant cost in energy consumption that we need to be aware of. This could **easily offset the environmental benefits** that the actual project offers. A **solution** could be found in **integration of renewable energy** sources and use of energy conservation techniques in order to **balance the tradeoff** between the project's implementation and the overall sustainability goals of the city.

After the analysis of the emerging patterns and their challenges, we observe a dual narrative: The use of digital tools can offer great opportunities for urban innovation, but many systemic barriers exist, such as scalability, interoperability and inclusivity that need to be addressed in order to boost the effectiveness and sustainability of the solutions.

Priority must be given to solutions that:

- Use more **modular designs**
- Use a better **standardization of data and frameworks**
- use more **citizen centered approaches**

This way future projects can really harness the full potential of the technologies and helps then to create a more sustainable and inclusive urban environment.

Patterns in case studies, both Literature and Beesmart projects

Based on the analysis of all 46 case studies and projects, this synthesis provides **an in-depth comparison of theoretical and also the practical findings among many domains**. Statistics from both provide us with a better understanding of trends, benefits, barriers and also the impacts of the actual projects offer in these real-world applications and help us derive critical results on what actually is happening today in the smart city renovation projects and which technologies could use a boost.

Environmental Impact:

The majority of the case studies (more than 40%) deal mainly with environmental impact and more specifically reduction of greenhouse emissions and energy efficiency improvements. Very high impact was noted in projects using LCA/UBEM technologies. (example the Rotterdam case, LCA reduced lifecycle emissions by 30%)

Technology adoption patterns:

As we can observe the technologies used in order of appearances as a solution are:

- Software Platforms, IoT
- GIS
- Emerging Technologies (VR/AR)

We generally see a trend of high us in **software platforms in combination with IoT and real time data processing** for providing the projects with enhanced smart city and building features. **GIS comes second** in use as it provides many benefits with renewable energy use mapping and also really enhances participatory planning. The previous observations from our sample case studies, clearly indicate that **VR/AR need a lot more research and implementation** since it's a really promising technology that actually helps a lot with the crucial problem of citizen participation in these projects. Advancing solutions and projects using these immersive technologies can really make a difference in the future and since these show extremely high benefits we need to consider using them more and more. (case study in Thessaloniki gave us a 30% increase in resource optimization using GIS)

Administrative Levels of Projects:

Majority of projects are **Municipal level**, but we see an increase of **partnerships with stakeholders, private sector** that also is becoming a trend. Municipal projects mainly deal with sustainability and engagement of stakeholders in the process. The more hybrid collaborations show an emphasis on collaboration between the stakeholders as a more important tool to success. (case study of Hamburg for example increased participation by 25%)

Barriers:

Most of the projects have **common barriers** that are dealing with the following in descending order:

- **Data Collection and Integration**: Problems were mainly found in the complexity of data collection and integration process. Technologies like DT, LCA, UBEM and GIS rely heavily on accurate and comprehensive data and collecting that data can be a challenge, because of the nature and diversity we meet in urban environments. Main challenges come for the heterogenous formats we meet, the lack of a standardization and also the resource intensity needed.
- **High Costs:** Many projects had faced financial constraints as a key limitation, and this was met more often on the projects using more advanced technologies. These include extensive IoT networks, serious games, and also energy modelling tools relying on real time data etc. Hefty initial investments were required from them projects in both infrastructure and expertise building. (for example, Geneva UBEM case needed both extensive and costly calibration and also maintenance, prohibiting its expansion to other smaller municipalities) This barrier could be possibly be alleviated by using public private partnerships that will ease the pressure from financial factors and also give the chance for a much broader adoption of the projects and technologies.
- **Digital Divide:** Participatory technologies, as an example we can use VR/AR platforms, require equitable access to digital equipment and infrastructure. The digital divide problem is crucial to be dealt with, especially in lower income areas so that more citizens can actually engage with the projects with proper education and also provision of digital equipment to do so. A good practice is for policymakers to address this digital gap and inequality, using targeted moves like for example creation of digital community workshops. (For example, we can use the Hamburg case where serious games showed there were accessibility issues. These came from equipment missing or digital education not sufficient for the citizens to take part in the project)
- **Expertise/Resource Constraints:** The more advanced the tools used the more technical expertise is required for operating them and the more resources are needed to use these properly. This can create problems in doing so for under resourced projects. (In Shenjing case skilled facilitators were used to work on spatial data, this way increasing both project time needed and also cost). A good practice is to create proper training programs and also use interfaces that can help out decreasing the expertise level needed in order to take active part in the projects.
- **Regulatory constraints:** These are met in a few projects and can lead to hindering the adoption of innovative technologies. Urban planners must overcome the challenge of aligning these tools with existing regulations in order to make the projects more efficient and also to comply with the local regulations. (A good example is the solar mapping in Thessaloniki came across regulatory issues in integrating GIS insights in the process) Good practice is to create more flexible policy environments.

Application domains:

On the application domain we noted a **diverse area of impact for all projects**. The projects studied cover a really **broad spectrum of domains**, showing that these are versatile technologically and can really address the complex urban challenges that are presented to them. We present our observations in descending order:

Most solutions dealt with **Smart Cities and energy optimization**. These had a main focus and laid the foundation for solutions that lead to low carbon emissions environments and also more sustainable energy grids.

Next were the projects dealing with **participatory approaches.** These varied from serious games, GIS and digital platforms and aimed to citizen participation in decision making. Using these provides for better citizen participation and also enhanced citizen trust and transparency in the process of urban planning providing for better and more socially equitable solutions.

Waste management and Environmental monitoring solutions were also very high in our observations. Technologies and solutions that dealt with waste management, reduction of contamination and monitoring of critical metrics such as air quality. These mainly help in creating more sustainable living environments and promote circular economy also.

Urban energy planning was very common too. Use of GIS and energy modeling to identify optimal solutions for solar and wind renewable sources installation and implementation. This supports the transition to cleaner energy sources and also supports in creating a more sustainable and resilient energy grid for urban environments.

Green infrastructure and Climate, also was in a few projects. Urban green areas, water related projects and also resilience planning to deal with future climate change impacts that can pose a threat to dense urban environments. Those solutions are more focused on ecological advantages from such projects and also deal with community well being and health related issues.

The least observed solutions where the ones based on **advanced visualization for urban design.** Using tools like AR/VR can really enhance the way stakeholders can participate in smart city projects. These aim in improving design of the projects developed in urban environments and also achieve a higher level of stakeholder's communication and participation, this way providing for more sustainable solutions that have a wider acceptance.

All the above **highlight the complexity of their nature but also the transformative potential that these technological solutions** give to the urban projects of renovations. Many challenges are identified and still remain, but the benefits these solutions provide for broad utility of these solutions. Using the proper strategies these barriers can be overcome, this way unlocking the full potential of these technologies, this way leading to more sustainable and equitable urban development.

