MASTER

Early integration of a sustainability assessment tool to aid decision making processes in urban (re)development projects

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Early integration of a sustainability assessment tool to aid decision making processes in urban (re)development projects

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Preface

In my immediate environment, numerous urban development projects are either in progress or in the final stages of planning, just before physical work begins. Having being involved in the redevelopment of Fuutlaan, a redevelopment project involving just a single street, I witnessed firsthand how slow and unstructured urban development processes can be. At times, it seems as though municipalities take a somewhat ad-hoc approach to urban enrichment, renewal, or development. Given that my core values are efficiency, optimization, and sustainability, it became clear that the idea of optimizing urban development in any form would serve as my starting point. Reflecting on these values, I believe there is significant room for improvement within the construction sector. With this realization, I began exploring topics that would inspire and challenge me, ultimately leading to the development of a research project that is both demanding and enlightening.

To pursue this, I started by reviewing academic literature on urban renewal. It quickly became apparent that while many assessment models exist, they are typically developed or evaluated retrospectively, based on data collected after the fact. In my view, there is little to be gained from improving or optimizing a project only after its completion. This insight led me to focus on academic work aimed at optimizing processes during the development phase of urban projects. Wanting to align the subject matter with something closer to my heart, I chose to incorporate one of my other core values, sustainability. Throughout this process, I found that there is a lack of academic research focused on sustainability during the development phase, which became the central focus of my research.

This focus naturally led to my choice of first supervisor. Dujuan Yang's expertise in the integration of data use within spatial environments, combined with sustainability, made her the ideal guide. Her academic knowledge was invaluable in shaping the direction of my research, and she provided vital support throughout the process. For my second supervisor, I sought someone who could help me consider the human dimension of the topic, while guiding and challenging my approach. This led me to Theo Arentze. Both supervisors granted me the independence to work autonomously, allowing me the freedom to define how I wanted to structure and execute my research.

The primary objective of this research was to determine whether it is possible to optimize urban development processes through the early integration of sustainability-focused assessment models. This topic had not been sufficiently explored in the literature, and I am proud to have delved into this uncharted niche and completed the research with positive results. The findings suggest that urban development processes would greatly benefit from models that provide dynamic, suggestive feedback on sustainability performance throughout the design development stages.

Finally, I would like to extend my heartfelt thanks to my family, friends, housemates, and teammates for their unwavering support. But more importantly, they ensured that, throughout this entire journey, I still found time for what I hold most dear; enjoyable moments of leisure, often with a cold beer in my hand! THANK YOU!

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SUMMARY

Urban development in the Netherlands faces growing pressures to meet sustainability objectives, particularly in the context of housing shortages and the transition to a circular economy. The Dutch government has set ambitious goals, including building one million homes by 2030 and achieving a fully circular economy by 2050. This has created challenges for urban planning, especially since construction on greenfield sites has been restricted. Given these constraints, there is a pressing need for more structured, efficient, and sustainability-focused approaches to urban redevelopment. This thesis addresses this need by developing a decision support system that integrates sustainability assessments early in the design process, using the DGNB UD framework as a model.

The thesis begins by exploring the limitations of current urban development practices, which often lack pre-emptive sustainability assessments during the planning stages. Existing tools, such as the DGNB UD, are typically employed after project completion, which limits their ability to influence design decisions in real time. To address this gap, the research aims to develop a decision support system that provides continuous feedback on sustainability performance throughout the design process, allowing urban developers and planners to make informed adjustments early on.

The research questions guiding this thesis focus on how urban redevelopment projects can be evaluated and improved during the design phase to result in more sustainable and higher-quality urban spaces. To answer these questions, the study first reviews the state-of-the-art sustainability assessment tools currently available and examines how they can be adapted for in time assessment during project (re)development. The DGNB UD tool is selected as the core framework for this decision support system due to its comprehensive coverage of sustainability dimensions, including ecological, economic, and social criteria.

The main objective of this research is to develop and validate a decision support system that allows for early integration of sustainability assessments into urban redevelopment projects. The system is designed to be user-friendly, providing dynamic feedback on how design choices impact the sustainability of the project. This feedback is based on criteria from the DGNB UD tool, which evaluates projects on various aspects of sustainability, including environmental impact, resource efficiency, and social inclusivity. By offering suggestive feedback, the decision support system enables developers and planners to make pre-emptive adjustments to their designs, thereby optimizing the sustainability of the project as it progresses through different design phases.

The methodology of this research follows a design cycle approach, starting with a comprehensive literature review and expert interviews to establish a knowledge base. This is followed by iterative model development, encompassing design, development, and validation processes. The literature review provides insights into the current limitations of sustainability assessment tools, which are generally used retrospectively, and highlights the need for methods that can offer feedback during the design phase. The expert interviews contribute to the practical development of the decision support system, ensuring that it is aligned with stakeholder needs and can be applied in real-world urban (re)development projects. The decision support system itself is developed as an Excel-based application, integrating Visual Basic for Applications to facilitate user interaction and data analysis.

The system is validated through expert input and hypothetical testing. Experts in urban planning, sustainability, and construction provided feedback on the system's functionality and effectiveness in improving project outcomes. The results of this validation process indicate that the early integration of sustainability assessments significantly enhances the quality and sustainability of urban projects.

The suggestive feedback mechanism proves particularly effective in identifying potential sustainability issues early in the design process, allowing for more efficient and targeted improvements.

This thesis concludes that the decision support system developed in this research offers a practical solution to the current limitations of sustainability assessments in urban redevelopment. By integrating sustainability considerations into the early stages of project planning, the system helps optimize urban development processes and aligns with broader environmental and societal goals. The research highlights the importance of suggestive sustainability feedback and suggests that further refinement of the model could make it applicable to a wider range of urban development contexts. Additionally, the study points to the potential for integrating the system with other technologies, such as Geographic Information Systems, to enhance its decision-making capabilities.

Thus, the early integration of sustainability assessment tools, such as the DGNB UD, into urban redevelopment projects offers a promising approach to improving both the sustainability and efficiency of urban development. The decision support system developed in this thesis provides a valuable resource for urban developers, planners, and policymakers, enabling them to make informed decisions that align with both local and global sustainability goals. Further research is recommended to expand the model's application and explore its potential in diverse urban contexts.

SAMENVATTING

Stedelijke ontwikkeling in Nederland staat onder toenemende druk om te voldoen aan duurzaamheidsdoelstellingen, met name in de context van woningtekorten en de transitie naar een circulaire economie. De Nederlandse overheid heeft ambitieuze doelen gesteld, waaronder het bouwen van één miljoen woningen tegen 2030 en het bereiken van een volledig circulaire economie in 2050. Dit heeft uitdagingen gecreëerd voor stadsplanning, vooral omdat de bouw op groenlocaties is beperkt. Gezien deze beperkingen is er een dringende behoefte aan meer gestructureerde, efficiënte en duurzaamheidsgerichte benaderingen van stedelijke herontwikkeling. Deze scriptie speelt in op deze behoefte door de ontwikkeling van een beslissingsondersteunend systeem die duurzaamheidsevaluaties vroeg in het ontwerpproces integreert, waarbij het DGNB UD-raamwerk als model wordt gebruikt.

De scriptie begint met het verkennen van de beperkingen van huidige stedelijke ontwikkelingspraktijken, die vaak geen preventieve duurzaamheidsevaluaties tijdens de planningsfase bevatten. Bestaande tools, zoals de DGNB UD, worden doorgaans pas na voltooiing van projecten ingezet, wat hun vermogen om ontwerpbeslissingen in real time te beïnvloeden beperkt. Om deze leemte te dichten, is het doel van het onderzoek om een beslissingsondersteunend systeem te ontwikkelen die continue feedback geeft over de duurzaamheidsprestaties gedurende het ontwerpproces, zodat stedelijke ontwikkelaars en planners vroegtijdig geïnformeerde aanpassingen kunnen maken.

De onderzoeksvragen die deze scriptie sturen, richten zich op hoe stedelijke herontwikkelingsprojecten tijdens de ontwerpfase kunnen worden geëvalueerd en verbeterd om te resulteren in meer duurzame en kwalitatief hoogwaardige stedelijke ruimtes. Om deze vragen te beantwoorden, wordt eerst een overzicht gegeven van de meest geavanceerde duurzaamheidsanalysemethoden die momenteel beschikbaar zijn, en wordt onderzocht hoe deze kunnen worden aangepast om tijdige feedback te bieden tijdens projectontwikkeling of herontwikkeling. De DGNB UD-tool is geselecteerd als het kernraamwerk voor deze beslissingsondersteunend systeem vanwege de uitgebreide dekking van duurzaamheidsdimensies, waaronder ecologische, economische en sociale criteria.

Het hoofddoel van dit onderzoek is het ontwikkelen en valideren van een beslissingsondersteunend systeem die vroegtijdige integratie van duurzaamheidsevaluaties in stedelijke herontwikkelingsprojecten mogelijk maakt. Het systeem is ontworpen om gebruiksvriendelijk te zijn en biedt dynamische feedback over hoe ontwerpkeuzes de duurzaamheid van het project beïnvloeden. Deze feedback is gebaseerd op criteria van de DGNB UD-tool, die projecten beoordeelt op verschillende aspecten van duurzaamheid, waaronder milieueffecten, hulpbronnenefficiëntie en sociale inclusiviteit. Door suggestieve feedback te bieden, stelt het systeemtool ontwikkelaars en planners in staat om preventieve aanpassingen aan hun ontwerpen te maken, waardoor de duurzaamheid van het project wordt geoptimaliseerd naarmate het door verschillende ontwerpfasen vordert.

De methodologie van dit onderzoek volgt een ontwerpcyclusbenadering, beginnend met een uitgebreide literatuurstudie en interviews met experts om een kennisbasis op te bouwen. Dit wordt gevolgd door een iteratieve systeemontwikkeling, bestaande uit ontwerp-, ontwikkelings- en validatieprocessen. De literatuurstudie biedt inzicht in de huidige beperkingen van duurzaamheidsanalysemethoden, die over het algemeen retrospectief worden gebruikt, en benadrukt de noodzaak van methoden die feedback kunnen bieden tijdens de ontwerpfase. De interviews met experts dragen bij aan de praktische ontwikkeling van de beslissingsondersteunend systeem, zodat deze is afgestemd op de behoeften van belanghebbenden en kan worden toegepast in reële stedelijke

herontwikkelingsprojecten. Het beslissingsondersteunend systeem zelf is ontwikkeld als een Excel-gebaseerde applicatie, waarbij Visual Basic voor Applications is geïntegreerd om interactie met gebruikers en data-analyse te vergemakkelijken.

Het systeem is gevalideerd door middel van input van experts en hypothetische testen. Experts op het gebied van stadsplanning, duurzaamheid en bouw gaven feedback over de functionaliteit van het systeem en de effectiviteit ervan bij het verbeteren van projectresultaten. De resultaten van dit validatieproces geven aan dat de vroege integratie van duurzaamheidsevaluaties de kwaliteit en duurzaamheid van stedelijke projecten aanzienlijk verbetert. Het mechanisme van suggestieve feedback blijkt bijzonder effectief te zijn bij het vroegtijdig identificeren van potentiële duurzaamheidsproblemen in het ontwerpproces, waardoor efficiëntere en gerichte verbeteringen mogelijk zijn.

Deze scriptie concludeert dat de in dit onderzoek ontwikkelde beslissingsondersteunend systeem een praktische oplossing biedt voor de huidige beperkingen van duurzaamheidsevaluaties in stedelijke herontwikkeling. Door duurzaamheidsaspecten te integreren in de vroege stadia van projectplanning, helpt het systeem om stedelijke ontwikkelingsprocessen te optimaliseren en sluit het aan bij bredere milieu- en maatschappelijke doelen. Het onderzoek benadrukt het belang van suggestieve duurzaamheidsevaluaties en suggereert dat verdere verfijning van het model deze toepasbaar zou kunnen maken in een breder scala van stedelijke ontwikkelingscontexten. Daarnaast wijst de studie op het potentieel om het systeem te integreren met andere technologieën, zoals geografische informatiesystemen, om de besluitvormingsmogelijkheden te verbeteren.

De vroege integratie van duurzaamheidsanalysemethoden, zoals de DGNB UD, in stedelijke herontwikkelingsprojecten biedt dus een veelbelovende benadering om zowel de duurzaamheid als de efficiëntie van stedelijke ontwikkeling te verbeteren. De in deze scriptie ontwikkelde beslissingsondersteunend systeem biedt een waardevolle bron voor stedelijke ontwikkelaars, planners en beleidsmakers, waardoor zij weloverwogen beslissingen kunnen nemen die in lijn zijn met zowel lokale als mondiale duurzaamheidsdoelstellingen. Verdere onderzoeken worden aanbevolen om de toepassing van het model uit te breiden en het potentieel ervan in diverse stedelijke contexten te verkennen.

ABSTRACT

Urban development in the Netherlands faces significant challenges due to growing pressures to meet sustainability objectives, particularly in the context of housing shortages and the transition to a circular economy. The Dutch government's ambitious targets for housing construction and a fully circular economy have placed constraints on urban planning, especially with restrictions on greenfield development. To address these issues, this thesis developed a decision support system for early-stage sustainability assessments in urban redevelopment, using the DGNB Urban Districts framework as a model. By providing suggestive feedback on sustainability performance, the tool enables urban planners and developers to make informed decisions throughout the design process. The methodology of this research follows a design cycle approach, starting with a comprehensive literature review and expert interviews to establish a knowledge base. This is followed by iterative model development, encompassing design, development, and validation processes of an Excel-based tool, offering practical solutions for integrating sustainability into urban planning. Validation results show that early sustainability assessments significantly improve project outcomes and support broader environmental goals. Further research is recommended to explore its application in diverse urban contexts and enhance decision-making capabilities through integration with technologies like Geographic Information Systems.

Keywords:

Sustainability, urban development, decision support system, DGNB, Excel VBA.

OVERVIEW | ABBREVIATIONS

OVERVIEW | FIGURES

OVERVIEW | LISTINGS

OVERVIEW | TABLES

1 INTRODUCTION

The relevance of sustainable urban development in the revitalization of cities is a topic that is becoming increasingly more important for urban development within the built environment. A short introduction will be given upon the elements regarding the incentives of this thesis research. This chapter will also present the research question along with its corresponding sub-questions, along with the research design and relevance. The chapter will conclude with a research guide.

1.1 Problem Definition

Looking at the construction sector in the Netherlands, the most dominant issue is the drastic housing shortage which the Dutch government aims to solve by creating one million new homes before 2030, a goal set in 2020. However, since 2012, constructing in an open field on the outskirts of a village or city has been prohibited unless exhaustively justified why a municipality cannot opt for an alternative, making the succession of this goal very hard. This regulation is known as the 'Ladder for Sustainable Urbanization' (Beemsterboer & Verhagen, 2020). Another critical noteworthy point is that the Dutch government has set up a program to achieve a fully circular economy by 2050 (Ministerie van Infrastructuur en Waterstaat, 2021). Through this program, endeavors are directed across five transitional agendas, ten cross-cutting themes, and at the regional level. One of these five agendas is purely focused on construction. It concludes that to enhance sustainability in the living environment, it is imperative to accelerate the adoption of innovations, including circular and modular construction methods. The program that they set up addresses that there is a need for new technologies and materials so that project delivery and the life-cycle performance is improved (Almeida & Bühler, 2016; Holland Circular Hotspot, 2019).

Many studies focused on the development of these technologies and processes, many of which revolve around the sustainability of redevelopment projects themselves. They should be sustainable in their own right, independent of their contribution to broader urban development strategies. There is argued that this can be achieved through detailed decision-making and case studies (Williams & Dair, 2007). There are also studies that emphasize the complexity of the redevelopment process by their multifaceted nature. Arguing that there is a lack of systematic investigations into the redevelopment process, which raised a fundamental question about how to define the success of redevelopment. Indicating the need for a comprehensive understanding of criteria and factors contributing to successful outcomes in redevelopment projects (Lange & Mcneil, 2004).