Recommendations

Enhance Hybrid Frameworks: Based on the above findings, we have several recommendations in order to guide future urban planning and sustainability projects. The integration of hybrid frameworks in urban planning, which combines methods that are quantitative like GIS, BIM and LCA with qualitative participatory tools, seems to give better results by achieving balance between us of technology and social inclusivity. The approach actually enhances the effectiveness of urban planning strategies, by ensuring that the different opinions are taken into account together with technical data in order to produce the best solutions. (Mert Ünal, 2023) It also emphasizes on the importance of using hybrid frameworks in urban design, to foster social value through transformational community engagement. Such a hybrid approach can ultimately lead to more sustainable and inclusive urban environments, as it allows for the incorporation of local feedback and values into the planning process. (Afieroho, et al., 2023) From the case studies we analyzed we can see this as evidence in Herrenberg Urban DT case that combined DT analytics together with public consultations, so it could achieve optimization of traffic management, while listening to the needs of the community.

Enhance Data infrastructure: For the support of the more advanced decision-making tools like Digital Twins, GIS based MCDA, we need to focus in utilizing high quality data collection and integration systems. It is pointed out that data infrastructure not only supports the provision of evidence based urban management solutions but also makes urban planning better in adopting community needs and adapting to environmental requirements. These technologies can be used in order to offer us a better understanding of the urban processes and also enhance management and planning through real time decision making. (McKenna, 2020) Using an example from the case studies we analyzed earlier in chapter 5, let's use Urbanistic planning Platform example, where the project used integrated data streams in order to enhance real time urban management and improve decision making process.

Foster public engagement: Encouraging public engagement is also crucial for effective urban planning. A focus on expanding the use of platforms, and using social media and gamification is encouraged for achieving better community engagement in the planning process. Using such tools can lead to better democratization of participation process, allowing for a broader range of opinions to be included in the decision-making process. This is really important in the context of smart cities, because of the fact that including diverse citizen voices can lead to more balanced and inclusive urban development projects and solutions. It is really important to ensure that the strategies used to empower engagement are focusing also on groups that are marginalized, so that the final outcome is as inclusive as possible, and taking into account everyone's opinion. (Suha Alawadhi, 2012) The most outstanding example on this is the Copenhagen #sharingcph initiative, that used social media to gather public opinions and build support for green areas development.

Promote capacity building: Capacity building among the stakeholders is important for the process of overcoming technical and also financial barriers coming with the adoption of these advanced urban planning tools. There are many enablers that can help overcome these barriers. A proposal can be gathering political support, strengthening laws and establishing more transparent governance structures as suggested by (Ganeshu, et al., 2023). Focusing on these stakeholders can enhance collaboration and improve the ability to tackle all these challenges in urban development projects. A good example here could be taken from GreenPocket Energy management Software where it shows that technical training was needed to maximize the benefits, we can have from using IoT in energy optimization process.

Focus on scalability of solutions: Scalability is really important also in the design of urban planning frameworks. In a paper by (Ceren & Ozkaya, 2020) they emphasize that the frameworks must be adaptable to various urban contexts, this way these can achieve successful replication to many different scenarios and settings. The adaptability part is really crucial also for dealing with the diverse challenges faced in different scenarios and cities worldwide, as this enables the planning team to tailor the solutions to local conditions, while taking advantage of best practices applied in other cases. One really good example is the Metrotaifun project that scalability was ranked really high due to the modular design it uses and the ease of adapting to different local needs.

The integration of theoretical frameworks from data analytics and participation, together with real world examples from the case studies, show us an encouraging path toward more **enhanced** and **inclusive urban management processes**. In our study we have explored some of the ways that technologies like BIM, GIS and Digital Twins combined with inclusive citizen engagement approaches, lead **to better, more efficient and more sustainable solutions** for urban planning and renovation. Although we noted all these advantages, we still have to deal with some issues, starting from data integration, inclusiveness and resource requirements that can impact our efforts for success. Dealing with all these properly can lead to better and more inclusive solutions that actually help in creating more sustainable solutions.

6.2 Implications for Urban Planning and Policy

Use of advanced technologies and participatory frameworks in urban planning process has significant effects for **policy development** and also **policy implementation process**. As cities continue to grow in size and evolve, they try to meet the challenges of creating more sustainable environments, be more efficient and build community engagement. Urban planning and policymaking must **be adapted accordingly** in order for strategies to adapt to the innovations and use them more effectively. In this part we will discuss on the implications of the theoretical and practical findings, we presented earlier, giving a focus on sustainable urban development, social sustainability, use of digital tools and the most important of all collaborative process in development and governance.

Sustainable urban development

Findings in this show the importance of sustainable development as a guide for successful projects and urban planning in general. Frameworks like **LEED-ND** (Leadership in Energy and Environmental Design for Neighborhood Development) perfectly shows how urban projects can be designed and implemented in order to promote more sustainable solutions for urban projects, by carefully considering of land and the environmental impact of the projects. (Smith & Bereitschaft, 2016) Standards must be a priority from the policymakers, so that they can

ensure that new developments can **actually have a positive contribution to urban environments and lead to benefits like community well-being.** A good practice is to integrate **sustainability indicators** into urban planning process, this way planners can have the data needed to actually assess the effectiveness of policies and projects that are implemented so that they can adjust them in the future if something is not quite as expected and provide more efficient solutions for future initiatives. (Braulio-Gonzalo, et al., 2015) This approach is really helpful and enhances accountability, and also fosters a method to achieve continuous improvement to the whole process of urban governance.

Social sustainability

This concept is being slowly recognized as one of the **most critical components** in urban planning process. The research shows that social **sustainability is a multidimensional variable** that includes: **community engagement, equal participation and thus social cohesion**. (Ghahramanpour, et al., 2013) Policymakers are required to make sure that the process of urban planning are both inclusive and participatory, this way providing a way for all diverse community voices to actually be heard. This way we can achieve **better decision-making** process that actually takes in mind the opinion of the many on urban design. This cam be achieved using participatory design practices like we studied in Hamburg's Serious games case, which used the citizens, and actively involved them in shaping urban environment. (Suha Alawadhi, 2012) Prioritizing social sustainability can help urban planners to create projects that really reflect the needs and values of the local communities, this way leading to a higher level of quality of the projects and the life of the citizens.

Digital tools and technologies

Using digital tools and technologies gave the urban planning process great new opportunities and also some challenges. GIS, BIM and Digital Twins facilitate data driven decision making, by enabling city planners and designers to simulate and analyze different urban scenarios in a really effective and realistic way. (Ismagilova, et al., 2019) Though success of these tools depends strongly on **how good the data we feed them with is**. Robust data infrastructure and also technical expertise is required to make these tools work as intended and give us results that we can actually use. Policymakers must invest in the process of training and capacity building initiatives to build the skill of urban planning team and stakeholders in order to effectively use these tools. Very important factor also is that digital platforms for public engagement can improve transparency and increase levels of trust between citizens and local governments, this way providing for a higher level of support of urban governance through a more collaborative approach. (Suha Alawadhi, 2012)

Collaborative governance

The findings in this area show how important collaborative governance is in urban planning. The main way to address the complex challenges, as all the studies show is to **engage as many stakeholders as possible in each project**. These can be government agencies, private sector stakeholders, community organization etc. and all are equally important in order to be able to create projects that are designed to tackle the complex problems we meet in urban areas. (Teodorovici, et al., 2022) **Multi-level dialogue and communication** among stakeholders is also important to ensure that all diverse points of view are considered during the planning process in order to create more equitable solutions, that everyone will use and enjoy.

Collaboration can lead us to better, more innovative and more effective solutions in smart city projects like the one we studied in Copenhagen case. (McKenna, 2020) Very helpful also is to create better and easier to use frameworks that can lead to better navigation of the complexities involved in urban planning, this way ensuring that both responsibilities and also interests are aligned among stakeholders.

Polycentric urban development

This concept offers a promising solution for **a better framework**, in order to address the problems created by urban density, and also improving transportation infrastructure. (Khasieva, 2021) Planners can **reduce congestion in the city and improve accessibility** of the residents, by **promoting development of multiple centers within urban settlements**. This way a reduction of congestion and enhanced accessibility can be achieved. These polycentric strategies in urban planning can be used to create more resilient and adaptable urban environments. This approach is in accordance with the principles of sustainable development and encourages efficient use of the land and resource management while creating more vibrant economies locally, this way enhancing socio economic outcomes together with creating more sustainable solutions for the projects.

Addressing environmental challenges

Modern cities face increased environmental challenges, mainly due to **high pollution levels** and **sudden resource depletion** due to people overcrowding the cities, leading to an urgent need for giving priority to environmental sustainability to all projects implemented. (Anwar & Sakti, 2024) Green infrastructure constructions must be a priority for modern smart cities, including parks, green roofs, better and more sustainable drainage systems etc. with the goal to tackle the impacts of urbanization on the environment. Also, some great tools to use include AI and data analytics into urban planning, this way enhancing the efficiency of resource management and creating more sustainable solutions for the projects. (Yigitcanlar, et al., 2020) Being more proactive, the planners are able to create better, healthier and more sustainable and livable solutions.

All the above findings lead to the need for a better and more **holistic approach** to urban development process. Giving priority to solutions with better sustainability, more social equity, focused on collaborative solutions, planners and also policymakers can achieve solutions that are more resilient and more inclusive that actually meet the requirements and needs of local communities. In this process using and integrating advanced technology solutions and participatory frameworks can be a crucial factor of achieving better navigation of the complex environment of urbanization problem. This way we can create better solutions for modern cities that are ready to face any future challenges and provide us with smart and sustainable projects.

Challenges and Limitations of Digital Solutions

As we stated in the previous part, using all the digital solutions in urban planning has great potential to enhance the process in all areas, such as participatory governance, improved decision making, and community engagement boost. But all these enhancements and tools have **certain limitations** and come with some **challenges** that need to be addressed in order to achieve their full potential. In this part of the study, we will explore some of the key challenges we spotted and are associated with the adoption of digital tools in the process of urban planning. We will use some extra material as references too, in order to provide more detail on the subject we deal with.

Digital divide and accessibility

This is one of the most important challenges of implementing digital solutions in urban planning. Digital Divide refers to the **disparities we find all the time, in the population, of access to digital technologies** among different socio-economic groups. It encompasses a wide range of factors from broadband availability, digital literacy, affordability of digital equipment, and finally but most importantly the actual capacity to use technology in ways that will enhance socio-economic outcomes. In this study by (Caragliu & Bo, 2023) they examined European smart cities and found out that there is a negative causal relationship, suggesting that higher levels of urban smartness, are always associated with a smaller intensity of the digital divide between urban residents. This shows that smart city projects can really have an effect on digital accessibility and participation and be more inclusive to the residents.

The lack of internet, or digital devices, or maybe the lack of knowledge on how to use them leads to the limitation or even exclusion of the marginalized communities from the process of urban development. This leads to **perpetuation of existing inequalities**, and also hurts the goals for better and more inclusive governance. In a recent paper by (Nechita, 2019) the author states that "while digital tools can enhance citizen engagement, they may also reinforce traditional barriers to participation if not implemented thoughtfully". This is why urban planners must give a priority to inclusivity, ensuring that digital tools are accessible and used by all community member, equally, regardless of their social and economic status.

Data privacy/security concerns

Digital tools use requires **collecting and analyzing vast amounts of data**, this alone leading to increased concerns about data privacy and data security.

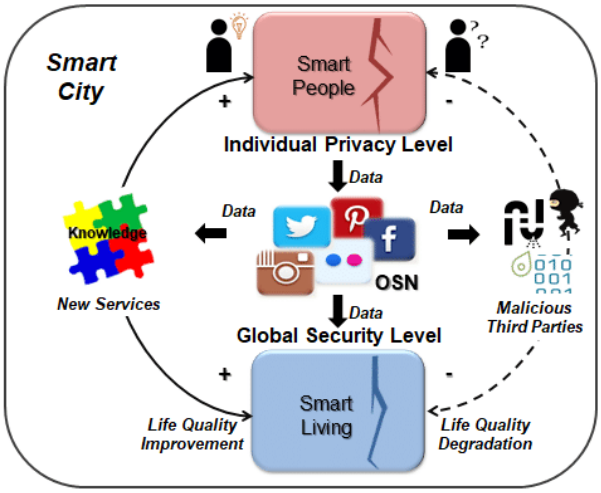

Figure 4 Smart City Data privacy vs security (Moustaka, 2018)

Citizens are **hesitant to engage** with digital tools and platforms because they tend to fear that their personal data could leak or be used in a non-proper way or even leak unprotected. This is very common in smart city initiatives where data driven applications are used, in order to achieve enhanced urban management. A recent paper and case study by (Fernandez & Schroeder, 2023) indicate that low-cost digital solutions can address urban challenges, but also need very robust frameworks on data governance in order to achieve and ensure that the data is being used in a responsible and effective way. **Clear guides must be created for data collection, data storage, and how the data is shared** so that we can achieve a higher level of trust among citizens and a higher level of participation as well in the urban planning processes.

Fragmentation of tools

A complex environment where **many applications and different platforms are used** in the field of urban planning, needing a bigger plan for creating a larger system, rather than using operational parts in isolation. The fragmentation of various applications and platforms operating in isolation, **creates challenges in data integration and also collaboration** among different stakeholders. As the study by (Degkwitz, et al., 2021) notes there is a **lack of interoperability between the different digital solutions** used, that can lead to hindering of effective use of them so this way crippling both planning and decision-making processes. Using integrated planning support systems is highly advised that facilitate data sharing between the various applications and tools, this way improving the final outcome and collaboration between the different stakeholders.

Resistance to change

Sometimes we encounter resistance to adopting digital tools and solutions in the process of urban planning and design. This either comes from the stakeholders themselves, because they are **reluctant to changes** of the traditional ways things happened, and also can come from institutions that **might not want the change**. Usually, this resistance comes from **lack of understanding** of the digital tools themselves, fear of loosing their job or even concerns about these new technologies and how these really work. As pointed out in a study by (Rönkkö & Herneoja, 2021) it is usual to face capability gaps as public administrations sometimes cannot use the digital tools in an effective way, which can lead to problematic and non-successful implementations of these digital transformation processes. Urban planners need to **engage in capacity building efforts** and processes so that they can **educate** all stakeholders on the use and also the true benefits of digital solutions. In order to address these challenges, urban planners must invest in building the capability of the stakeholders in using these digital tools, and also encouraging their widespread use in all projects.