This comprehensive understanding is often achieved via rigorous assessment. This entails not only considering the typically daily-focused research and innovation efforts but also focusing on innovative policies and their associated planned activities. In other words, the emphasis should not solely be on exploring new construction methods to make projects environmentally friendly. Instead, the focus should shift towards adapting redevelopment plans comprehensively, eliminating the need for compensatory measures with new construction methods to comply with environmental aspects and goals. All with the critical goal to provide a better quality of life in cities. This increasingly critical link between quality of life and the built environment underscores the importance of thorough and comprehensive assessment for urban (re)development plans (Mouratidis, 2021).

The assessment criteria for (re)development projects aim to grade projects and determine their environmental impact. Some assessment tools are affiliated with officially registered sustainability bodies, potentially resulting in project accolades. However, these recognitions also occur only after project completion (Chomsky, 2023; GmbH, 2023; Kenlon, 2021). Projects are generally assessed with the overarching objective of aligning with the goals established by relevant governmental bodies, emphasizing circularity. Nevertheless, there is a tendency to overlook broader perspectives, such as European environmental goals. Many assessment tools are already available for various types of projects (Boyle et al., 2018; Garau & Pavan, 2018), each evaluating them based on different criteria. In the study conducted by (Lin & Shih, 2018), several assessment tools were compared. The research paper involved both qualitative and quantitative analyses of globally recognized assessment tools, with an overall conclusion that each tool had its benefits and its deficiencies. Numerous research papers each delve into the evaluation of a single assessment tool, yet they each typically occur post-project completion to assess projects on various criteria (Ameen et al., 2015; Garau & Pavan, 2018; Kaur & Garg, 2019).

The significance of conducting assessments during the planning and development stages of urban redevelopment projects becomes apparent when considering that assessments are typically conducted after project completion, thus lacking the ability to incorporate feedback retroactively. Holistic assessment during these early stages allows for feedback to be preemptively integrated, thereby facilitating the creation of higher quality development plans. Moreover, when prioritizing sustainability, it becomes evident that the broader context of European environmental goals should be tightly integrated. This is crucial as governmental bodies ultimately aim to achieve these larger goals set by higher entities. In summary, the underutilization of sustainability assessment tools during the development process presents missed opportunities, particularly given the rapid advancement of new technologies. There is immense potential for integrating sustainability assessment tools to preemptively implement feedback, thereby enhancing the overall quality and sustainability of urban redevelopment projects.

1.2 Research Questions

The research problem that this proposal aims to address is the unexploited early integration of a sustainability assessment tool in the design phase of urban (re)development projects for continuous feedback. There currently is no general tool to evaluate a development plan during the composition of the design itself on its sustainability impacts and possible improvements. This is a significant limitation of the construction industry's current project assessment capabilities. While there are multiple tools widely available, they are all focused on retrospective assessment.

The intention is to test whether early integration of a state-of-the-art existing sustainability assessment tool can aid in decision-making in the design process during a development project. In the study, design phases of the development process, holistic third-party assessment tools, and stakeholder insights will be reviewed. The data and methods will form the backbone of the model. The compiled research questions and sub-questions are progressively in line with the expected components and development process of the model, in which the collected answers result in the next development step. The main research question is formulated as:

How can a decision support system be designed to evaluate and guide (re)development projects during the design phase to result in higher quality sustainability assessment?

Coherent the next sub-questions are researched:

1. *What are the current state-of-the-art sustainability-focused assessment tools, and how do these tools enable pre-emptive adjustments?*
2. *How do sustainability assessment tools evaluate projects and what are their limitations?*

3. *How can a decision support system be effectively designed to incorporate a broad range of sustainability criteria from an established assessment tool, ensuring ease of use and adaptability while preserving the tool's integrity?*
4. *How can the temporal aspects of a development plan be effectively integrated, considering diverse time frames and criteria with an ongoing project plan?*
5. *How can the design and functionality of a decision support system be influenced by stakeholder input while accommodating their diverse needs to ensure a user-friendly and universally applicable solution?*

1.3 Objectives

The primary objective of this research is to develop a model for the improvement of the design phase of urban development plans on their sustainability aspects by means of suggestive feedback. The aim is to aid developers in evaluating their design during the design process stages with the proposed model (a prototype decision support system), so that certain considerations or trade-offs can be made in the design to raise the sustainable quality of development. The research will make use of expert validation to test the system for realistic, interpretable and user friendly results. The ultimate goal is to contribute to the creation of higher-quality (re)development projects that align tightly with their environment, local requirements, and overall European environmental goals, thereby enhancing the overall quality of urban spaces in various aspects.

To ensure the decision support system is easily accepted by different end users, it is crucial to gather appropriate and feasible feedback. This entails considering users' principles and objectives, as well as the determining attributes of the project. Furthermore, to accurately assess the design's current status, the support system must track the progress completed over time. This requires incorporating criteria from a third-party assessment tool, considering the various temporal aspects of the design phase, and including the alterations made during the design process. In summary, the model will evaluate the current status of the design of a development plan to entered parameters, and improvements to these parameters can be implemented after tool evaluation.

1.4 Research Outline

Figure 1 schematically outlines the core elements of the research approach. Given that the research focuses on the development and testing of a new method, a comprehensive understanding of the existing literature in this specific field is essential. This understanding will be obtained through both general and focused approaches, which will be elaborated upon in the next chapter. The methodology chapter will detail the entire model development process, encompassing expert interviews addressing various aspects of currently utilized Decision Support Systems (DSSs) and implementations, the implementation of criteria from an assessment tool developed by Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), the interlinking of criteria within the new decision support system, and the computation and feedback model of the new decision support system. Upon completion of the model, an implemented version will undergo testing for validation of the system. This implementation will also serve to validate the method through consultations with the previously engaged experts. Following this phase, the research will conclude with a discussion that evaluates both the model development and the validation process. The final chapter will discuss the relevance of the research and suggest potential directions for future research in this domain.

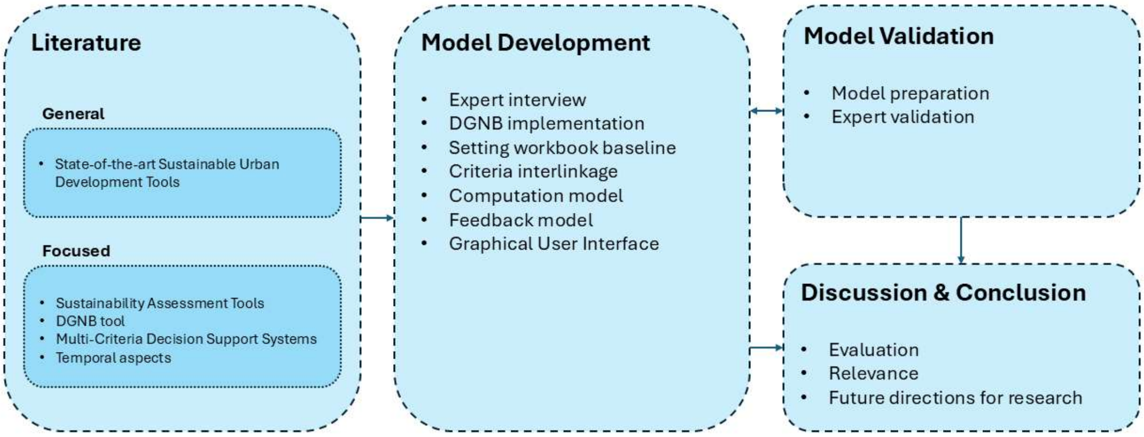


Figure 1: Overview of core elements of the research structure.

1.5 Social, Practical and Scientific Contribution

The contribution of this research on the social aspect should be mainly found in the contribution to the spatial quality of the urban domain after completion of development projects. The integration of a holistic sustainability assessment tool into a decision support system ensures that if used properly, the optimal developed design has a high importance to the social aspect of the design. Additionally, since an assessment tool that focusses on the European environmental goals, which are in line with the sustainable development goals set by the United Nations, directly translates its values to a profound integration of social goals.

Deeming the scientific relevance, the shortcomings in literature and studies regarding the implementation of sustainability assessment tools during the development of the design of a development plan have been mentioned in section 1.2 and will be further elaborated upon in Chapter 2. This study revolves around developing a new methodology of this early integration of a third-party assessment tool, and testing it with a prototype model. The model is an additional instrument for project developers, urbanists, consultants and other similar or involved parties in the development of the urban fabric. The model evaluates the status of a development plan's design based on the criteria that correspond with the temporal aspect of the process of the development itself. From this evaluation, it provides feedback based on the presets filled in by the user, to which the user can take action to improve the design in the current temporal phase. Especially, the possibility to adapt ones design based on pre-emptive assessment is missing according to the consulted literature, which does value the assessment of projects as a learning curve for future projects. The model also tries to bridge the gap between multiple stakeholders within a project, by determining the presets together, the feedback generated by the model will consistently align with the diverse visions involved in the development process.

1.6 Reading Guide

This thesis is structured as follows. Chapter 2 will provide a comprehensive overview of the state-of-the-art sustainable urban development tools, along with a focused literary background required to be able to develop this new methodology and implementational model. It will further discuss what already has been researched on these topics with a focus on what has been learned from previous research and recommendations and possibilities for future studies. Chapter 3 will elaborate on the design cycle methodology of this research, consisting of the setup of the model development, gathering expert input, and integration of the criteria from the DGNB tool. The fourth chapter will provide a detailed overview of the model development process, beginning with the establishment of a knowledge baseline, followed by an in-depth exploration of the technical aspects, and concluding with a description of the model’s interface. Chapter 5 will show the applicability of the developed model by hypothetical testing followed by expert validation. The sixth chapter will evaluate the process of the development and validation of the model. The research will be concluded in Chapter 7 by answering the research questions, highlighting the relevance and stating the limitations of this research and the recommendations for further research and model development steps.

2 LITERATURE STUDY

This chapter aims to comprehensively synthesize the available literature regarding sustainable urban development, organized into two distinct sections. First, a general literature review will be conducted to identify the state-of-the-art sustainable urban development tools. However, the purpose of this research extends beyond these tools, the development and new methodology that will be tested need more literary support. Therefore, an additional focused literature review is conducted. This focused review will deal with specific topics aiding in the development of both methodology and model. It will delve into the most holistic sustainability assessment tools, methods that accommodate for implementing assessment tools into decision support systems, and the temporal aspects that are crucial in this early implementation research.

2.1 State-of-the-Art Sustainable Urban Development Methods

To make sure all available literature regarding the scope of this research will be evaluated, a focused query has been set up. Web of Science was used to search available literature using the following search query: ("urban development" OR "urban redevelopment") AND "decision support*" AND (sustainability assessment OR environmental assessment) (last accessed: March 19th, 2024). The results of the search included 52 publications (journal publications = 44, conference papers = 8). Each publication was screened manually to discount unrelated or unavailable papers with similar phrasings, the filtering stage resulted in 22 publications that were each reviewed in detail.

The reviewed papers shows a growing trend on the topic of sustainable urban development when looking at their year of publication, see Figure 2. In the last decade more and more papers have been published (except for the corona pandemic years), within the first 3 months of this year already 2 papers have been published on the topic. This indicates that there is recognition for the importance of this topic within the academic world as well.

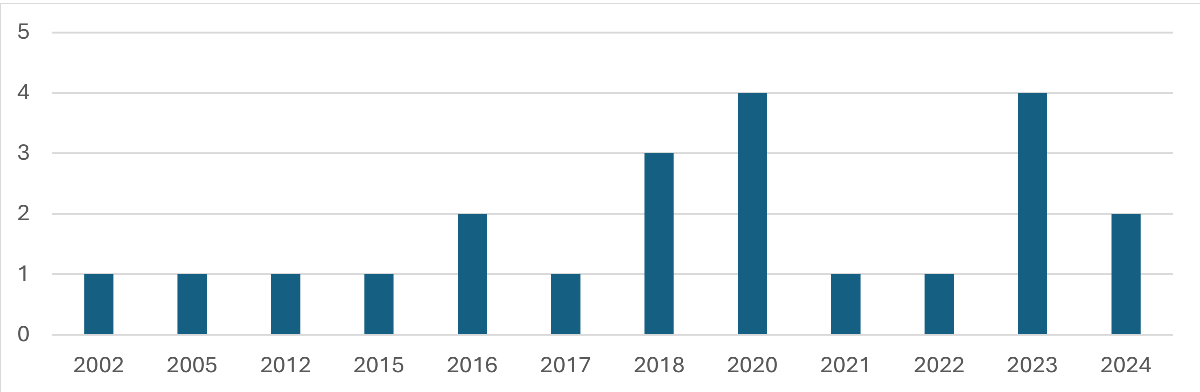


Figure 2: Frequency of Sustainable Urban Development related academic articles published.

When looking at the geographical distribution of the countries of origin of the 22 sources (Figure 3), it is evident that all the papers come from countries prominently featured on renowned sustainability-focused lists. This is unsurprising, given their relevance and significance in the field (Arcadis, 2024; Disruptive Technologies, 2021). The translation of the frequency of appearance of English, Dutch and German cities in these lists to their recurrence in the literature only confirms this.

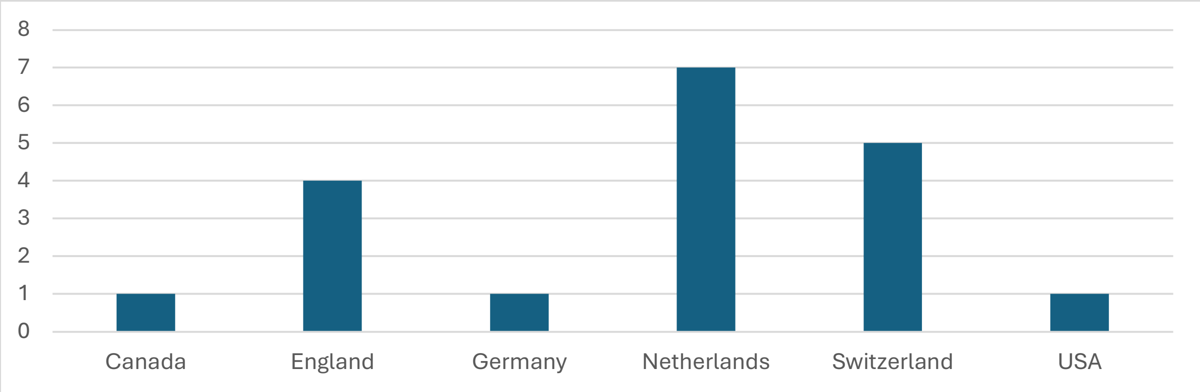


Figure 3: Countries of origin for the 22 sources.

To effectively address the research questions, it is essential to properly categorize the key topics covered in each paper. For this literature review, four overarching categories have been identified. By organizing the gathered literature into these four categories, the crucial elements can be extracted to comprehensively answer the research questions. The four categories chosen are; (1) Quantitative SAT, (2) Qualitative SAT, (3) Decision Support Systems, (4) Stakeholder Involvement. To address sub-question 1 and 2: "*What are the current state-of-the-art sustainability-focused assessment tools, and how do these tools enable pre-emptive adjustments?*", and "*How do sustainability assessment tools evaluate projects and what are their limitations?*", categories one and two are used. To address sub-question 3: "*How can a decision support system be effectively designed to incorporate a broad range of sustainability criteria from an established assessment tool, ensuring ease of use and adaptability while preserving the tool's integrity?*", category one to three are used. To address sub-question 5: "*How can the design and functionality of a decision support system be influenced by stakeholder input while accommodating their diverse needs to ensure a user-friendly and universally applicable solution?*", category 4 is used. An overview of the papers belonging to each category can be found in Table 1.

The findings from the reviewed publications will be discussed below, first the use of quantitative and qualitative Sustainability Assessment Tools (SATs) in the reviewed literature will be explored. Subsequently, the differences between SATs and DSSs in sustainability assessments will be elaborated upon. Followed by a discussion about the used or developed DSSs by the reviewed studies. Finally, the chapter will examine the involvement of key stakeholders in the sustainability assessment process across the reviewed studies.

This structure is chosen to first establish an understanding of the different types of SATs utilized, ranging from quantitative to qualitative approaches. Building upon this foundation, the discussion will then shift to how DSSs complement or integrate with these assessment tools. Lastly, the chapter will investigate the critical aspect of stakeholder involvement, which is a key consideration in the effective application of both SATs and DSSs for sustainability analysis.

Table 1: Categorization of papers akin Sustainable Urban Development.

Category	References
Quantitative SAT	(Leon et al., 2018; Lotteau et al., 2015; Oregi et al., 2016; Schebek & Lützkendorf, 2022; Zhang et al., 2021)
Qualitative SAT	(Bentivegna et al., 2002; Chaguetmi & Derradji, 2020; Cremer et al., 2020; Feleki et al., 2020; Ferdinand & Yu, 2016; Leon et al., 2018; Oregi et al., 2016; Pignatelli et al., 2023; Shen et al., 2020; Zhang et al., 2021)

Decision Support Systems	(Abdel-Galil, 2012; Pérez et al., 2018; Pignatelli et al., 2023)
Stakeholder Involvement	(Abdel-Galil, 2012; Banai, 2005; Kokkinos et al., 2023; Pignatelli et al., 2023; Rashevskiy et al., 2023; Rovai et al., 2023)

Sustainable Urban Development (SUD) is a critical framework for addressing the multifaceted challenges faced by modern cities. It integrates environmental, economic, and social dimensions to create urban areas that are resilient, inclusive, and capable of supporting the needs of present and future generations. This approach prioritizes reducing environmental impacts through energy efficiency and resource management, fostering economic growth that is both innovative and equitable, and ensuring social inclusivity by providing access to essential services and promoting community engagement. Through integrated planning and participatory governance, sustainable urban development aims to enhance the quality of life for all urban residents while safeguarding the planet for future generations.

A dominantly recurring topic in the reviewed literature are sustainability assessment tools, these tools play a crucial role in evaluating the dimensions of SUD, particularly in urban settings where the need for sustainable development is becoming increasingly important. The urban landscape, with its diverse challenges and opportunities, necessitates a comprehensive understanding of sustainability principles to guide decision-making processes into achieving higher quality sustainable urban environments effectively. As urban areas continue to evolve, the need for robust assessment tools becomes paramount to evaluate their sustainability performance and facilitate informed planning and development initiatives. Therefore, the methodologies, applications and limitations of these assessment tools in the retrieved literature are delved into to provide insights into their efficacy and potential for guiding SUD.

Within this domain, Neighborhood Sustainability Assessment (NSA) tools emerge as pivotal instruments, offering diverse approaches tailored to the specific objectives of assessments. These tools, categorized into Multi-Criteria Voluntary Sustainability Evaluation (MCVSE) systems and Harmonized Calculation Methodologies (HCM), enable distinct types of assessments based on the specific objectives and system boundaries considered. One prominent classification distinguishes between tools associated with MCVSE and those employing harmonized calculation methodologies to quantify impacts. The former emphasizes subjective evaluations, often assigning scores to different parameters to generate a final rating, while the latter adopts a more objective stance, focusing on quantifying impacts during the use phase or through a life-cycle perspective (Leon et al., 2018; Oregi et al., 2016). Central to these assessments is the Life Cycle Assessment (LCA) methodology, as delineated by ISO standards, which offers a comprehensive means to evaluate the environmental impacts of activities. Leon et al. (2018) elaborates on the development of new tools based of the LCA methodology, highlighting its application in assessing the environmental impact of districts. Within their framework, it is discussed that the user has the opportunity to choose between two assessment tool groups: qualitative and quantitative assessment approaches, whose main difference is the calculation methodology and the result interpretation system. While qualitative tools rely on subjective scoring systems, quantitative tools apply harmonized methodologies to quantify, distinguishing between operational and life cycle perspectives. Moreover, the development and application of indicators in urban planning underscores the complexity of integrating sustainability objectives into practical frameworks. While indicators are highly valued for their role in supporting decision-making processes, challenges persist in selecting appropriate sets that balance specificity with flexibility. The literature reveals a tension between the need for adaptable indicator sets tailored to diverse urban contexts and the imperative to align evaluations with overarching sustainability goals (Schebek & Lützkendorf, 2022).

A quantitative assessment tool that often recurred in the reviewed general literature is the Neighborhood Evaluation for Sustainable Territories (NEST) tool, which is designed to assess and enhance the sustainability of urban neighborhoods through a structured quantitative LCA approach. It uses predefined indicators linked to the three dimensions of SUD to score performance, helping planners and stakeholders identify strengths and areas needing improvement. It emerged as a pioneering instrument in assessing the sustainability of new or renovated districts from a comprehensive life-cycle perspective (Leon et al., 2018; Lotteau et al., 2015; Oregi et al., 2016). In these three studies that are involved with this tool, each gives a different insight into the application of the tool, however all are in line with one another, agreeing on the fundamental principles of the tool. Both Oregi et al (2018) and Leon et al (2016) simply describe and use the tool to derive refurbishment scenarios from it for the case studies they have chosen in their research. The paper by Lotteau et al. (2015) expounds the tool and its development.

Operating directly on the 3D master plan of neighborhoods, NEST offers a user-friendly graphical interface, simplifying analysis and action. Developed as a Plugin for Trimble SketchUp, a widely used 3D modeling platform, NEST utilizes a set of indicators developed through a scientific approach, providing a graphical and ergonomic interface for analysis (Leon et al., 2018). Its analysis considers four major components within the neighborhood's system boundaries: buildings, land use, infrastructure, and daily mobility patterns, facilitating a thorough assessment of sustainability impacts throughout its lifecycle. A notable feature is its ability to aggregate LCAs of various neighborhood components and subcomponents, considering their respective lifetimes and replacement rates. Despite its strengths, there's a recognized need to enhance NEST's interoperability with existing city information systems like Geographic Information Systems (GIS), which would streamline modeling and increase usability (Oregi et al., 2016).

Lotteau et al. (2015) expounds the tool by focusing on a new neighborhood development, NEST was instrumental in evaluating two scenarios—one prioritizing sustainability and higher density, and the other reflecting conventional planning approaches with more individual houses. The analysis provided visual representations of these alternatives scenarios, emphasizing the value of quantitative assessment to aid decision-making. Despite its NEST's effectiveness, ongoing development of the tool is conducted to assist urban planners in balancing sustainability dimensions even better, such as expanding on the sets of indicators to, for example, integrate urban microclimate considerations as design inputs, to provide a more comprehensive understanding of various dimensions of SUD.

Oregi et al. (2016) broadened the list of indicators for better qualitative assessment, although the economic indicator was not assessed in the case study due to the preliminary phase of the research. However, the socio-economic indicator aimed to perform a quantitative assessment, offering decision-makers objective results for reflection. Notably, the study focused solely on altering the environmental indicator, indicating the potential for future research to explore other dimensions. Similarly, the NEST tool has been utilized to address key issues in sustainable urban planning by considering a broad range of indicators (Leon et al., 2018). Environmental indicators within NEST are categorized into LCA-based indicators and flow indicators, offering a comprehensive assessment of environmental impacts. The study utilized the inventories of Ecoinvent v3.0 to calculate these indicators, presenting scenarios for campus refurbishment strategies aligned with European guidelines. While the study did not incorporate mobility scenarios due to decision-making constraints, it underscores the potential of the NEST tool in guiding SUD initiatives.

There are also studies that introduce their own holistic tool based on multiple other sustainability assessment tools. Indicator System for Characterization of Urban Sustainability (ICARUS), was introduced especially tailored for the Euro-Mediterranean contexts, addressing the lack of region-specific SATs (Feleki et al., 2020). It incorporates a scoring system based on long-term research analyzing 25 of these SATs. It aggregates indicators into thematic categories, equally weighted across four dimensions of sustainability (environment, society, economy, and spatial). An important phase in ICARUS is focusing on transforming results into strategies and prioritized measures, beginning with citizen surveys and expert panels to transform results into actionable strategies. The study utilizes the ELECTRE III technique for multicriteria analysis, for its effectiveness on this aspect together with its practical applications in carious thematic areas. The study concludes that ICARUS offers a practical tool for bridging the gap between SATs and realistic characterization of urban areas. It provides a comprehensive framework for assessing sustainability, incorporating both top-down and bottom-up approaches, and in turn facilitating informed decision-making for policy makers and urban planners on SUD via its outcomes.

In another research by Zhang et al. (2021), a soft computing approach based on System Dynamics (SD) was used to assess the three domains of SUD for the long-term impacts of tunnel infrastructure development. SD integrates qualitative and quantitative methods to address dynamic urban systems. While SD effectively forecasts future changes and validates policies, it struggles with processing massive and fuzzy data. To address this, Granular Computing (GrC) and a Cloud Model (CM) were proposed to manage uncertainties and fuzziness in urban sustainability grading. The study concludes that the SD model is a systematic and appropriate technique that is warranted for effectively forecasting future changes over time and validating selected indicators and proposed policies for dealing with changes. The SD model is even able to transform qualitative concepts into quantitative data. However, the research highlights the limitation that despite these additions to the model, achieving the desired efficiency becomes challenging when expanding the range of indicators for SUD issues, as the GrC and CM demand significant computing power.

Another exceptional SAT is Building, Environmental Quality Evaluation for Sustainability (BEQUEST), it aims to support SUD by offering a structured approach to decision-making (Bentivegna et al., 2002). Through its logical structure, BEQUEST offers an integrated representation of SUD, bridging socio-economic and technical dimensions, planning, property, design, and construction interests in both time and space. It provides a simplified model of SUD, classifies assessment methods, and tailors existing guidance for different scenarios. It concludes that success in development depends on fostering dialogue among stakeholders and integrating various disciplines. Urban policymakers and professionals must act as change-managers, adopting flexible strategies that address local needs and conditions.

The last exceptional SAT that was derived from the literature is Haute Qualité Environnementale et Economique Réhabilitation (HQE^{2}R). The study emphasizes the importance of methodological considerations, highlighting HQE^{2}R as particularly effective for its integration of sustainability dimensions and adaptability to local contexts (Chaguetmi & Derradji, 2020). Heritage-Quality-Diversity-Integration-Social link (HQDIL), a component of HQE^{2}R, facilitates comprehensive neighborhood sustainability diagnosis, employing six principles, five goals, 21 targets, and 73 indicators. By populating the indicators in the indicator impact model, stakeholders can visually assess sustainability via the model-generated charts like histograms or spider diagrams and engage in collaborative discussions to address environmental concerns. The application of HQDIL in an Algerian neighborhood demonstrates its efficacy in identifying and remedying urban issues, ultimately improving environmental quality.

In a study by Shen et al. (2020) a divergent approach to SUD has been taken, the concept of Urban Resource Environment Carrying Capacity (URECC) is utilized as a crucial metric. The study introduces a novel approach, URECC with the Load-and-Carrier perspective method (URECC-LC), which offers a comprehensive framework for assessing urban carrying capacity and is significantly departing from previous approaches. This approach considers both the capacity of urban resources environment and the extent of loads imposed on it, contributing to a deeper understanding of urban sustainability. The evaluation of URECC serves as a vital link between policy formulation for urban resources environment management and the pursuit of sustainable development goals at the city level.

Oregi et al. (2016) discussed that the integration of qualitative sustainability assessment tools in the settlement level (orientation, compactness, urban density) is increasingly recognized as crucial in urban development, which translates to plan adaptation in the early design phases in urban development projects. As a consequence, Urbanists are now incorporating environmental and energy efficiency parameters into district designs and regeneration projects, highlighting the importance of tools for assessing these parameters. However, existing assessment tools face limitations as stated by Pignatelli et al. (2023), including insufficient criteria, methodological sophistication, and automation. To address these limitations, participatory and multidisciplinary criteria selection procedures are being developed to account for these limitations, such as iiSBE (International Initiative for a Sustainable Built Environmental rating system), SBtool 07 (Sustainable Building tool 07), BREEAM (Building Research Establishment Environmental Assessment method), and LEED (Leadership in Energy and Environmental Design). However, according to Ferreira et al. (2023), the market share in Europe of these tools is wide-ranging, where iiSBE and SBtool 07 both have a market share of less than one percent, LEED has a share of 5.5% and BREEAM has a dominant share of 65%. BREEAM, the biggest shareholder of these tools, has been developed for solely the European market, whilst the other tools can be applied to any development globally.

These tools are gaining popularity globally, each providing valuable support for SUD on the three defined limitations. iiSBE, through its extensive stakeholder engagement, tackles the issue of insufficient criteria by incorporating diverse perspectives, ensuring a comprehensive set of indicators that reflect various sustainability dimensions. SBtool 07 enhances methodological sophistication by integrating advanced algorithms and spatial explicitness, allowing for more precise and context-specific evaluations. BREEAM, with its rigorous standards and detailed methodologies, addresses the need for sophisticated assessment techniques, combining quantitative and qualitative data to provide a holistic view of sustainability performance. LEED focuses on improving automation and reproducibility by utilizing a well-defined, standardized framework that simplifies data collection and analysis, enabling consistent application across different projects (Ferdinand & Yu, 2016).

These tools emphasize principles of smart growth, new urbanism, and green building to enhance access to information, public participation, and collaboration among planners and stakeholders. Utilizing executive dashboards as data visualization tools aids in consolidating and analyzing data to prioritize development options. Furthermore, integrating LCA into city-scale environmental decision-making processes is explored as a means to assess operations and beyond (Cremer et al., 2020). Integrated LCA aims to address methodological challenges related to local government influence and proposes a structured framework for environmental assessment at various levels. Despite challenges in addressing activities beyond local government influence, this framework lays the groundwork for standardizing city environmental assessments with a life cycle perspective.

Table 2: Overview of Sustainability assessment tools discussed in the general literature review.

tool	Sources	Function	Quantitative/ Qualitative
BEQUEST	(Bentivegna et al., 2002)	Supports SUD through a structured decision-making approach, integrating socio-economic and technical dimensions.	Qualitative
BREEAM	(Ferdinand & Yu, 2016; Pignatelli et al., 2023)	European-focused tool with rigorous standards for a detailed assessment of sustainability performance.	Both
HQE2R	(Chaguetmi & Derradji, 2020)	Provides neighborhood sustainability diagnosis with the HQDIL model and visual assessment charts.	Both
ICARUS	(Feleki et al., 2020)	Aggregates indicators for urban sustainability in Euro-Mediterranean contexts, using a scoring and ELECTRE III method.	Both
iiSBE	(Pignatelli et al., 2023)	Uses extensive stakeholder engagement to develop diverse indicators for comprehensive sustainability evaluation.	Both
LEED	(Ferdinand & Yu, 2016; Pignatelli et al., 2023)	Uses standardized framework for automation and reproducibility in sustainability assessments globally.	Both
NEST	(Leon et al., 2018; Lotteau et al., 2015; Oregi et al., 2016)	Assesses urban neighborhoods' sustainability using LCA and predefined indicators in a graphical interface.	Quantitative
SBtool 07	(Pignatelli et al., 2023)	Enhances methodological sophistication with advanced algorithms for context-specific evaluations.	Both
URECC	(Shen et al., 2020)	Assesses urban carrying capacity using Load-and-Carrier perspective method.	Quantitative

In preceding paragraphs there has been notion of various assessment tools aiding in the decision-making processes into achieving higher quality sustainable urban environments effectively. An overview of these tools with their function can be found in Table 2. The aid however can be interpreted in various ways by different users, since the user has to draw their own conclusions from the outcomes of these tools. Therefore, it is important to note that there is a distinct difference between a sustainability assessment tool and a decision support systems. SATs primarily focus on evaluating and measuring the three dimensions of urban projects and policies. They provide metrics, indicators, and benchmarks that help stakeholders understand the sustainability performance of a given development. These tools are often used for certification, reporting, and deriving guidance for improvements in design and operation. In contrast, DSSs are designed to assist planners, developers, and policymakers in making informed choices by offering scenario analysis, predictive modeling, or data visualization capabilities. They facilitate the exploration of various development alternatives and their potential outcomes, helping stakeholders to prioritize actions and allocate resources effectively. While SATs provide the necessary data and insights on sustainability performance, DSSs use this information to support strategic planning and decision-making processes, ensuring that sustainable practices are integrated into urban development projects from the outset. A discussion of decision-making principles and the DSSs mentioned in reviewed literature is elaborated upon in the next paragraphs.