Quality of data

Digital tools can really enhance data collection and analysis, but these also raise concerns for both **quality and reliability** of the data. The massive amounts of data created with using digital platforms can really lead to information overload, creating a problem that most urban planners cannot deal with, this way making them unable to extract any meaningful insights from that data. As stated in the paper by (Stéphanie Hasler, 2017) the success of the participatory processes, is usually **taking data quantity as an indicator instead of data quality** or the impact this had on decision making process. Robust data management practices must be developed and take place to ensure on the accuracy and relevance of the data collected, this way enabling more effective decision-making processes.

Evaluation of digital participation

One more variable that is really hard to evaluate is **digital participation**. There are challenges associated with integration of both **qualitative** and **quantitative** data that can lead to complications in the assessment of participatory processes. (Billger, et al., 2016) There is a need for **clear metrics and also evaluation frameworks** that will capture the **impact** of digital engagement on decision making and also the community outcomes that derive from that. This must not only consider the number of participants but also the quality of their contributions to the project and decision-making process and also the extent of their influence on the actual outcomes and planning decisions. This way a more transparent and effective engagement will be taking place and will lead to increased levels of participation in the future.

Conclusion

Digital solutions offer many significant benefits in enhanced urban planning and fostering of citizen engagement, these do not come without challenges and some limitations. As a starting point, issues that relate with accessibility, data privacy and quality, fragmentation of tools, resistance to change are essential in order to achieve better overall digital tools effectiveness and performance in urban planning. Urban planners should adopt a broad proactive approach with these challenges, this way ensuring that digital solutions and tools are implemented in a way that is effective and gives results, by promoting inclusivity, transparency and also helping in creating meaningful participation in the planning process.

Future Research Directions

Integration of digital solutions in participative design and scenario modeling for urban building renovation, is a very promising area for study that will help future projects achieve enhanced sustainability, improved health and also socio-economic outcomes. Cities will continue to expand and try to achieve higher levels of smartness in order to become more resilient and manage to overcome the challenges that accompany urbanization. There are many areas that make use of **advanced technology and use data driven approaches** that lead to better results as we studied in this paper. In this section we will expand on the potential research directions based on the existing landscape and solutions out there and the new emerging technologies and trends. We can split these directions to categories:

Integration of Immersive Technologies

In most case studies we analyzed **we didn't see a lot of cases using AR/VR technology**, that really enhances user interaction with the projects and boosts their actual perception of the final results in real time and also **improves engagement overall**. Future research should be focused in how these technologies can further enhance urban planning process and what more could be these used for on this area.

For example, research could explore how effective these technologies are in various different scenarios, like workshops, public consultation sessions etc. A great area for further study also could be the actual engagement enhancing of these technologies. We could measure the level of engagement before and then measure again after implementing and using it in the process of participatory design. Also, a great measure of effectiveness is to gather **user satisfaction** from using this new technology and the impact this has in the outcomes for the design process.

Data Driven Decision Making

Real time data can be very helpful in understanding important metrics such as energy use, environmental impact, social dynamics, that can lead us to better decision making if we decide to use these and use them effectively. Future research in the area should concentrate in the **establishment of frameworks on how to incorporate real time data** in participatory design processes. Developing of **decision support tools that integrate real time data analytics** in also important. We can use and evaluate case studies were data driven approaches have been successfully used and implemented in order to assess their impact on the project outcomes. This way we can create tools based on existing successful practices and be able to use these in future projects that will benefit from them.

Resilience and Sustainability

Further investigation is also required on how digital solutions can **enhance climate resilience** in urban planning. Since every city is facing climate change and climate related challenges, we should focus future research on how these new tools can facilitate assessment of climate risks and how these actually help the planners to deal with the challenges related to climate change using adaptive strategies. A more detailed view on projects that examine the effectiveness of digital solutions in enhancing resilience is suggested and also the development of scenario modeling methods that have **climate resilience as a core component** in order to achieve projection of possible impacts to the actual performance of the projects of urban development and renovation.

Socio economic Impact

During this study and the analysis of many use case scenarios we noticed a **gap in the assessment of impacts** of the projects using digital tools in the **socio-economic area**. Understanding the impacts is really important for the community itself and its member, especially the more vulnerable ones. Research must focus on developing methods for assessing these impacts in a more comprehensive way for planners to study and decide upon the solution that must be followed in order to avoid any unwanted results in the project.

Collaborative Governance Models

An extensive examination of the role of collaborative governance models in facilitating stakeholder engagement in the process of urban renovation is also highly recommended.

Collaborative governance gives **emphasis to inclusivity** and also shared decision making process among the different stakeholders which is a cornerstone for success of participatory design process. Identifying **which practices are better** for implementing the collaboration process in urban renovation projects is crucial for better and more inclusive decisions and results. It would be a good idea to analyze different governance models and identify the factors that play the most important roles to contributing in successful engagement of the stakeholders. A need for better guidelines for future use in projects is also suggested and must be studied further.

Conclusion

The integration of digital solutions in the process of participative design and scenario modeling for urban building and area renovation offers great potential. Potential for better sustainability, better health and well-being, and also improved socio economic outcomes for the local population. Future research must focus more on use of immersive technologies as these really show potential for greatly improving engagement of stakeholders.

Leveraging immersive technologies, real time data analytics, socio-economic impact assessments and also resilient strategies and collaborative governance models will lead to better overall projects that are really impacting our environment and living in the best way possible. By addressing all the above research directions, the different stakeholders can deal with all different complex problems that come with urban renovation process in a better way and create solutions that really benefit all community members.

Figure 5- VR in smart city development (freepik.com, 2024)

Discussion on Smart Urban Renovations Projects in Europe

Smart urban renovation projects are leading the wat towards making cities in Europe greener, smarter and also more inclusive. These projects are trying to **deal with some of the biggest challenges that we face worldwide**, including climate change, energy challenges, and participation of citizens. Across Europe many cities are already leveraging these new technologies, innovative design principles and the participatory approaches, in order to create projects and solutions that meet the needs of the local communities and also help in creating more sustainable urban environments. In this section we will discuss on the ongoing projects across Europe, their objectives and also their **alignment to the findings of our study**.

The **key objectives** of the European smart urban renovation projects at this time are:

1. **Energy efficiency and green transformation**: The projects main aim is to reduce energy consumption and minimize energy waste, promotion of renewable energy sources and also through this the alignment of the cities with EU climate neutrality goals. This is based on the European report on Smart Cities (Auditors, 2023)
2. **Sustainable urban renovation**: One more important area that the projects deal with is the sustainable urban renovation process. Development of holistic models that really support inclusive decision making, lead to wider scale projects that are more sustainable and allow for improved city transformation process. This is based on the EU research results located in (CARTIF, 2020)
3. **More focus on Citizen Involvement in the design process**: Engagement of citizens in the process of planning the projects, making sure that the projects address their needs and desires and enhances the results of them, providing more sustainable and with better quality solutions. (CARTIF, 2020)
4. **Focus on mobility and public transport**: There is a great focus on better and smarter transportation systems, that aim to improve mobility and also reduce environmental impact it. (Auditors, 2023)
5. **Creating Innovative Citizen services**: Using advanced technology to provide for better public services expanding from education, to healthcare and also public safety. (Auditors, 2023)

There are many good examples of European ongoing projects are in progress. Some that really stand out are:

- The Ellinikon Project: One of the most promising projects in Greece that transforms the former airport into a smart city, featuring all the latest technology and focusing mainly on green infrastructure and sustainable development. (Glover, 2024)
- Paris, France: The 15-minute city concept is being implemented, that will ensure all essential services are within range of each citizen regardless of the area he lives in, this way improving urban life and making the city more sustainable. (Wikipedia, 2020)
- REMOURBAN (Regeneration Model for Accelerating the Smart Urban Transformation): This project is being implemented in Spain, UK, Turkey and focuses on large scale interventions, that includes the renovation of buildings in large scale and also the use of electric mobility in large scale. This project aims in creating a sustainable urban regeneration model that aims for large scale renovations and transformations of urban environments. (CARTIF, 2020)

- EU-GUGLE (European cities serving as Green Urban Gate towards Leadership in sustainable Energy) Cities of Vienna, Aachen and Milan aim to renovate residential buildings in order to reach net zero standards. This project's objective is to demonstrate how feasible it is to create zero energy buildings in smart urban areas, this way promoting greener solutions that will help in creating more sustainable buildings and enhancing the energy grid resilience in the cities. (Greenovate, 2024)
- Euromediterranean: This is an urban renewal project that aims to create an eco-district in the La Joliette district, that takes advantage of EU's first geothermal marine power station for the energy needs. The main objective is to transform urban areas into more sustainable ones, using both new technologies and green technologies for energy production.

Conclusion

All the above projects show **the commitment of Europe to smart urban renovation process** that focuses more on **sustainability, energy efficiency, and improved quality of life**. These findings are **aligned with our study findings, that show both advanced technologies and citizen participation are crucial for success in smart urban renovation projects**. Barries exist but these innovative approaches give potential solutions and validate the insights of our study and offers us with more practical models for overcoming these challenges, this way helping out in bridging the gap between theoretical foundation and practice in the process of urban renovation.

6.3 How did the Research Questions get their answers

In this section we will point how the research questions are being answered in this thesis:

RQ1: How can immersive technologies, such as virtual and augmented reality, be effectively integrated into participative design and scenario modelling for urban building renovations to enhance sustainable energy solutions, health outcomes, and socio-economic impact assessments?

The reply to this question is initially found in practical findings in 3.1.3 where the solutions using immersive technologies are presented and 3.1.8 where we present the logic behind the variables used for grading the solutions to answer RQ1. In part 4.3.4 we present the solutions studied in theoretical part of this study where VR/AR technology together with AI are used in many successful scenarios presented there. All the information from these parts of this study provides for a proper answer to this RQ.

RQ2: What are the impacts of immersive digital solutions on energy efficiency, health outcomes, and socio-economic factors in urban renovation projects?

The impacts of immersive digital solutions in the different areas are presented in part 2.2.1, 2.3.5, 2.3.6 and 2.6. Also, part 3.1.3 that provides us case studies from our research that show these impacts. Chapter 6, 7 discusses all the findings together of the smart city projects.

RQ3: What are the benefits and challenges of using these digital solutions?

This question in answered with example projects in 3.1.3. In part 3.1.6 our logic behind rankings is explained. And chapter 2 explains the theoretical background of all involved solutions. Chapter 6 also provides the summary of challenges. The discussion provides for the results that these benefits have and also give some suggestions on how to deal with the challenges.

Chapter 7: Conclusion

7.1 Summary of Key Findings

This broad review, of smart city solutions discussed in this thesis, has revealed many patterns and insights about the theoretical background and practices that are used in the projects. The findings from our research show the important role that data plays in the creation of the projects and the data driven technologies used to achieve their goals. It shows that the use of frameworks for sustainability and stakeholders centric approaches give solutions and address many of the challenges presented in the urban planning process. In this section we will analyze further the synthesis of the distinct areas and themes we studied and try to explain how these are related to the success of the solutions and their actual impact on them.

The result matrices created summarize all findings and give an extensive overview of factors that affect the various different scenarios and projects we studied and we chose for the literature review. There we can read upon the details of each project, compare the results and different metrics about the project and also have an analysis of its impact according to our study of the material provided for each one. Overall, there are two key areas identified from our research that is summarized in:

The transformative Potential of smart City projects: All the different technologies we studied in this research, offer us with pathways for dealing with some of the most common and important to be dealt with urban challenges. Many uses at their core, the power of data and automation in power, waste, resource management. Examples like Virtual energy Audit, Metrotaifun demonstrate both the feasibility of the solutions in actual environments but also the adaptability across different contexts. True impact of these solutions goes well beyond operational efficiency as the main priority is sustainability and also community well-being, these solutions provide and contribute to a **much broader vision** that cities are much more dynamic and inclusive were technological innovation and environmental sustainability are both important for successful implementations of the smart city projects. Decarbonization as a Service is one great example on how urban systems can align with global sustainability goals, helping in achieving net zero emissions and more inclusive and circular economies. In another example, we can see a really impressive percentage of 40% reduction in landfill waste and also improved efficiency and reduced traffic used in Metrotaifun project, achieved with IoT driven automation. In other case studies we saw reductions in traffic of up to 20%, using Digital Twins, that also helps in a lot in cases of highly congested areas.

Need for collaboration and policy Support: Also, really important finding was the **critical role of collaboration** among different stakeholders for the success of the projects. A collaborative work is required in order to **achieve the transformation drive** required for the urban systems we studied. Cooperation and collaborative design were of great importance on the success of the projects and helped a lot in creating this sense of ownership among the stakeholders. **Public private partnerships** are very important too in order to achieve shared goals, like resilient solutions that are also sustainably developed. Equally the role of policy in facilitating the adoption of smart city technologies is very crucial. Proper regulatory frameworks must be developed so that these can support innovating solution while protecting privacy, security, and ensure equity too. Also, all of the projects studied required robust frameworks on data privacy and security, which will boost the trust of the citizens in them.

The findings of the study **strongly align with United Nations Sustainable Development Goals** (SDGs). Proving how digital technologies and innovative frameworks can be used to contribute in achieving more sustainable solutions for the urban environment. We can expand on a few examples to showcase this statement. (Nations, 2024)

SDG 13: Climate Action-Take urgent action to combat climate change and its impacts

Starting with Beesmart case studies, Decarbonization as a Service Project, this initiative uses AI, BIM and IoT to track and reduce carbon emissions for buildings. It does Carbon footprint assessment, provides tailored decarb strategies, does monitoring and optimization, helping in achieving an up to 20% reduction in energy use and lowering carbon footprint of urban infrastructure.

How does it align with SDG 13: With the proactive approach this solution offers, it aligns perfectly with this goal and provides tools to monitor and help in mitigating climate impacts in a larger scale.