Decision support systems are considered indispensable aids, offering insights into the strengths and weaknesses of urban interventions to identify optimal strategies, guided by predefined values (Pérez et al., 2018). These systems leverage indicator systems tailored to the built environment, encompassing a spectrum of methodologies such as checklists, certification methods, technical modeling tools, and Multi-Criteria Decision Making (MCDM) methods. Significantly, their design and functionality are molded by the imperative to assess urban renewal projects against holistic sustainability criteria, encompassing the three sustainability dimensions, particularly pertinent within the context of post-industrial European cities.

The landscape of decision support systems in urban (re)development projects is rich and diverse, encompassing various approaches tailored to address specific needs and objectives. One such approach involves the development of Spatial Decision Support Systems (SDSSs), which integrate quality of life, technology, and cultural vibrancy with a focus on environmental preservation (Pignatelli et al., 2023). These systems leverage Multicriteria Analysis (MCA) and GIS to enable simultaneous consideration of multiple criteria, manage large datasets, and visualize results effectively. By employing an indicators-based assessment method, these SDSSs facilitate sustainability evaluations and scenario-building exercises at the city level, aiding urban planning endeavors. Furthermore, when looking at sustainable urban renewal projects, the introduction of tailored Spatial Decision Support Systems such as URBIUS demonstrates a concerted effort to address the specific needs of neighborhood-scale interventions (Pérez et al., 2018).

URBIUS integrates MCDM methods with GIS technology to offer a comprehensive assessment framework. With a hierarchical structure based on sustainability objectives, URBIUS facilitates a holistic evaluation of neighborhood projects, supporting informed decision-making by urban planners and decision-makers. Additionally, this spatial Urban Sustainable Management System (USMS) represents a paradigm shift towards integrated assessment approaches in sustainable urban management (Abdel-Galil, 2012). Unlike previously mentioned impact assessments primarily focused on environmental criteria, URBIUS adopts a holistic perspective encompassing economic, social, and environmental dimensions in the spatial domain. By prioritizing indicators based on Maslow's hierarchy of needs, the USMS provides a comprehensive view of urban sustainability, offering insights into potential impacts and conflicts arising from different economic bases in the GIS environment. These examples underscore the breadth and depth of decision support systems available for urban development projects, each tailored to address specific challenges and objectives. From city-level sustainability assessments to neighborhood-scale interventions and integrated urban management systems, these tools offer valuable insights and support for decision-makers in navigating the complexities of sustainable urban development.

Over the past three decades, there has been a significant shift towards participatory approaches in urban planning, emphasizing the importance of engaging stakeholders in decision-making and planning processes. Such as Pignatelli et al. (2023), highlighted that broad public participation in decision-making processes stands as a fundamental prerequisite in Agenda 21. Central to these participatory approaches is the concept of co-creation, where end-users actively participate in various stages of the planning process, thereby fostering collaboration among diverse stakeholders to address complex urban challenges. Moreover, the engagement of stakeholders in various decision support system researches have offered valuable diverse insights and enriched the methodology and outcomes within those studies. Such as in the research of Pignatelli et al. (2023), where stakeholders played a crucial role in refining indicators through interviews, questionnaires, and workshops to supporting Key

Performance Indicators (KPIs) selection. In a study by Abdel-Galil (2012), the stakeholders were involved to the same extent, the stakeholders contribute diverse perspectives and expertise in urban development research, covering various disciplines and professions, and validate scenarios to enhance the robustness and relevance of findings from the used DSS. Kokkinos et al. (2023) used stakeholder participation in their study on healthcare waste treatment and management, to address the complexities of multi-criteria decision-making processes, which offered evaluations using linguistic phrases and guided the establishment of criteria hierarchies used in a new DSS. And in yet another SUD focused research, stakeholders are central to establishing criteria priorities and assigning weights using the Analytic Hierarchy Process (AHP) method, ensuring inclusive decision-making and transparency (Banai, 2005). Moreover, stakeholders can offer essential insights, e.g. identifying relationships between sub-criteria, performing assessments, obtaining estimates, co-defining strategic development steps, which help tailor the research approach to address diverse environmental and public health considerations, enriching the methodology with diverse perspectives (Rashevskiy et al., 2023). Furthermore, stakeholders' engagement can also be facilitated by mapping Ecosystem Services (ESs) through AHP and GIS, which gives space for a dialogue among experts and stakeholders, enhancing awareness of the territory's role in providing ESs and enabling scenario analyses for sustainable territorial development strategies (Rovai et al., 2023).

Collectively, these examples underscore the significant role of stakeholders in decision support systems research, highlighting their contributions to methodology refinement, diverse perspectives, and inclusive decision-making processes across various domains. Stakeholders' input profoundly influences the design and functionality of decision support systems in urban development projects, enriching them with diverse insights, expertise, and perspectives. Their active participation ensures the methodological foundation of indicator selection, assessment framework refinement, and alignment with local contexts and priorities, ultimately fostering collaboration and facilitating informed decision-making. Integrating stakeholder input into decision support systems enables researchers and practitioners to better address the complex challenges of urban development, promoting more sustainable and equitable urban development outcomes.

2.2 Focused Literature Review

The general literature review does not provide enough information to fully answer most of the research questions. To ensure that no crucial determining factors are overlooked during the development of the new methodology and its accompanying decision support system, it is imperative that every relevant element is thoroughly addressed. Looking at the findings for the first research question, the literature examines the current state-of-the-art sustainability-focused assessment tools, revealing that while many tools exist, their capacity for enabling pre-emptive adjustments has not been discussed or developed in the papers.

The tools reviewed primarily offer retrospective evaluations rather than proactive planning capabilities, indicating a need for further research to enhance their forward-looking functionalities to shape the design of sustainable urban development. Secondly, the evaluation methodologies and inherent limitations of these sustainability assessment tools are explored. While tools like LEED, BREEAM, and others provide comprehensive assessments across various sustainability dimensions, they often face challenges related to insufficient criteria, lack of methodological sophistication, limited automation, and globally applicability. These limitations underscore the necessity for continuous improvement and adaptation to ensure robust and effective assessments. Thirdly, the influence of stakeholder input on the design and functionality of decision support systems in urban development projects is highlighted. Stakeholders play a crucial role in refining methodologies, enriching the tools with diverse perspectives, and ensuring that local contexts and priorities are considered. Their active participation fosters collaboration, enhances the relevance and accuracy of assessments, and ultimately contributes to more sustainable and equitable urban development outcomes.

Thus, the reviewed literature provides a glimpse into the diverse implementations and advancements of state-of-the-art sustainability-focused assessment tools and the absence of possible pre-emptive adjustments. However, to fully address the gaps identified in answering the first research question, further research is essential. Given the scope of this study, which aims to develop a decision support system integrating a sustainability assessment tool, quantitative SATs are prioritized. These tools can enhance proactive planning capabilities by focusing on nuanced quantitative insights, thereby advancing the field towards more effective strategies for sustainable urban development.

This chapter aims to address the research gaps identified above. As well as finding proper answers to the following research questions: "*How can a decision support system be effectively designed to incorporate a broad range of sustainability criteria from an established assessment tool, ensuring ease of use and adaptability while preserving the tool's integrity?",* and *"How can the temporal aspects of a development plan be effectively integrated, considering diverse time frames and criteria with an ongoing project plan?".*

To achieve this, the chapter is divided into four sections, each dedicated to answering one of these questions. The information will be gathered through a focused approach, specifically targeting topics related to the scope of this research. The first section identifies and addresses the research gap found in the general literature review. The second section explores the chosen quantitative sustainability assessment tool for this research. The third section discusses Excel-based tools and their methodologies. Finally, the fourth section examines the temporal aspects of development plans to provide insights into the phasing of design processes in development projects. The chapter concludes with a summary that addresses the research questions based on the comprehensive literary review.

2.2.1 Quantitative Sustainability Assessment Tools

As mentioned before, sustainability assessment tools played a pivotal role in shaping urban design and development, especially in the context of urban redevelopment projects. To gain a better understanding of the actual state-of-the-art SATs, there has been looked into different sources affiliated with the topic of this research. An extensive review study by Ameen et al. (2015), focused on six globally recognized quantitative sustainability assessment tools, BREEAM Communities, LEED-ND, CASBEE-UD, SBtoolPT–UP, Pearl Community Rating System, and GSAS/QSAS. The study aimed to compare and contrast these tools concerning key characteristics, assessment methodology, scoring, weighting, and suitability for diverse geographical contexts. The research highlighted the tools' evolution from individual buildings to entire urban developments and neighborhoods, emphasizing their instrumental role in advancing sustainability through assessment and certification. It was concluded that there are notable disparities in the scope of topics covered by global sustainability assessment tools. While energy, water, recycling, and environmental aspects receive attention, there is a lack of emphasis on social and economic effects. Additionally, the paper pointed out that the coverage of themes related to SUD indicators varied significantly among assessment tools. Despite demands for single targets, there was disparity in the emphasis on dimensions of urban sustainability. The study underscored the importance of addressing all sustainability dimensions, to make substantial contributions to local sustainable development.

In a separate literature review conducted by Kaur and Garg, (2019), six quantitative SATs were compared, which are BREEAM, CASBEE, GBI, LEED, IGBC, and GRIHA. Unlike previous studies, this analysis did not prioritize the tools based on their level of recognition, but instead concentrated on those most frequently utilized in practice. Notably, three of the six sustainability assessment tools overlapped with those examined in earlier study, highlighting their enduring relevance and significance in the field of sustainability assessment. The research underscored the limitations of conventional urban sustainability approaches, which often focus on specific aspects while neglecting others, resulting in an incomplete understanding of sustainability's interrelations and interdependencies. Meaning that existing frameworks fail to establish complex relationships among various criteria, assessing each criterion in isolation. To address these shortcomings, the study recommended the development of a comprehensive list of indicators and a flexible range of weightages tailored to specific contexts. This approach would enable the creation of context-specific sustainability assessment tools and methods to monitor development in environmentally sensitive areas, facilitating a holistic consideration of urban sustainability by planners, designers, and developers. Additionally, the study revealed a fragmented understanding of sustainability, with tools often failing to address the intricate relationships among criteria. Recognizing sustainability assessment as crucial for decision-making across environmental, economic, and social contexts, the study emphasized the importance of comparative tool analysis to identify gaps and inform future developments.

In comparing these two literary review studies on urban sustainability assessment, significant differences emerge in their focus and perspectives. The first study by Ameen et al. (2015), elucidates the evolution of sustainability assessment tools, emphasizing their role in advancing sustainability through the assessment of entire urban developments and neighborhoods. It highlights disparities in the coverage of topics among global sustainability assessment tools, particularly the lack of emphasis on social and economic topics. In contrast, the second study by Kaur and Garg (2019), delved into the limitations of conventional urban sustainability approaches, stressing the incomplete understanding of sustainability's interrelations and interdependencies. It advocated for the development of comprehensive indicators and weightages tailored to specific contexts to address these shortcomings. So, while both studies address different aspects, they both recognize the need for a more integrated and comprehensive approach to sustainability assessment to effectively address the multifaceted challenges of urban development

Recently, the integrated and comprehensive approach has been discussed by Ferreira et al. (2023). The study specifically focused on quantitative sustainability assessment tools applied to the built environment, its findings hold relevance for research on SUD for several reasons. Firstly, the study evaluates prominent sustainability assessment tools based on their European market share like LEED, BREEAM, and DGNB, which are used in various urban development projects. Understanding the strengths and weaknesses of these tools, particularly in terms of their emphasis on environmental, social, and economic dimensions, can inform decision-making in urban redevelopment projects to ensure holistic sustainability outcomes. Additionally, the study highlighted the evolution of sustainability assessment methods towards aligning with sustainable redevelopment trends, indicating broader shifts in sustainability practices that may influence urban development approaches. Moreover, the emphasis on DGNB as a method achieving a balanced integration of sustainability dimensions, including operational costs and energy demand values, suggests valuable insights for urban redevelopment projects seeking to optimize resource efficiency and enhance overall sustainability performance.

Schuetze et al. (2016) delved deeper into the research for obtaining more holistic sustainability outcomes for district assessment. The literature showed that the DGNB Uban Districts (DGNB UD) tool is the most comprehensive and balanced sustainable urban district assessment and certification system that can both be applied internationally and adapted to specific local conditions. Therefore the DGNB UD tool was utilized to assess the sustainability of redevelopment plans for a district by comparing award winning project proposals with the status quo of previous urban redevelopment plans. By applying the same DGNB UD methodology to both the new and previous plans, the researchers aimed to evaluate the extent to which these redevelopment proposals could enhance the district's overall sustainability. The study acknowledged the challenges of designing and building green and smart cities through the development of existing built environments. It was found that projects struggled to meet integrated and holistic certification requirements, emphasizing the need for a comprehensive approach to sustainability assessment. This indicates that addressing sustainability challenges in urban development requires more than just isolated assessments of individual criteria. Instead, it necessitates a comprehensive evaluation that considers the interconnectedness of environmental, social, and economic factors. DGNB ensures that all aspects of sustainability are adequately addressed and integrated into development plans, contributing to the creation of truly sustainable urban environments. The study concluded that achieving balanced sustainability required the proper utilization of comprehensive assessment and evaluation systems during preparation and design phases of (re)development plans.

In conclusion, the literature reflected a growing recognition of the importance of quantitative SATs in the context of sustainable urban development. These tools, such as BREEAM, LEED, and DGNB, evolved to address the complexities of urban sustainability. However, challenges persist, including the need for earlier integrated and comprehensive approaches to sustainability assessment in the context of SUD projects. Three out of the four papers highlighted that these assessment tools significantly contributed to the decision-making process for urban sustainability projects. Particularly, the DGNB tool stood out the most, emphasizing its triple-bottom-line approach, which makes it the most comprehensive and profound tool for evaluating sustainability across environmental, social, and economic dimensions.

2.2.2 The DGNB Urban Districts Tool

The Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), or German Sustainable Building Council, developed the DGNB Urban Districts (DGNB UD) sustainability assessment tool to promote and evaluate the sustainability of urban developments. This tool provides a holistic framework to guide planners, developers, and municipalities in creating sustainable, livable, and future-proof urban environments. The development of the DGNB UD tool was driven by the need to address the growing complexity of urban sustainability challenges, as indicated in the afore mentioned literature. Initiated by the DGNB in collaboration with experts from urban planning, environmental science, and sustainability sectors, the tool integrates economic, ecological, and socio-cultural aspects of urban development. Extensive research, stakeholder consultations, and pilot projects ensured its applicability and relevance across various urban contexts.

Built around six core principles, the DGNB UD assessment system utilizes various criteria within the tool: People are at the center, Circular economy, Design quality, Sustainable Development Goals (SDGs), EU conformity, and Innovation. "People are at the Center" emphasizes the importance of health and happiness in design and construction decisions, ensuring that projects prioritize the well-being of individuals who will inhabit and use these urban environments. The principle of "Circular Economy" focuses on the conscious use of resources, involving foresight in selecting products regarding their content and future structural changes. It promotes material cycles for reuse or recycling, adhering to the cradle-to-cradle philosophy, and rewards innovative circular economy solutions with bonus points. Recognizing creativity and quality in design and construction as integral to sustainability, the "Design Quality" principle incorporates recommendations from an independent commission for design quality and offers the “DGNB Diamond” award for exceptional projects, ensuring buildings and open spaces contribute positively to urban development. Supporting the United Nations’ Sustainable Development Goals, the DGNB aims to contribute concretely to these goals through certification (see Appendix 1). Every certified project receives a statement on its contribution to the SDGs, motivating alignment with these global objectives. Bonus points are awarded for significant contributions to climate action and other SDGs. Aligning with the European understanding of sustainability, the "EU Conformity" principle incorporates life-cycle assessments from production to operation and dismantling, in accordance with EU standards, using scientifically defined benchmarks to evaluate and optimize environmental impacts. Recognizing the future-oriented nature of sustainability, the "Innovation" principle encourages new and courageous projects through "innovation areas," motivating planners to pursue the best and most sensible solutions, supporting a culture of active engagement with specific construction tasks and customizing projects accordingly.

The assessment system is structured around five key areas: Ecological Quality, Economic Quality, Socio-Cultural and Functional Quality, Technical Quality, and Process Quality. Ecological Quality evaluates environmental impacts, including resource efficiency, climate change mitigation, and ecosystem protection. Economic Quality considers life cycle costs, economic viability, and market potential. Socio-Cultural and Functional Quality focuses on user comfort, health, safety, accessibility, and community engagement. Technical Quality assesses the durability, adaptability, and resilience of infrastructure and buildings. Process Quality ensures that sustainability considerations are integrated into planning, design, and construction processes, creating a comprehensive assessment framework.

Employing a point-based approach, the DGNB UD scoring system assigns specific weights to each criterion, reflecting its importance in the overall sustainability of the project (see Appendix 2). Projects are evaluated against these criteria, earning points based on their performance. The total score determines the level of DGNB certification, ranging from Bronze to Platinum. Bronze is awarded for projects meeting minimum requirements across all areas, Silver for significant improvements and good practices in sustainability, Gold for excelling in various sustainability aspects and serving as exemplary models, and Platinum for achieving the highest standards and innovation in sustainability.

Typically involving several key stages, the DGNB UD process includes Project Registration, Pre-Assessment, Planning and Design, Implementation and Monitoring, Final Assessment, and Certification. This is broader than the typical design phases of a development project, it focused on the bigger picture of project completion. Developers or municipalities begin by registering the project with the DGNB company, initiating the certification process. An initial evaluation by the company identifies strengths, weaknesses, and potential areas for improvement, helping set realistic goals and strategies for the project. During the planning and design phases, the DGNB criteria are integrated into all aspects of the project to align with the DGNB standards so that the company can aid the project developers. Subsequently, the company monitors the project development during construction to ensure adherence to the planned sustainability measures. The company has developed their tool in such a way that they must be involved throughout the entire life cycle of a project, making it impossible for developers to use the DGNB tool independently. Upon completion, a detailed assessment evaluates the project's performance against DGNB criteria. Based on the final score, the project is awarded a DGNB certification level, serving as a mark of quality and sustainability.

Numerous urban districts worldwide have adopted the DGNB UD tool, demonstrating its versatility and effectiveness (German Sustainable Building Council, n.d.). Case studies highlighted how the tool has guided projects in achieving significant environmental, economic, and social benefits. For instance, urban districts in cities like Hamburg, Munich, and Vienna have utilized DGNB UD to create green, resilient, and vibrant communities.

2.2.3 Multi-Criteria Decision Support Systems

Over the years, a significant number of Multi-Criteria Decision Support Systems (MCDSSs) have been designed, including strategic planning, selection, site group decision making, and negotiation. These systems, which can be easily computerized, have shown promise in testing expert systems for sustainability-related issues. For instance, MCDSS can support international policymaking by allocating weights to various sustainability domains, internally weighting key criteria, and combining outputs to generate the best policy options. This method is particularly useful in the initial stages of policy development, complementing and making explicit key trade-offs in the process (Razmak & Aouni, 2015).

Decision support systems, as computer-based tools, bring together information from various sources to assist in organizing and analyzing data, facilitating the evaluation of assumptions underlying specific models. These systems allow decision makers to access relevant data across an organization, aiding in the analysis and choice among alternatives. DSSs allow decision makers to analyze data from transaction processing systems and other internal sources, as well as access external information. This interactive support enhances decision-making quality by performing complex computations quickly, decentralizing data processing, and improving reliability by reducing human error. Hammond et al. (2021) defined the categorization of DSSs in their critical review, and concluded that DSSs can generally be categorized into two main types: (1) information-based systems, which primarily present information and may include some basic data analysis, such as maps of interpolated concentrations, and (2) model-based systems, which typically incorporate problem-solving components, like numerical decision analysis methods, like MCDA. This study summarizes a range of decision-making methods currently applied in environmental management DSSs, illustrating the diverse approaches in practice.

DSSs have become extensively used in business and management for tasks such as stock market decisions and marketing strategies. The advantages of computerized DSS include rapid computations, efficient data handling, reduced human error, and improved decision quality through evaluating more alternatives. However, it is crucial to maintain the primary mission of DSS as decision-aiding systems rather than decision-making systems, especially when incorporating intelligent features.

Different technologies could be used to design a DSS. A recent study by Baizyldayeva et al. (2013) compared ten MCDSSs and found that all systems were running on a Windows platform, with one designed to be used with web interface. This MCDSS support decision-making by aiding in prioritization and revealing stakeholder preferences. This web-based tool offers a wide range of capabilities, including support for decision-making, prioritization, and the discovery of stakeholder preferences. It allows users to consider alternatives and allocate budget or other scarce resources. The tool can also facilitate large-scale, customizable group decision-making processes, involving potentially thousands of participants, through various decision activities. It uses the patented PAPRIKA (Potentially All Pairwise Rankings of All Possible Alternatives) method to assess preferences with pairwise questions across criteria. The software's tab-based interface supports, unlike the Windows based tools, multiple result analysis options and offers features for sharing results, voting, and conducting surveys online. What was noteworthy about the comparative analysis of the ten MCDSSs ranked in this study is that a large number of the assessment criteria are all standard functions of spreadsheet-based tools, e.g. visual scoring, decision trees, visual graphs, X-Y graphs, sensitivity analysis, and model calculations. Showcasing the importance of these functions within MCDSSs.

Şeref and Ahuja (2008) describe spreadsheet-based DSSs as model-based systems that use data from spreadsheets or databases, leveraging problem-specific methodologies to assist users through graphical interfaces. Developed within a spreadsheet environment, these DSSs encompass components for data storage, analysis, solution development, and Graphical User Interface (GUI) creation. Microsoft Excel is particularly suited to DSS development due to its accessibility and ease of use, providing essential features such as data storage, calculation, statistical analysis, optimization, and simulation. Enhanced by Visual Basic for Applications (VBA), Excel supports advanced functionalities like automation, custom GUI design, and complex data manipulation, making it a versatile platform for DSS applications. Excel's components integrate seamlessly: data is stored in worksheet rows and columns, calculations are performed using built-in functions or VBA, and GUIs are created through user forms and control tools, establishing Excel as a robust and user-friendly DSS development platform.

Excel, coupled with VBA, is highly suited for developing spreadsheet-based DSSs, offering efficient data storage, complex problem-solving, and user-friendly interfaces, making it practical for diverse applications. Spreadsheet-based DSSs excel in mid-sized business settings, providing quick, reliable decision support. Jablonsky (2014) notes that such DSSs are used in financial decisions, statistical analyses, database management, graphical representation, optimization, and modeling. Examples like DEA Excel Solver, for efficiency analysis, and Sanna, for multi-criteria evaluation, showcase this versatility and are accessible to professionals and students alike. Excel's adaptability and ease of use have made it a preferred tool for constructing Multi-Criteria Decision Support Systems in both research and practical applications.

One notable example is the POpt application by De Piante Henriksen and Palocsay (2006), it was designed to evaluate and compare competing portfolios of R&D projects by leveraging the synergies between projects. POpt uses Excel's Solver, a powerful add-in for solving Nonlinear Programming (NLP) and Goal Programming (GP) problems, to determine the optimal combination of projects. The integration of Solver with VBA enhances Excel's capabilities, allowing for automated and sophisticated decision-making processes. The application consists of several VBA forms and multiple Excel worksheets, facilitating data entry, synergy matrix creation, and the solving of optimization problems. This structured approach not only automates complex calculations but also presents results in an accessible and organized manner, making it a valuable tool for portfolio optimization in R&D settings. Similarly, the PScore tool exemplifies the practical application of Excel in decision support. PScore is designed to score and rank proposed R&D projects based on multiple criteria, including relevance, risk, and expected returns. By utilizing Excel's VBA for creating dialog boxes, forms, and automated calculations, PScore streamlines the data entry process and generates comprehensive evaluation results. This tool supports decision-makers by providing clear and detailed outputs, including tables and graphical charts, which are essential for managerial review and strategic planning. PScore's methodology accounts for trade-offs between different decision criteria, ensuring a balanced and rational approach to project selection and resource allocation.

The successful deployment of these tools highlights Excel's strengths in handling multi-criteria decision-making tasks. Excel's functionalities, such as data storage in worksheets, powerful calculation capabilities, and the flexibility offered by VBA, make it an indispensable tool for developing MCDSS. Moreover, Excel's GUI capabilities enable the creation of intuitive and user-friendly decision support systems. These systems can perform complex computations, display results effectively, and allow for interactive "what-if" analyses, thereby enhancing decision-making quality and efficiency.

In conclusion, Excel's comprehensive capabilities, including data analysis, optimization, and automation through VBA, position it as an ideal platform for developing Multi-Criteria Decision Support Systems. tools like POpt and PScore demonstrate how Excel can be leveraged to create robust, efficient, and user-friendly decision support applications, making it a valuable resource for both researchers and practitioners in various fields.

2.2.4 Phasing in the Design Process

The integration of sustainability assessment tools into the design process has been proven essential for ensuring that urban development projects achieve holistic sustainability outcomes (Oregi et al., 2016; Pignatelli et al., 2023). While the general literature review has provided valuable insights into the existence, usage, limitations, and potential improvements of these tools, there remains a gap in understanding what the different phases of the development process are and how integrated sustainability assessment tools can be effectively phased into the design process, ensuring that sustainability considerations are embedded from the early stages of project development.

In a study by Ionescu-Heroiu (2010), focused on urban redevelopment projects, it is stated that the different phases of the development process are iterative and often circular. However, there is a linear 4-step logic to the way these processes can be tackled. Within this logic, the managing public entities play a pivotal role. The initial step entails data collection and evaluation, which is performed via site and market assessment, where also legal actions are carried out. Subsequently there is the pre-feasibility stage, which involves the development of preliminary development concepts and the performance of a preliminary risk assessment. Following this stage is the feasibility stage, which goes one step further in the analysis, also identifying financing and investment arrangements and remediation and redevelopment options. The last step focuses on implementation of the plan, which involves an iterative process of remediation and redevelopment, and usually also includes monitoring and site marketing. In turn, Urban Learning (2017) presents a planning process comprising five principal phases, each delineated by its own steps, stakeholders, related activities/responsibilities, and the instruments and tools employed in planning urban development projects. It is stated that in most cases the plan needs to be adapted when new projects are being developed. The five principal phases of an urban planning process are; preparatory planning, feasibility and master planning, formal planning, design and implementation, and the operational phase. Another study by Cappai et al. (2019) focused on stakeholder involvement, 8 stages within the life cycle of an urban development project were identified. After a series of interviews with a multitude of stakeholders the stages were determined coherent to development projects, being; evaluation ex ante, programming, conception, design, approval, implementation, use, and evaluation ex post. These stages are in line with those of a construction project and can be applied to any kind of urban project. In a separate study by Aquilué et al. (2021), the determination of stages is predominantly examined through an Urban Living Labs perspective, where researchers have worked from a case study to define a Four-Phase Model. The phases are labeled; problem and ideation, development of design and structural elements, implementation, testing & assessment, and final proposal. The proposed phases are sequential, though occasional overlaps may occur. Notably, the model excludes the commercialization process, focusing instead on projects that yield profits in terms of social impact, value, and return. Therefore, in the case study where the model was implemented, the final phase involved integrating the outcomes and products into an open-source repository. Additionally, a study by Hammond et al. (2021) stated that the planning and development process for development project can depend on project or site-specific requirements. To offer a clearer understanding of the processes within these projects, a framework for typical planning and land development process has been developed, it highlights the relationships between land use planning scale, development stage, uncertainty in decision making and data needs. Their framework contains six phases: strategic planning, pre-planning, planning application, preparing for construction, construction, and the closeout. Within these phases there are multiple sub-elements, one of which is design and implementation. The paper does not delve deeper into the contents of the framework, instead it focuses on how decision support systems can aid the planning during development projects.

When comparing the different uses of stages in the urban development processes (Aquilué et al., 2021; Cappai et al., 2019; Hammond et al., 2021; Ionescu-Heroiu, 2010; Urban Learning, 2017), there are some corresponding stages, however it is clear that there are many possible methods and systems to work with to guide a development project. For each project the design and implementation are a recurring crucial phase, however how this phase is shaped is different for each project. Meaning that, to get a better understanding of how this can be incorporated into the DDS there must be looked beyond the available academic literature.

In an essay by Van Campen (2008), on quality assurance in Vinex-neighborhoods, seven neighborhoods are evaluated and compared. It starts by stating that quality assurance is closely linked to quality development. Each 'assurance' represents an opportunity for further development. Thus, a cyclical process of development and assurance emerges on different scale levels. The cyclical process illustrates how labor-intensive quality assurance is: every building or layout plan must fit into, and impact, the larger context and therefore must progress through the various levels of quality assurance, typically in three stages of conceptual design, preliminary design, and final design (in Dutch SO, VO, DO). These three stages are also used by the municipality of Oosterhout in their report "Guidelines for the Design of Public Spaces" (Bakker et al., 2008). In this report, the requirements and conditions that the new or renovated public space must meet are outlined. These requirements are aimed at creating a beautiful and usable environment, as well as one that is maintainable and affordable. It essentially represents a compilation of years of experience that the municipality has gained in designing and managing public spaces. Over the years, this has been done by using the following structure: conceptual design, preliminary design, final design, and specifications phase.

In contrast to the essay by Van Campen (2008), the municipality of Oosterhout have another phase after completion of the final design phase. During this phase the final design is turned into detailed instructions for project execution, which is beyond the scope of project design development, thus irrelevant.

A study by Meijer (2016) delved into how the different actors are involved in the engineering process within BAM. From this research it has been shown that BAM divides the engineering process into four phases. In chronological order, these are the initial phase, the conceptual design phase, the preliminary design phase, and the final design phase. This initial phase entails an analytical approach to gain a better understanding of the project area, which is crucial to understand what is demanded and fitting for the project area, thus a key element in the design of a development project. This analytical approach of the initial phase is widely incorporated within multiple Dutch-based urban development companies (Boeijenjong Architecten, 2020; Brouwer Bouwkunde, 2019; PTA Midden Nederland, 2021; Roest Architecture, 2023). Overall, the initial phase is the phase of initiative, feasibility, and project definition, which marks the beginning of the design process. Prior to the design work, thorough discussions, examinations, and documentation of prerequisites are undertaken. These principles and prerequisites collectively shape the framework within which the design project evolves.

Zeiler et al. (2007) argued that the progression through these stages comes with a trade-off. As the design takes shape, the ability to influence the project decreases. At the project's commencement, developers and managers can make drastic changes to project plans, as seen in Figure 4. However, as the design process advances and more information about the problem and potential solutions becomes available, the freedom to make decisions within the solution space diminishes. Early on, there is limited knowledge but considerable flexibility in addressing the design problem. By the end of the design process, although there is a clearer understanding of the task, the options for design choices are significantly restricted. Consequently, decisions made in the early phases have a greater impact on the final outcome than those made later, even though early decisions are based on less comprehensive knowledge about the objectives to be achieved.