Rotterdam LCA renovation also adds to this goal by providing an up to 30% reduction in carbon emissions, using LCA method to optimize material choices and use and also reduce the produced from the process waste. It evaluates the environmental impact of the process of construction for a building, reducing the GHG emissions and also promotes more resource friendly practices in urban renovation process.

Using and also scaling solutions like the previously mentioned, can really amplify their impact to the environment, and can make a significant difference in helping us meet the cities climate goals targets.

SDG 7: Affordable and clean Energy

The goal in this one is to ensure that all have access to affordable, reliable, sustainable energy for all. Many cases we studied try to do this and succeed. For example, Greenpocket Energy management Software project uses AI and IoT to optimize energy consumption. This helps in achieving a 25% reduction in peak hour energy usage and reduces energy waste. It promotes also the efficient use of energy this making in align with SDG7. Virtual energy audit is also a project that enables low-cost energy efficiency audits for buildings, trying to make energy saving technologies accessible to everyone. It kind of democratizes access to these energy efficiency tools providing for the affordability and sustainability aspects of SDG7.

SDG 11: Sustainable Cities and communities

The goal is to make cities more inclusive, safer, more resilient and also more sustainable. This has many scenarios that stand out. Some include Copenhagen's #sharingcph which is leveraging Instagram and social media to achieve higher levels of participation in sustainability projects taking place. How this aligns? Social media boost the engagement process, giving the power to more people to actually input their ideas and take part in the decision-making process. This aids in the inclusivity and expanded resilience of the local communities.

In Metrotaifun case the project helped with the automatic waste collection system, to reduce traffic congestion caused by garbage trucks and reduce waste, thus aiding in a more sustainable urban environment which is core element of SDG11.

SDG 10: Reduced Inequalities

The goal is to reduce inequality within and among countries. Projects like Scotland Place Standard that empowers communities, that are usually left out, to actually participate in urban planning decisions with the use of workshops. How does this align? Including many different voices otherwise not heard, this project aims for SDG10 goals, by ensuring equity in urban decision-making process. One more example was the Herrenberg Urban DT project that used a combination of digital twin to enhance urban energy management, together with integration of feedback that came from different community groups giving feed. How this aligns? The creation of this inclusive process where all citizens could contribute to the decision made, helps in reducing inequalities and directly aligns with SDG10-equitable access.

SDG 12: Responsible Consumption and Production

The goal is to ensure sustainable consumption and production patterns. Projects such as Preoptima Concept use BIM and LCA, and with their platform enable planners to minimize material waste while the building is in construction or renovation process. How this aligns? Optimizing resources is supporting SDG12 and reduces environmental impacts that are associated with the process of construction. One more project example is Arqlite SPC. This is a circular economy projects that converts plastic waste to sustainable building materials, that way is removing all this waste from the landfills and actually making a good use of it. How does this align? Its promoting resource recycling and this way reducing waste. It addresses the aspects of production and consumption within SDG12.

Integrating all these technologies shows that all of them have clear alignment with multiple SDGs. All the projects have measurable environmental and also economic benefits and most actually foster higher levels of inclusivity and community engagement, adding to more resilient solutions. In order to move forward to the future, we need to scale these solutions up and address the various barriers that we see, in order to maximize the contribution to the SDGs and help us build more sustainable and efficient solutions.

7.2 Contributions to Knowledge

Data-driven systems as the backbone of Smart Solutions

Many of the use cases had real time data and analysis of that data as a backbone to the solution itself. The critical role of the data was in establishing more informed decision making that led to better choices for the actual project implementation. In solutions like AmbiAir and Virtual Energy Audit this is shown in great length as real time data is used and plays a critical part in improving energy consumption, air quality and also operational efficiency this way leading to more sustainable solutions for the projects. Cyber-physical systems and IoT models and architectures use feedback mechanisms for adaptation, and this is validated with practical applications. Data driven systems enhance the operational efficiency and provide insights for the preventive management of the resources used. This way these help in a great degree with performance, sustainability and also reliability of the projects and solutions implemented.

These solutions studied align with the systems theory, where it states that feedback loops between inputs and outputs can lead to creating more adaptable systems. This approach is also working well with IoT principles, that prioritize interconnections between sensors and devices and this way provides for better and more responsive reaction to changing conditions.

Future potential research can focus on AI driven systems, like the ones envisioned in Decarbonization as a Service scenario we studied, that have great potential in combining multiple data streams. These can be combined to make better and more precise and sophisticated decisions, pushing outcomes and projects in net-zero targets, leading to the most efficient and sustainable solutions possible. (Sarker, 2022)

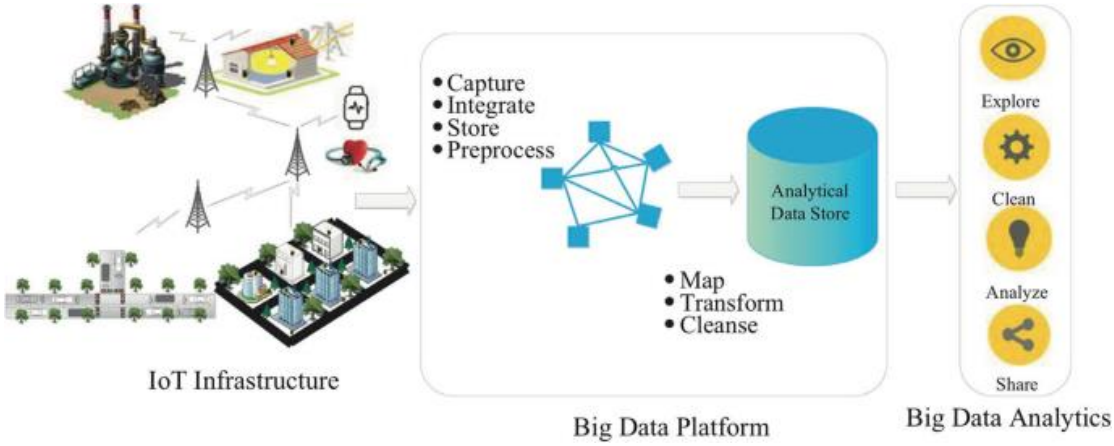

Figure 6 Big data analytics (Bibri, 2023)

Sustainability as Core Design principle

Sustainability in nearly all cases and solutions studied plays a core role. This comes in alignment with frameworks like UN sustainable Goals (SDGs), Paris Agreement and demonstrates their commitment in reduction of environmental impacts. Some examples studied focusing more on sustainability are Arqlite SPC and Decarbonization as a Service. These show us how we can embed sustainability factor into operations, for example in Arqlite SPC they focus into transforming non-recyclable materials and plastics into lightweight, very durable building materials, this way achieving to implement a circular economy model that takes waste from landfills and also reduces the carbon footprint of the actual construction. In the other case Decarbonization as a Service offers tailored strategies to lower emissions by integrating renewable energy solutions and also improving energy efficiency.

Both these projects are based in theories of resource optimization and lifecycle analysis, and also underline the importance of waste reduction and minimizing carbon footprints. The outcomes that both gives are very important and show a significant reduction in carbon emissions and provide measurable outcomes. For example, in another similar case study, Encompass Blue the carbon emissions were reduced by up to 70%, with optimization of energy usage and also integration of renewable energy sources.