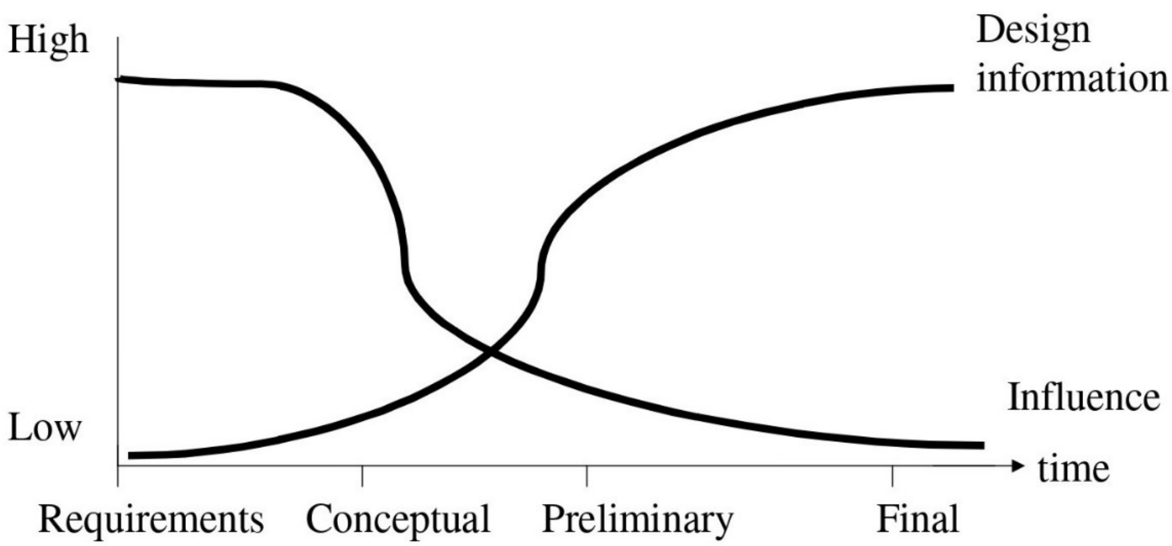


Figure 4: Influence on design decisions throughout the development of the design phase. Source: Zeiler, W. et al. (2007)

In urban development, a conceptual design is the first phase where design sketches are created based on the data collected during the initial phase. During this phase, the project's main shape emerges, along with initial ideas regarding layout and the selection of colors and materials. The sketches and potential variations are discussed with the client until a solid foundation for a design is established.

Upon approval from the client, the design is further developed. Subsequently the preliminary design is further developed based on the sketch design. The design is often rendered in 3D and translated spatially and functionally into a series of drawings and other visual representations. The preliminary design is presented to the client. Only when the preliminary design has been officially approved by the client and further development has been commissioned, does the final design phase begin. In the final design phase, the focus shifts from designing to technical elaboration with a detailed examination of all aspects. At the end of the final design, the design is completed. All data are then known. The floor plans, elevations, materials, structures, installations, dimensions, etc. are all finalized. Additionally, in this phase, the design is reassessed to ensure it fits within the budget (Boeijenjong Architecten, 2020; Brouwer Bouwkunde, 2019; PTA Midden Nederland, 2021; Roest Architecture, 2023).

The available sources regarding the design phases of urban development projects emphasize the significance of four defined design phases in urban development projects. These phases, the initial analysis, conceptual design, preliminary design, and final design phase serve as the backbone of project progression. Stakeholder involvement, quality assurance, and adherence to guidelines ensure the alignment of designs with project objectives and budgetary constraints.

2.3 Conclusion

The focused literature review on quantitative sustainability assessment tools reveals significant insights and highlights critical gaps in the current methodologies, underscoring the need for enhanced systems and approaches in sustainable urban development. Current state-of-the-art sustainability-focused assessment tools are primarily retrospective in nature, assessing completed or ongoing projects rather than providing capabilities for proactive, pre-emptive planning. This limitation indicates a crucial area for further research: developing forward-looking functionalities that can shape and guide sustainable urban development projects more effectively from the early planning stages. Since with these findings the research gap is still not resolved, the answer will need to be found during the development of the model itself.

To effectively interlink different assessment criteria from multiple categories in a DSS, a holistic approach is essential. This involves dynamically adjusting to varying project requirements and stakeholder inputs. The integration demands an advanced system capable of evaluating and balancing the interdependencies between different sustainability dimensions, such as economic, ecological, and socio-cultural aspects. After comparing existing tools and methodologies which have been developed for assessment, the DGNB UD tool stood out as the most holistic and globally applicable tool currently on the market. By developing a comprehensive model that considers these interdependencies, it is possible to create a DSS that not only evaluates the current state but also anticipates future impacts and adjustments needed for custom sustainability objectives.

The design of a sustainability-focused decision support system with an integrated third-party assessment tool can be best achieved by leveraging multi-criteria decision support systems. These systems utilize advanced computational methods to manage large datasets and complex criteria effectively. Spreadsheet-based DSS, particularly those developed in Microsoft Excel, demonstrate significant potential due to their widespread availability, user-friendly nature, and powerful data handling capabilities. Integrating third-party assessment tools within these systems can enhance their functionality, enabling more detailed and reliable evaluations. Seamless integration allows for comprehensive data analysis and direct updates, which support informed decision-making processes by providing detailed insights into various sustainability criteria.

Effectively integrating and measuring the temporal aspects of a development plan, considering diverse time frames and criteria for evaluating its compatibility with ongoing project plans, requires a dynamic and phased approach to the design process. The chosen design phases: (1) initial analysis, (2) conceptual design, (3) preliminary design, and (4) final design phases, involve specific activities, stakeholders, and decision points that must be carefully managed to align with sustainability objectives. Each phase should accommodate iterative processes and allow for continuous monitoring and adjustments. By embedding sustainability considerations from the early stages and adapting them as the project evolves, the new model ensures that the project remains aligned with sustainability goals throughout its development cycle.

3 METHODOLOGY

From the insights gained in the literature study, this chapter will delve into the methodology used to address the unanswered and remaining research sub-questions linked to the model development process. Drawing from the literature study, the DGNB UD sustainability assessment tool has been identified as the third-party assessment tool that will be integrated in the decision support system, and Excel has been proven to be an excellent environment for the development of this model. The chapter will outline in detail the methods and approaches employed in this research, building upon the insights gathered from the literature study. This chapter will start with elaborating on the development approach within this research, followed by multiple sub-chapters each related to the crucial parts of the development process of this new methodology.

3.1 Design Cycle

To address the research questions, a specific structure is introduced, which will be elaborated and refined throughout the applicable research cycle. For this study, the design research cycle is chosen as the most suitable framework, aligned with academic research standards (4TU, 2023). Described as an iterative process, the design research cycle follows the principles outlined in the design science methodology theory (Martakis, 2015; Wieringa, 2014). Acknowledged in academic literature, this cycle is integral to the engineering process, comprising three distinct phases: treatment design, treatment validation, and implementation evaluation. Where in this research the treatment is the model itself. Furthermore, the design cycle is recognized as the core of any design science research endeavor (Hevner, 2007). The study emphasizes the interconnectedness of the design cycle with the relevance cycle and the rigor cycle, both of which contribute to and are influenced by the design cycle. Within this framework, the design cycle iterates more swiftly between model construction and evaluation. Additionally, it connects the relevance cycle to the requirements of the designed model and the rigor cycle to the acquisition of evaluation theories and methodologies.

While Hevner (2007) outlines four phases, they align in essence with the three phases identified directly by Martakis (2015) and Wieringa (2014). This thesis will adhere to the afore mentioned three phases identified within the design cycle. Firstly, the design problem will be examined and synthesized (design research cycle stage: read and plan). Next, the model will be developed to address the problem (design research cycle stage: solve). Finally, the developed model will be validated and evaluated (design research cycle stage: check) (4TU, 2023). In the following chapters of this research, the latter two will be approached.

However, these stages are approached slightly differently compared to the original design cycle due to the specific scope, purpose, and structure of this research. The adapted design cycle is illustrated in Figure 5. The most significant change lies in the phase definition. While Martakis (2015) and Wieringa (2014) focus on the types of questions directly related to the general contents of treatment development, this research emphasizes the procedural steps necessary to develop the model, indicated by chapter organization. This construction enhances the coherence of both the report's contents and the development structure itself. Each chapter will elaborate on the relevant aspects designated for exploration in subsequent sections of this paper. Another notable change involves the redirection of the bridge step within the cycle. In the original cycle validation and implementation were separate steps, with a bridge link connecting validation to evaluation. However, since this research concentrates on model development, these steps have been consolidated under a single phase. Consequently, the bridge link has been redirected between the design and development phases. This redirection facilitates feedback during the implementation phase to refine the design based on real-world challenges. Any necessary adaptations can be made before experts validate the model.

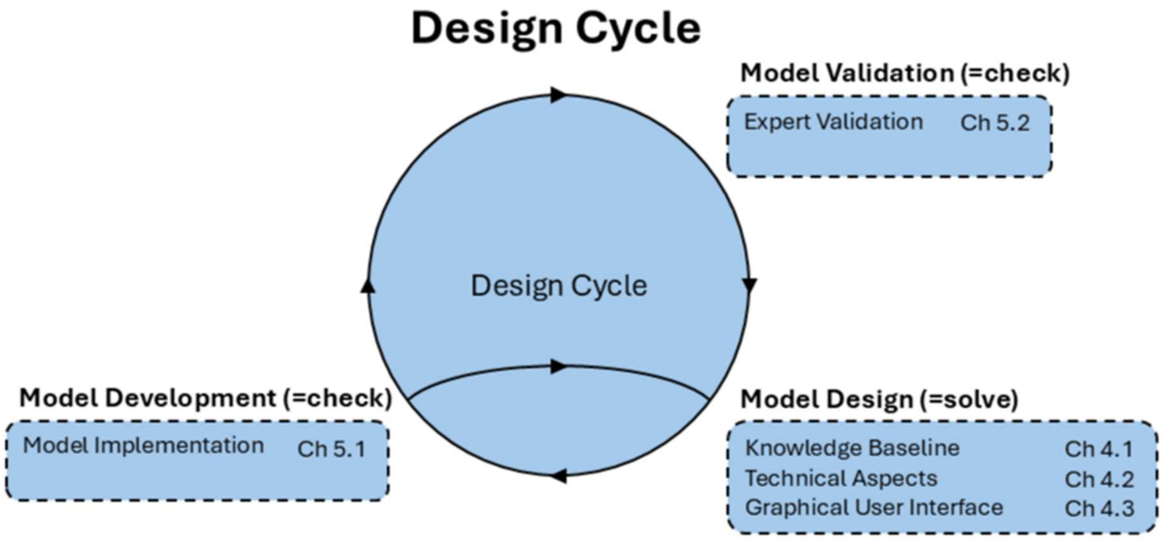


Figure 5: Customized design cycle to fit the purpose of this research.

To elaborate to the design cycle more in detail, Model Design (=solve), encompasses three distinctive steps. First, the Knowledge Baseline will be set, which will be elaborated upon in Chapter 4.1. This step involves listing the requirements and external knowledge that is necessary to start to develop the decision support system. It consists of expert interviews on the temporal aspects of project development, personal goals or preferences for a project, and their experience in the usability of assessment tools. Chapter 3.3 elaborates on the methodology used for these interviews. Additionally, to this step, the Knowledge Baseline involves understanding the opportunities and criteria the DGNB UD tool has, so that it can be transformed and implemented in a new environment, which is elaborated upon in Chapter 3.4.

The next phase of the research focuses on the detailed Technical Aspects of the decision support system development, breaking down its core components and operational mechanics, which will be elaborated upon in Chapter 4.2. This involves defining the baseline structure of the workbook, outlining how preset inputs are handled, explaining the computational methods employed, describing the feedback mechanism, and illustrating how the DSS supports an iterative design development process. The structure of the DSS is built around Microsoft Excel, leveraging its widespread availability and user-friendly nature to create a versatile platform for sustainability assessment. The development process follows the principles of the effectuation methodology, which emphasizes working with the resources and means at hand to shape the direction of the design. Rather than starting with a fixed end goal and acquiring the necessary tools or resources to reach it, effectuation begins by assessing what is currently available and determining the most effective ways to use those means to develop the system. As new requirements or constraints emerged, the design and technical approach were adapted to find the best possible solutions within the existing framework. This approach aligns with the core goal of developing a system that is not only functional but also flexible and adaptable to different projects and contexts.

The last step of the Model Design is designing the GUI, the interface of the DSS, which will be elaborated upon in Chapter 4.3. This step consists of two elements, first is the worksheets and how the user interacts with them. The second step deals with all the VBA code that is working in the background to create a more user-friendly DSS and so that the processes run more smoothly. For this step of the design, the User-Centered Design (UCD) methodology is used. UCD is a design methodology that focuses on user needs, preferences, and behaviors throughout the development process. It ensures that the interface is intuitive, user-friendly, and aligned with the actual users' requirements.

Moving to the next phase of the design cycle, Model Development (=check), where the DSS needs to be prepared for testing, which will be elaborated upon in Chapter 5.1. The methodology applied for this step is the Minimum Viable Product (MVP) approach. While the model was initially developed with full functionality in mind, certain features have been streamlined or removed due to time constraints, particularly given the limited availability of experts for the validation process. By focusing on the core functionality, this approach ensures that the essential elements of the model can be tested effectively, while secondary features are set aside for later refinement. This enables a more efficient validation process, allowing experts to evaluate the fundamental aspects of the model within the available timeframe.

The last step of the design cycle is the validation of the model itself, Model Validation (=check), which will be elaborated upon in Chapter 5.2. The methodology used for this last step is called User Testing, it involves allowing users (in this case, experts) to interact with the DSS to evaluate its usability, functionality, and overall performance. The methodology on how these interviews are taken can be found in Chapter 3.3. The insights garnered from these interviews will serve to validate both the method and the model, with the concluding findings discussed in Chapter 5.3.

3.2 Model Development Setup

This study revolved around developing a new methodology for the early integration of a third-party assessment tool in a DSS for sustainable urban development projects. The methodology required designing a model to serve as an additional instrument for project developers, urbanists, consultants, and other stakeholders in urban development. The model aimed to evaluate the status of a development plan based on criteria corresponding with the temporal aspect of the design development process. Throughout this research, the methodology is referred to as a novel approach to sustainability testing. This involves developing a model implemented as a decision support system.

Several elements were involved in the model development process. First, a quantitative holistic sustainability assessment tool was necessary to test the research's purpose, identified through the literature as the DGNB UD tool. The decision to focus on a single assessment tool, rather than comparing multiple tools and selecting criteria in collaboration with stakeholders and experts, was driven by the scope and objectives of this research. The primary goal of this study is not to develop a new MCA tool rather to explore the feasibility of simplifying existing sustainability assessment tools and making them more accessible for use in urban development projects. This research aims to translate the complexity of established tools, such as the DGNB UD tool, into a more user-friendly format. The intention is to enhance accessibility for stakeholders, thereby encouraging more frequent and effective integration of quality assurance in the design stages of urban development. Engaging with multiple assessment tools and collaboratively developing new criteria would have expanded the scope beyond the central focus of this study, which is on improving the usability of existing assessment methods rather than creating a new framework.

Second, the means in which this new model could be tested needed to be determined. The literature indicated that a multi-criteria decision support system in the form of spreadsheets was the best method, given its ability to manage large datasets and complex criteria effectively, as well as its widespread availability, user-friendly nature, and powerful data handling capabilities. Therefore, Microsoft Excel software was chosen to develop the validation system for this research. Another crucial aspect to early integrating the SAT was the temporal aspect, which allowed for suggestive feedback and pre-emptive adjustments. Chapter 2 concluded that effectively integrating temporal aspects required a dynamic and phased approach to the design process. According to the literature, the most common phases used by project developers were the initial analysis, conceptual, preliminary, and final design phases. These phases were considered during model development to ensure easy interpretation by the system's users once fully developed. An additional crucial element defining the new model as a Decision Support System was its ability to compute scores and generate feedback based on user-entered information. This required setting up both a computational model and a feedback mechanism within the model. To enhance user-friendliness, an iterative process was incorporated. As the DGNB tool adopted a holistic triple-bottom-line approach with numerous set criteria, it would be cumbersome if users had to repeatedly fill in the same criteria at different temporal phases. Thus, the model saved progress at each stage to make it more adaptable. Finally, the overall usability of the model was paramount. The literature consistently emphasized that integration should minimize human error in interpretation and decision-making. Therefore, developing a user-friendly graphical user interface was crucial. The GUI needed to be straightforward and intuitive to ensure accessibility and efficiency for users. All these elements were schematically represented in Figure 6, ensuring the model's robustness, adaptability, and user-friendliness to support sustainable urban development effectively.