Figure 7 Sustainable Smart City (Bouzguenda, 2019)

Stakeholder and community centric approach

Community engagement and stakeholders' cooperation is vital for any smart city project and the success of it. Many of the solutions actually prioritize user-friendly designs and participatory approaches in order to ensure better adoption and sustainability for the solutions. Good examples are Talking Wastebins that use audio feedback, to make proper waste disposal by engaging with the community members in order to achieve a behavior change. This solution is really effective in public spaces, trying to reduce litter and promoting a more sustainable and responsible waste disposal process. Another solution, Cobundu, helps in enhancing workplace efficiency by monitoring the actual space utilizations and indoor air quality, in order to help with creating more comfortable spaces for the occupants and helps building managers in optimal layouts.

All the above are supported by current theory in participatory urban planning. All underline the importance of user engagement in creating a better system overall and a better and more sustainable environment.

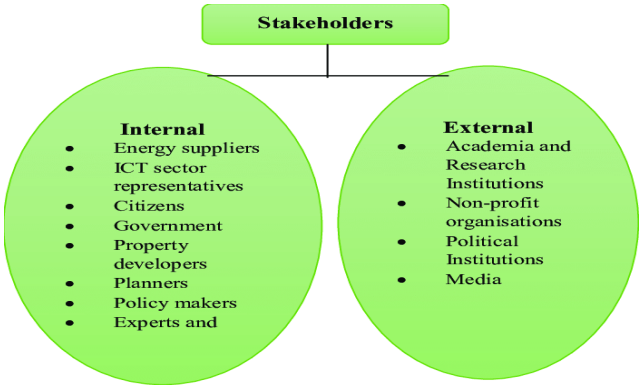

Figure 8-Stakeholders (Jayasena, 2019)

Interoperability and Scalability

Interoperability and scalability were the core design feature for platforms like LORIOT LoRaWAN network Server and bGrid and these highlights how important is to be able to have compatibility across different systems and hardware. These attributes are in alignment with theory, that emphasizes in modularity of urban ecosystems, allowing them to be more adaptable to various evolving technological and also infrastructural demands that arise. Also, really important fact is that scalable solutions enable us to do gradual deployment of the solutions, this way helping to reduce economic barriers that might be blocking us from a full-scale integration. Modularity leads to better designs and easier to control systems as we can control locally and deal with local issues more effectively.

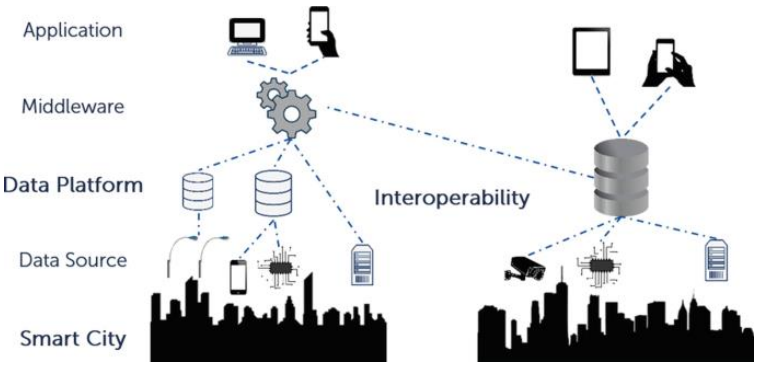

Figure 9- Interoperability (Buchinger, 2021)

Cross sector impacts

All the solutions studied deal will many critical challenges across multiple different sectors. These include energy management, waste reduction, air quality improvement and also urban planning process.

Projects like Greenpocket and Virtual Energy Audit provide us with enhances efficiency with actionable insights, this way reducing costs and also emissions. Metrotaifun and Arqlite SPC use innovative methods for collecting waste and also reuse plastic waste by recycling materials, this way both deal great amount of impact in the environment and also give operational benefits. Air quality improvement was implemented in AmbiAir and AuraAir provided healthier indoor living spaces and environments, this way improving overall public health. Tools like Sustainaccount and Urbanistic Planning Platform give data driven support for a more sustainable urban development, emphasizing more on resilience and also environmental sustainability.

Challenges identified

All the solutions studied were really impactful and transformative, but the reality is that many challenges still remain to be solved or minimized at least. Main categories we identified in all the projects came from:

- Cost Barriers: A high initial investment was required that might be the main reason of limited adoption, especially in cities with a tight budget
- Integration Challenges: Old implemented systems may pose obstacles to integrating newer ones, and might need very extensive adjustments and upgrades to be able to adapt to the new ones.
- Data Security and Privacy: Robust mechanisms are needed in all cases where data is collected in real time, so that we can protect sensitive information from unwanted access and misuse. Data Security and Privacy is also a reason for people avoiding to join smart city projects development as they tend to fear data misuse and data leaks.
- Public acceptance/Adoption: This is also really important factor that needs to be addressed with more participative design in project planning process. Involving the public will lead to a sense of ownership, this way helping in accepting the change that the project will implement.
- Maintenance Costs: This factor is important in cases we need extensive maintenance that can lead to even higher costs. This is really prohibitive for tight budgets and can lead to projects failing if the maintenance is not properly performed.
- Regulations: All projects need to be within regulations and comply with them. Regulations are of high importance since the projects might be declined before even starting if their parameters are not within regulations. A careful study and creating a compliance of the project with these is highly advised.

Addressing all the above challenges requires most of all collaboration from all stakeholders and also using policy that actually supports changes and helps these develop.

7.3 Recommendations for Practice

In this part we will expand on the main observations we did regarding the areas that need our attention in the future. The main areas identified that need more development and can really make an impact on future projects are:

- AI and machine learning can really have a great impact on predictive analytics, this way allowing the actual systems to address challenges in advance and be more resilient towards sudden changes. For example, AI can predict energy need spikes on the grid, and redirect excess power to that area. This way we prevent the system failing to respond to this energy spike and leading to a temporal shutdown.
- Renewable energy sources are the best solution for integrating in all future project of urban building renovation and development. Smart systems together with renewable energy sources lead to drastic reduction of carbon emissions and also gives more independent buildings that rely on their own power production in case there is a power cut in the area. Also, the excess produced power can be redirected to areas that need it and thus make the whole city grid more reliable.
- Creating standardized protocols and common practices for IoT and smart city technologies could really lead to better and faster integration of solutions and help in ensuring that these are interoperable and easier to adapt to the urban environment. As we saw in Urbanistic project, a need for open-source platform is rising to address all the interoperability issues that arise.