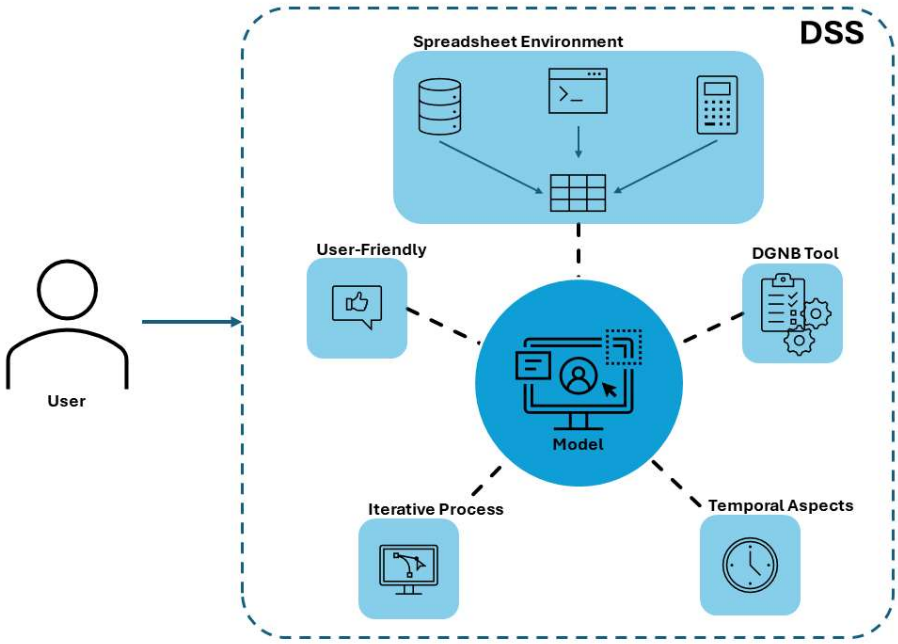


Figure 6: Elements of the decision support system.

As outlined in the development cycle, the final phase of this research involved validating the methodology through a working prototype of the model. Before validation by experts in the field of sustainable urban development, it was important to understand their perceptions and experiences with sustainability assessment tools. These insights were essential for refining the user interface and overall functionality of the DSS. They helped answer questions such as how users would interact with the system, when they would use it, what type of information they sought, and how they preferred to receive feedback. Addressing these questions enhanced the system's user-friendliness, increasing the likelihood of positive validation. Therefore, expert interviews were necessary for developing this model to gather valuable feedback and suggestions.

To integrate the DGNB UD assessment tool, more details about its contents were required to properly set up the calculation models and scoring system. Additionally, for the model to fully integrate into the design process, detailed knowledge of its contents was required to set up accurate calculation models and a scoring system. Moreover, for the model to fully integrate into the design process, its aspects needed to align with the temporal phases previously identified. Therefore, a thorough assessment of the SAT and its contents was needed to provide insights that would inform the model's development.

As stated, the DSS was developed in Microsoft Excel. The specific features and functionalities of the system were determined during its development. Without a comprehensive understanding of the aforementioned elements, the system architecture of the model could not be fully composed. The following sections elaborate on these necessary components for the model's development, ensuring a robust and user-friendly decision support system for sustainable urban development.

3.3 Expert Interview

In line with the research objectives delineated earlier, expert interviews constitute a pivotal component aimed at garnering nuanced insights essential to this study. Building upon the groundwork laid in the previous chapters, which underscored the significance of expert input, this section elaborates on the methodological approach employed for these interviews. Structured in a semi-structured format, the interviews aimed to facilitate organic exploration of relevant topics while ensuring alignment with research sub-questions four and five. A diverse array of experts spanning different roles and sectors within urban development was targeted for participation. Invitations were extended to professionals occupying positions such as Project Managers, Project Developers, Urbanists, and representatives from Consultancy firms. Additionally, outreach efforts were made to urban planning departments within Municipalities to incorporate insights from the public sector. The interviews were conducted through a blend of online and in-person meetings, accommodating participants' preferences and constraints. This hybrid approach facilitated broader participation while maintaining the depth of interaction essential for qualitative data collection. All interviews were recorded, either visually or via voice recording, to ensure accuracy and completeness for subsequent review and analysis.

A diverse group of professionals from the fields of project development, urbanism, and consultancy were consulted. These experts brought a wide range of experience to the table, with years of professional expertise ranging from 15 to 30 years, as shown in Table 3. The inclusion of spatial consultants with over two decades of experience, alongside urbanists with significant expertise in urban planning, ensured that the initial interviews captured a broad spectrum of industry knowledge. The purpose of these interviews was to gain insights into critical unknown factors and industry practices relevant to the research topic. The depth of experience among the interviewees provided a solid foundation for understanding various aspects of project development, urban planning, and sustainability.

Table 3: Overview of conducted interviews for first round.

When	How	Duration of interview	Profession	Years of Experience
12/03/2024	In Office	1 hour	Urbanist	15
14/03/2024	Microsoft Teams	1 hour	Spatial consultant	16

14/03/2024	Microsoft Teams	1 hour	Urbanist & Project leader	24
21/03/2024	Microsoft Teams	1 hour	Innovative and sustainability project manager	16
21/03/2024	In Office	1 hour	Project manager	30

Structurally, the interviews were designed to explore various thematic areas critical to the research objectives. Key focus areas included the integration of temporal considerations in urban development projects, stakeholder needs and requirements relevant to decision support systems, and preferences for the design and functionality of the decision support system. The underlying goal of the interview was to identify ways to incorporate expert feedback into the DSS development process, ensuring that the DSS aligns more closely with current market practices and user needs. The list with questions for these interviews can be found in Appendix 3. Following data collection, recorded interviews underwent thematic analysis to distill key insights and recurring themes. This iterative process facilitated the identification of patterns and trends crucial for informing the development of the decision support system, which will be discussed in the following paragraphs. Ethical considerations remained paramount throughout the interview process, with strict adherence to protocols ensuring confidentiality, informed consent, and participant anonymity. All data collected were treated with utmost sensitivity and handled in accordance with established research ethics guidelines.

To validate the prototype of the decision support system, expert interviews were taken again which followed a more structured format. The interviews covered various elements such as the timeframe considerations, preset determinations, utilization of the system, methods for inputting design information, and preferences for receiving feedback from the system.

During the expert validation, professionals with a focus on urban development, project management, and the built environment were engaged to assess the developed decision support system and its applicability. The interviewees' experience levels varied from 5 to 30 years, representing both emerging and seasoned professionals. For instance, some project developers had five to eight years of experience, offering fresh perspectives, while others, such as urbanists and project managers, brought 15 to 30 years of expertise to the validation process. This range of experience allowed for a comprehensive evaluation of the model, as the feedback reflected both innovative ideas from younger professionals and well-established industry practices from more experienced individuals. The variety of expertise across different domains within urban development ensured that the validation was thorough and covered multiple dimensions of the system's functionality and relevance. A simplified overview can be found in Table 4. The validation results can be found in Chapter 5.2.

Table 4: Overview of conducted interviews for second round.

When	**How**	**Duration of interview**	**Profession**	**Years of Experience**
02/09/2024	In Office	1 hour	Development manager	21
03/09/2024	In Office	1 hour	Project developer	5
03/09/2024	In Office	1 hour	Project developer	8
04/09/2024	In Office	1 hour	Project manager	30
20/09/2024	In Office	1 hour	Urbanist	15

3.4 DGNB Tool Integration

The integration of the DGNB Urban District tool into an Excel-based DSS followed a structured methodology to ensure both functionality and ease of use. The process began by organizing the criteria of the DGNB tool into the different design stages of the urban development process, which were identified as the initial analysis, conceptual design, preliminary design, and final design phases. This has been performed by means of the Construct Validity Assessment (CVA) methodology, wherein each criterion was systematically evaluated to determine its relevance to the specific goals and activities of each phase. Using CVA ensured that only the criteria pertinent to each stage were selected, enhancing the DSS's efficiency and making it responsive to the unique requirements of each design phase. This allowed for the gradual assessment of sustainability as the project advanced, aligning the DSS' use with the natural flow of project development.

Excel was chosen as the platform due to its data management and calculation capabilities. The DGNB criteria were mapped into Excel, with a structured system of formulas to compute sustainability scores based on user inputs. By leveraging Excel's functionality, the system was designed to automatically update scores and provide feedback. Automation was an important part of this integration, using Excel's built-in programming environment, Visual Basic for Applications VBA, to streamline processes such as data entry, score calculation, and feedback generation. This ensured that the system operated efficiently while minimizing manual errors, enhancing both the reliability and usability of the decision support system.

A user-friendly interface was also developed to make the system accessible to non-technical users. Input forms, drop-down menus, and navigation systems were created to guide users through the process of entering project data and evaluating results. This structure ensured that the DGNB tool's complex sustainability criteria could be managed easily within the Excel environment, while still delivering the detailed feedback necessary for informed decision-making in sustainable urban development projects. This methodology ensured that the DGNB UD tool was effectively integrated into an accessible and functional DSS, providing users with a practical way to evaluate sustainability throughout different phases of their projects.

3.5 Conclusion

The core methodology applied in this research is the design circle approach, which applied to develop a decision support system that integrates the DGNB Urban District tool into a user-friendly, Excel-based platform. Rooted in the design science research cycle, the iterative process of design, validation, and refinement ensured that the DDS met both theoretical and practical demands, enabling sustainability assessment at the design stage of urban development projects.

A key feature of this methodology was its focus on accessibility. By leveraging Excel's flexibility and familiarity along with automation through VBA, the DDS minimized manual errors, streamlined data entry and score calculation processes, and adapted to diverse project types and scales. The integration of an intuitive graphical interface further facilitated ease of use, ensuring that even non-technical users could interact with the DSS effectively.

Expert validation was crucial in shaping the DSS' functionality. Interview results from professionals in urban development was instrumental in refining the user interface and feedback mechanisms. The iterative engagement with intended end users ensured that the DSS aligned with industry standards and addressed the needs of its intended users. The model demonstrated its ability to integrate the widely adopted DGNB UD tool into a versatile and accessible DSS. By emphasizing expert feedback, user-centered design, and a structured iterative process, the resulting DSS offers stakeholders a transparent, efficient, and data-driven approach to support sustainability objectives across all design phases of project development.

4 PROTOTYPE DESIGN AND DEVELOPMENT

This chapter is divided into three parts. The first part, Chapter 4.1, will revolve around establishing a knowledge base to be able to develop the decision support system. Within this knowledge base there is built on insights gained from the literature review, so that insecurities or unknowns are resolved and a proper base is set to start and develop the DSS. The literature review chapters identified some key elements needed to design and develop the model, which are insights into how forward-looking functions can be integrated to allow for pre-emptive adjustments, proper integration of expert defined requirements, and understanding how dynamical interactions between criteria work to facilitate a user-friendly DSS. These elements ensured that the model was insightful, user-friendly, and not overly complicated. In this sub-chapter, first the expert input regarding additional elements that should be addressed in the system design is examined. Following this, the integration of the DGNB tool is explained, leading into a discussion of the system architecture.

The second part, Chapter 4.2, of this chapter will deal with the technical aspects of the system development, such as the workbook baseline, input presets, the computational model, the feedback mechanism, and the integrated iterative development process. Thereafter, Chapter 4.3, elaborates the development of the graphical user interface by covering the details about the setup of the worksheets and VBA code to facilitate the user-friendly interface.

4.1 Knowledge Baseline

The first section discusses insights from expert interviews, which highlight critical considerations such as phased assessments, user adaptability, and real-world challenges in urban development. These insights shape the DSS's functionality to ensure it meets practical demands. The second section analyzes the DGNB UD tool, exploring how its sustainability criteria can be integrated into the DSS. This includes understanding its core dimensions and assessing how they can be streamlined for real-time decision-making. The analysis also identifies which DGNB elements should be adapted or excluded, ensuring the DSS aligns with the project's goals. The third section discusses the system architecture, drawing from insights in previous chapters to establish a framework that will guide the DSS development process in the following chapters.

4.1.1 Expert Interview

The initial expert interviews revealed varied approaches to phasing in urban development projects, yet common themes emerged. Several experts emphasized the importance of a structured phasing approach, beginning with an initial context analysis and proceeding through stages such as initial analysis, conceptual design (SO), preliminary design (VO), and final design (DO). Some experts noted the necessity of having a process overseer, such as a tender manager, to coordinate internal deadlines and ensure sustainability goals were met. This coordination often started with delivering references and vision documents to the municipality, followed by a selection phase and a permitting phase. Despite practical challenges in achieving uniform structure, the desire for standardized processes was evident. Experts highlighted the importance of an initial context analysis to align with municipal requirements and project-specific goals, emphasizing flexibility. They agreed on the crucial role of detailed analysis in the early phases, including conducting preliminary studies and understanding the development area's context. The design plans' detail level needed to increase progressively through each phase, aligning with the specific criteria and key indicators relevant to the project's goals. The consensus was that detailed, phased development work ensured early and consistent integration of sustainability considerations, leading to more successful urban development projects.

Sustainability criteria within the DSS were a point of discussion. Experts agreed that the model should allow users to set and prioritize specific goals, such as CO_2 emissions reduction or sustainable material use. The inclusion of human-centric values, circular innovation, and resident participation was repeatedly emphasized, suggesting the model should support a holistic approach to sustainability, which the DGNB tool already does. They suggested that project teams collaboratively establish preset values, potentially using sliders to indicate the relative importance of each one. Integrating the decision support system from project kickoff meetings would enable it to function as a checklist, helping teams identify opportunities, set agendas, and establish project deadlines. This approach would ensure that the system remains flexible and user-friendly, facilitating smoother collaboration among stakeholders and supporting effective planning from the outset. There was also a consensus that the DSS should avoid information overload and remain simple and clear. Some experts recommended integrating the DSS into project kickoff meetings, using it as a checklist to identify opportunities and set agendas. Additionally, the ability to adjust preferences per project phase was seen as highly valuable, allowing the DSS to evolve with the project and provide relevant guidance at each stage.

Providing tailored, context-specific feedback emerged as a central theme, with interviewees acknowledging the system's current ability to offer this while envisioning diverse applications for the DSS. Experts expressed differing views on feedback's form and necessity. Some were skeptical about generalized feedback, arguing it might not always align with local regulations or project-specific needs. Instead, they suggested providing ratings with explanatory comments to facilitate informed discussions and highlight clear KPIs. Others emphasized the importance of moral auditing, cautioning against using the system purely for scoring purposes, which could lead to financial exploitation rather than genuine sustainability improvements. They all saw the DSS as a means to ensure projects adhered to ethical and sustainability standards, contributing to better spatial development. Feedback was also seen as a possibility to guide project teams through sustainability considerations. Experts recommended using the DSS to provide checklists and highlight ambitions within plans, ensuring critical sustainability aspects were consistently addressed. This approach would support the system's role as an aid in the design process, helping achieve sustainable objectives without making the highest score the sole focus.

The expert interviews also discussed the developing a DSS that integrated the DGNB UD tool for sustainable urban development. The findings highlighted the importance of a structured yet flexible phased approach, allowing for tailored sustainability goals and criteria to be set and adjusted throughout the project, which they recognized in the DSS. Experts emphasized the need for the model to support human-centric values and holistic sustainability considerations, recommending features such as collaborative presets and adaptable phase-specific preferences. Feedback mechanisms should be tailored and context-specific, focusing on providing actionable insights rather than generic scores. The DSS supports ethical auditing and better spatial development by emphasizing sustainability aspects relevant to individual projects. By addressing the specific needs and preferences of different stakeholders, the model could significantly enhance sustainable urban development, facilitating more successful projects. This was incorporated into the model by allowing users to determine project goals, which could be adjusted as the project developed, providing adaptable and case-specific user needs.

4.1.2 DGNB Tool Integration

The DGNB UD sustainability assessment tool is a comprehensive and intricate instrument, characterized by its triple-bottom-line approach. This tool, designed to evaluate the sustainability of urban development projects, encompasses five core dimensions: Environmental Quality, Social Quality, Economic Quality, Technical Quality, and Process Quality. Each of these five dimensions comprises multiple sub-criteria, which are further delineated into numerous criteria contributing to a maximum score of 100 points per criterion. In summary, there are 31 criteria, totaling 232 individual components, being sub-criteria to these 31 criteria. However, throughout this report, the terminology of the DGNB tool will be adhered to for clarity. An overview of the buildup of the tool is visualized in Figure 7.