  Using successful implementations and common practices from various projects can help in creating something like an implementation guide for the future projects. Splitting projects into sectors, identifying their effects on the environment and rank how successful these are can really help others with similar needs, to implement solutions that will be successful. Also, very good practice would be an effort to rank them for economic viability or total cost according to project size so that cities with tight budgets can really make their mind if they can try the implementation of the projects in the future or not.
- Modular technology implementation: Scalable and cost-effective technologies must be developed further in order to help budget constraint cities to use them and expand as much as possible in these. Solutions like Virtual Energy Audit, that provides improvement of energy efficiency, without breaking the budget with the financial requirements.
- Improvement of Citizen Participation: Inclusivity is the key to success for all projects. Combining participatory platform with gamification for example could lead to higher levels of engagement from younger ages. More people participating always boosts the quality of the final project and it certifies that it meets the needs and requirements of the local community. A focus on more simplified and easier to understand, and use tools is also required for the more marginalized parts of the community. This way we can achieve better levels of inclusivity.
- Capacity building for the Stakeholders: Training programs for stakeholders and the respective decision-making parties, must be implemented in order to make full use of the innovative tools like BIM and Digital Twin. Improving technical proficiency and capacity in using advanced tools is a priority in order to make full use of their capabilities. Examples like Decarbonization as a service project showcase how important it is to have governance support in achieving the goals of the projects.

7.4 Final Thoughts

The synthesis of the results proves the alignment of smart city solutions with the existing theory and practical implementations. Using data and data analytics, giving priority to more sustainable solutions, implementing meaningful stakeholders' engagement, all the projects we have studied are trying to address critical urban challenges in an effective way. Advanced technologies being used and demonstrate how these can deliver tangible benefits, ranging from emissions reductions, energy savings, better public health and environment and also cost savings, all leading to more resilient and sustainable solutions and projects.

Technologies like BIM, GIS, Digital Twins are revolutionizing urban planning and enhance sustainability efforts, but all deal with the same persistent challenges that require our attention. In this section we reflect on the observations and offer some comprehensive recommendations on how to improve the different aspects and address the limitations that derived from our research on the various projects.

Role of Data integration and interoperability: The recurring theme in the above analysis is the nature of data systems that at this point in time and as research shows is quite fragmented. Many tools take advantage of data integration but face significant challenges in data harmonization from different sources leading to problems in implementation of the projects. We need a better standardization to overcome this problem and stop using ad hoc solutions that do not solve problems in interoperability as efficiently as a standard version for all data would do. We also notice a need for robust data governance frameworks, this way we can achieve better integration and sharing of data among the different stakeholders, allowing also for more security and better integrity of the data. Open-source platforms could be a proper solution to this so that different tools can be used together with no problems in communication. By adopting all the above we have solutions that are consistent, can lead to faster decision-making processes, and with proper training for the team managing the vast amounts of data we can really find solutions to the complexity that it comes with it.

Financial constraints: One of the most significant barriers to the wider adoption of the digital tools in urban renovation process, has to do with the really high upfront cost that some projects have to deal with. Higher costs usually mean the solution is a struggle to achieve funding for smaller budget municipalities, but here we see that public-private partnerships (PPPs) can really help in such situations. Also really helpful is to use funding from European Union as a solution so that under resourced municipalities can handle the high costs of an innovative and effective project for their urban development. Another solution is to use pay-per-use systems so that the project can be more affordable for the municipality to implement in their projects.

Digital Divide: A really important issue in the undermined effectiveness of the digital tools because of the unequal access to technology and the limitations in the actual knowledge to use such tools. This phenomenon limits the inclusivity in the efforts for more inclusive solutions, and also creates alienating effects in vulnerable parts of the community. A need for simple, user-friendly digital tools, that are easy to use is a priority for all projects. A good solution is to use community technology workshops and hubs that provide the necessary tools and education for everyone to be involved.

Enhanced stakeholder engagement: This is also very critical for success of projects. Participatory approaches must be used with tailored to each project strategies. Cultural and logistical aspects must be taken into account, in order to achieve meaningful participation, leading to positive project outcomes. A solution that seems to be working effectively is the use of hybrid approaches, using the digital platforms in addition to use of in person workshops can provide for higher levels of participation. Easier involvement of groups that are otherwise marginalized seems to be achieved with this strategy. Very important also is the sense of ownership created to the stakeholders by applying these participatory techniques.

Scalability, Replicability of projects: Many of the projects we studied have great potential for scalable solutions, but as we observe this is often limited by resource availability and also policy related constraints. In order to achieve more scalable projects, the future implementations must try to become more modular, using modular frameworks, so that these can be more easily adopted to the various urban contexts. Using methods of collaborative work between municipalities, sharing resources and expertise on the projects, can really make a difference in the actual success and scaling of the solutions. Academic institutions and technology providers can be also a good alternative to promote the scalability of projects as these can support in the development of scalable versions of the projects that address the problems met in the current scenario of implementation.

Policy and support: In order for solutions to be successful, a supportive environment is needed that provides for better collaboration and promoting innovation. Progressive policies that boost sustainability goals can really accelerate the use of digital tools and advance projects that are based on them. Regulatory hurdles can really cripple the efforts for a project to be successful and limit the actual effectiveness of it. Policymakers must develop flexible and adaptive regulations that will lead to better and innovative solutions being implemented. Collaboration can bridge the gaps between the stakeholders and viable solutions can be implemented effectively, giving better sustainability and creating a healthier ecosystem.

Practical Implications

There are many different implications for the various categories of stakeholders. The main points we identified from this study that they need to focus more on are:

Policymakers:

- Give priority to funding on scalable and modular technologies, in order to make these more accessible to lower budget cities
- Develop the foundation for creating public private partnerships, so that the financial barrier can be overcome. This will help is expanding the use of technologies such as Digital Twins and BIM which are resource demanding.

Urban Planners and Designers:

- Must make more use of hybrid frameworks that combine quantitative tools such as GIS and LCA with more qualitative participatory methods. This way they can create a balance between technical data and community input and feedback.
- A higher focus on tailored solutions to local needs must be used. Using global case studies for reference and guide, adjusting these to the local requirements.

Technology Creators:

- Create tools that are simple to use, with simple interfaces and improved accessibility. Tools like Greenpocket is a good example
- Develop standardized protocols to solve the interoperability problems we saw in many of the studies.

While the findings are really promising for the future projects, many barriers still block the wider adoption and implementation of these advanced technologies. Scalability of the most promising ones like Digital Twins, has many challenges expanding from financial constraints to infrastructure requirements. Resource limitations also hinder the adoption since many high-end solutions require a robust digital infrastructure which is not available in regions that are not developed. For example, some projects have high energy needs that can offset the environmental benefits thus need to be balances with renewable energy sources, like we say in AuraAir project. Digital divide is also one of the most important obstacles, especially when we have to deal with marginalized communities. Ways to bridge the divide with targeted actions must take place, such as workshops and educational programs.

The opportunity for us to reshare the future of our cities in a more sustainable and inclusive environment is within our grasp. Using all these innovative tools, fostering proper collaboration that is inclusive, we can create future cities that are both efficient and equitable, resilient and also in perfect alignment with the aspirations of the communities.

Note!!! The results shown in the tables are included in an excel file showing everything we include in this thesis in more detail. LINK TO GOOGLE SHEETS

https://docs.google.com/spreadsheets/d/e/2PACX-1vQtNpSoEKXTeLIQWxEJ7MAXZRMWfcUYLv8EEN7ElLejJiUrK31YlDg85K3tUQnE6dHCLoKEkaeRtyO0/pub?output=xlsx

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