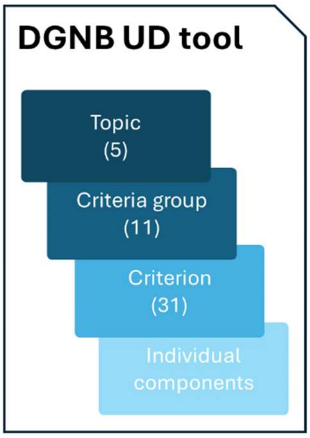


Figure 7: Schematic overview of the buildup of components within the DGNB UD tool.

The handbook of the DGNB UD tool has already incorporated weighting for the criteria based on different types of districts (five in total) and includes Agenda 2030 bonus points for projects contributing to climate action and other UN sustainability goals. Given the focus of this research on urban (re)development, emphasis is placed on the "City" district, thus establishing predefined weightings and excluding certain criteria and bonus points from the scoring mechanism. To facilitate the evaluation process, a thorough analysis of the remaining criteria was conducted to identify the types of information required for each component's evaluation. The SAT had three ways to test a component: addition, interpolation, and selection. The addition method involved achieving the maximum score for a component by complying with multiple scoring criteria that added up to the total maximum score. The interpolation method involved earning points by progressively putting more effort into the component's contents (e.g., for weighted environmental impacts, the project could be placed in one of four categories, with better positions earning more points). The selection method was similar to the interpolation method, but it involved choosing between multiple options (often two), so a project could not score higher by putting more effort into that component.

These three ways of component testing were integrated into the DSS so the computational model could easily compute the scoring based on user-entered details. Certain criteria required additional information from the project location or characteristics, necessitating a project attributes module for the user to fill in when using the system. This list of presets was necessary for the model to accurately score a project's design, elaborated further in Chapter 4.2.2.

Another critical aspect of this methodology involves associating the criteria with temporal phases. Building upon insights from the literature study, the system's usability is enhanced by aligning with established temporal aspects commonly utilized in the field: the initial phase, conceptual design phase, preliminary design phase, and final design phase. Each component is linked to the appropriate temporal phase, necessitating adjustments to the categorization and maximum scores achievable per aspect. This was done by carefully evaluating each component and allocating it to one of the four phases based on the level of detail required to answer that component. Although literature suggested that this process was best performed with experts in the field, the time-consuming nature of evaluating 232 components with multiple experts made this impractical. Therefore, the categorization was performed by carefully evaluating each component and allocating it to a certain phase based on its requirements. This allocation of criteria directly translated to a stepwise element in the model. Each phase dealt with more criteria, meaning that in the initial phase, the maximum achievable points were lower than in the definitive design phase. To compensate for this otherwise skewed representation of the achieved score, the overall scoring mechanism was altered. All the achievable points per phase were totaled, then based on the details filled in by the user, the score was determined relative to the project's current temporal phase. For example, if in the initial phase the score of the total project was 8% compared to all criteria, the actual score representable for that phase might be 80%, since not all criteria were valid for that temporal phase yet. This compensation assigned computational models to each phase, allowing for a realistic representation of the score for each temporal phase.

Based on interviews, some components might belong to a certain phase, but if they were not applicable to a specific project (due to location, regulations, or other factors), these criteria should not be included in the scoring mechanism. However, if a certain component had not been performed but could be for the project, a score of 0 should be given. Thus, for each component, the user had options that included the scoring elements determined by the DGNB tool, as well as a 0 score and a method to indicate that the component was not applicable to the project.

4.1.3 System Architecture

It was established in Chapter 4.1.1 that the model should allow users to set and prioritize specific goals at the initiation and adjust them throughout the project design phase. Consequently, a Project Goals (PG) module was added to the model to facilitate customizable goal-setting for aspects like CO_2 reduction and sustainable material use. From Chapter 4.1.2, it was evident that to effectively utilize criteria from the DGNB UD tool, certain project attributes needed to be specified for accurate scoring. To address this, a Project Presets (PP) module was also integrated. Moreover, expert feedback underscored the importance of enabling adjustments to both the PGs and PPs across the four design phases of the project, leading to the inclusion of a navigation menu to support seamless modifications during project evolution. It allows the DSS to adapt preferences and priorities according to the project's phase. This phase-specific flexibility enables the DSS to evolve alongside the project, providing relevant guidance and minimizing information overload for users.

The need for structured temporal phases was emphasized as crucial for the development of the model. This meant that to provide feedback to the user during each temporal phase, the model had to calculate the scores at any given time. As mentioned, the criteria from the DGNB UD tool were allocated to different phases. To avoid a skewed representation of the achieved score, it was essential that each temporal phase had its own connected computational model.

To support collaborative and holistic planning, the DSS has been integrated with the project kickoff process requirements, where the component activation can be altered by its users by means of a checklist to help identify sustainability opportunities, set agendas, and establish project deadlines. This checklist approach enhances early-stage planning and ongoing collaboration among stakeholders.

Insights per phase and the use of checklists for feedback were identified as necessary for the tool's usability. These requirements were gathered through expert interviews, which underscored the value of a stepwise procedure per phase. The use of checklists was deemed the most effective method for users to fill in details for each phase. These checklists facilitated a structured approach to data entry and progress tracking. Additionally, it was crucial that the details filled in by users were saved in the model for future reference and analysis. Given that the model was developed in Microsoft Excel, setting up a database for these checklists was relatively straightforward, leveraging Excel's robust data management capabilities.

Lastly, to further enhance usability, the DSS includes an introductory window outlining its purpose and functionality, as well as a final assessment window that provides a tailored overview of the project’s sustainability performance. This final view not only summarizes overall criteria scores but also offers targeted feedback aligned with the project’s goals, highlighting key areas of success and identifying opportunities for improvement. By structuring feedback in this way, the DSS addresses expert recommendations for clear, actionable insights and supports project teams in achieving specific sustainability objectives throughout the design process.

Concluding, the computational model integrated the PGs and PPs modules, the allocated DGNB UD criteria, and user input for each temporal phase. By incorporating goal customization features, such as adjustable scores for prioritizing sustainability goals, the DSS allows users to tailor the assessment to project-specific objectives like CO_2 reduction and sustainable material use. This integration allows for the calculation of scores designated to each specific phase, providing a comprehensive and dynamic assessment of the project's sustainability performance. The complete model, illustrating this integration, can be found in Figure 8, with a zoomed-in version available in Appendix 4. The following technical aspects sub-chapters will elaborate on the individual elements of the model in detail, providing a thorough understanding of their roles and functionalities within the model.

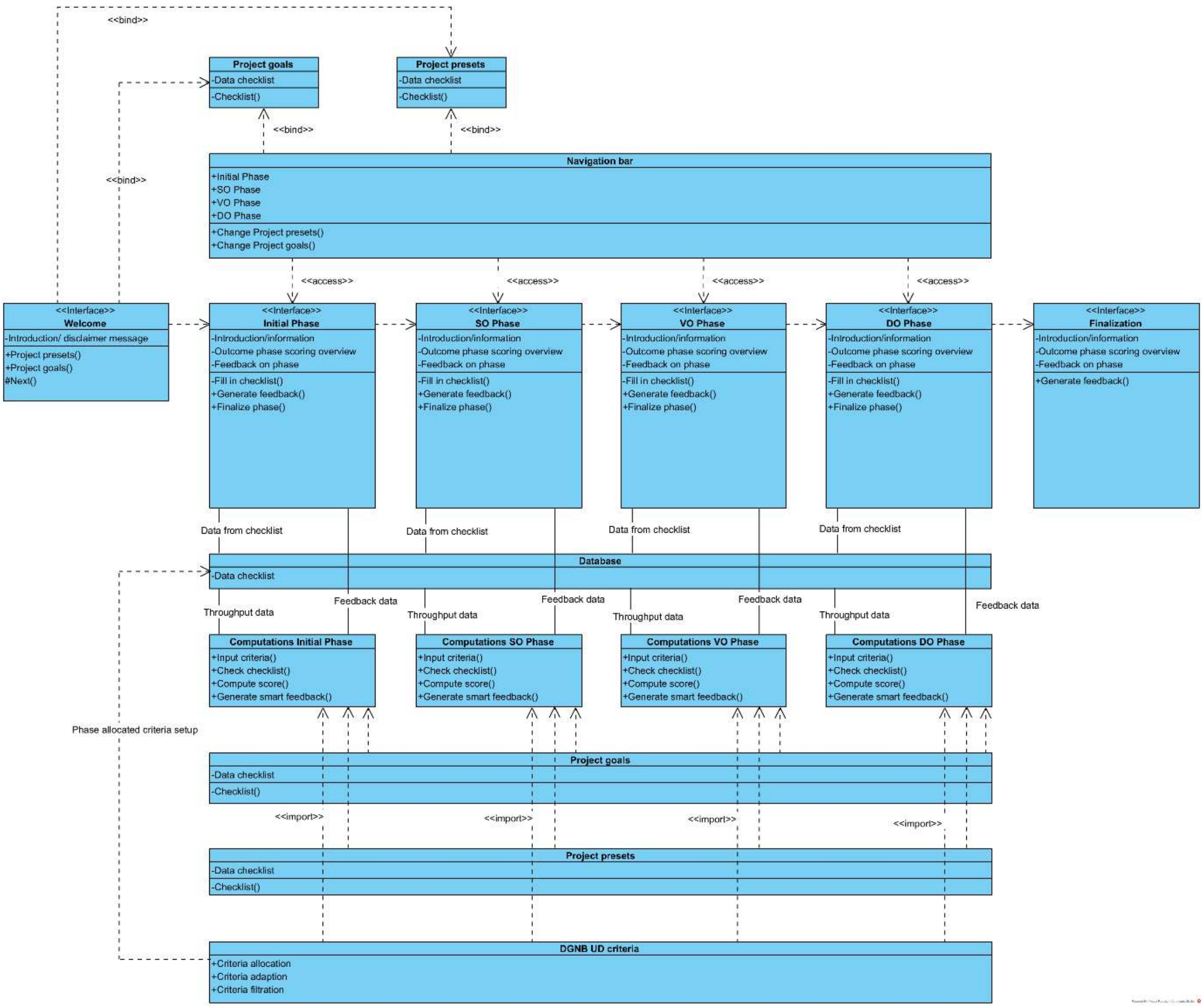


Figure 8: System architecture of the proposed model.

4.2 Technical Aspects

This chapter covers the technical components essential to the development of the DSS. It begins with the workbook baseline, outlining the structure and setup of the Excel environment. Next, the input presets are explained, detailing the necessary inputs for personalized calculations and how the database and code support this. The computational model is then described in detail, enabling future replication of the tool. The chapter also discusses the feedback mechanism, explaining how and why the system provides suggestive feedback. Finally, the iterative development process is addressed, highlighting how continuity of data is maintained, ensuring ease of use for users throughout all project stages.

4.2.1 Workbook Baseline

As stated in Chapter 2.2.3, to be able to work within a Microsoft Excel environment and use all the integrated components and macro programming language, the environment of the model has to be set to a certain standard: Excel Macro-Enabled Workbook (*.xlsm). This type of safe file allows for automated processes and coding in Visual Basics for Applications, essential for the desired automated processes such as filling in details, generating feedback, and supporting the iterative nature of the model.

From the system architecture, it became clear that two modules and ten worksheets were necessary for the model to function properly. These worksheets included four interfaces for temporal phases to receive feedback, four computational models connected to each temporal phase, a database for storing user-entered details, and a worksheet listing the criteria from the DGNB UD tool. Users were not required to interact with the computational models and the database directly. Therefore, it was crucial to ensure that users could only alter or add their project information without interfering with the underlying code or systems. This was achieved using built-in Excel functions for protecting worksheets and workbooks (Microsoft Support, 2024c, 2024b).

To ensure the integrity and security of the data within the Excel-based model, several protection measures were implemented throughout its development. Cells in the Excel worksheet were locked, and the sheet was protected with a password, preventing users from accidentally or deliberately changing, moving, or deleting data. Only specific, designated parts of the sheet were made editable, such as buttons for filling in presets, generating feedback, and checklists for the temporal phases of the model. This restriction ensured that users could not modify data in any other region of the sheet, thereby protecting the underlying data and formulas. Additionally, the structure of the Excel workbook was secured with a password to prevent users from viewing hidden worksheets, as well as from adding, moving, deleting, hiding, or renaming worksheets. This measure was crucial in maintaining the model's structure intact and ensuring that only authorized modifications could be made, thereby maintaining the accuracy and reliability of the system. Different levels of user permissions were also established, allowing only certain users to make critical changes while ensuring that general users could still interact with the necessary components of the system. These combined efforts in data security and integrity protected the model from potential misuse and ensured its reliability and accuracy over time, enhancing the trust and confidence of its users.

Automation and the use of macros were central to the development of the DSS model in Excel, significantly enhancing its functionality and user experience. The integration of VBA allowed for the creation of automated processes that streamlined various tasks within the model. VBA scripts automated data entry, ensuring that users could input project details quickly and accurately without repetitive manual work. These automated scripts also facilitated the generation of feedback based on the data provided, allowing for direct updates and insights crucial for the model's iterative nature. Key macros were developed to handle complex calculations and processes, such as dynamically updating the Project Goals and Project Presets modules as new information was entered. These macros also ensured that the computational models corresponding to each temporal phase were updated accurately, reflecting the most recent data inputs and criteria adjustments. This level of automation not only reduced the potential for human error but also made the decision support system more efficient and responsive.

Data backup procedures were also put in place to prevent the loss of information. Regular backups ensured that data could be restored in case of accidental deletion or corruption. These combined efforts in data security and integrity not only protected the model from potential misuse but also ensured its reliability and accuracy over time, thereby enhancing the trust and confidence of its users.

4.2.2 Input Presets

Given the uniqueness of each project, some criteria from the DGNB UD tool might not correspond with the specific project's agenda. Users might therefore want to allocate criteria differently from the standard temporal phases used in development projects. However, as mentioned in Chapter 4.1.2, the development process of this model is complete when the 232 components are allocated by a group of experts in the field of SUD, making a standardized version available for users. To facilitate a user-friendly and widely applicable model, both standardized and user-defined criteria allocation options are available. Users can choose either the standardized criteria allocation or allocate each component to their corresponding phase. To provide a frame of reference, users can view how the standardized allocation of the criteria is set up. This has been implemented using the Macro Recorder in Microsoft Excel. Macro Recorder captures actions performed by the modeler and converts them into VBA code, such as entering text, selecting cells, using commands, formatting, and importing data. Efficient macro recording ensures smooth execution, and any issues can be resolved by re-recording or manually modifying the VBA code (Microsoft Support, 2024a).

The standardized list created by experts has been imported with a macro. After starting the recording, the first step is to navigate to the worksheet with the DGNB criteria and click the "Standardized list" button. The macro then clears the contents of the four temporal phases to eliminate double data, resulting in blank columns. Each component is manually marked with an “x” in the expert-allocated temporal phase, and the recording is stopped, producing a standardized list in the DGNB criteria worksheet.

Users can also allocate criteria themselves by filling in the list manually. To facilitate this, a "Clear Selection" button has been added, linked to a macro that clears the criteria allocation section, allowing users to start with a blank worksheet. Users preferring a hybrid approach can load the standardized list and adjust the “x” placements as needed. To ensure proper allocation, the DGNB UD handbook is embedded as a PDF file in the Excel Workbook.

To save the allocation of criteria for use throughout the model, a "Save Criteria Allocation" button has been created, linked to a macro (Listing 1). This automated process ensures that criteria are activated for each temporal phase following the one to which it was allocated. The macro first checks each row for the occurrence of “x” via a validation loop. If errors are found, an error message lists the problematic rows. If no errors are found, the macro fills in “x” for subsequent phases after the manually entered “x”. Upon successful completion, a confirmation message box is displayed. This ensures a user-friendly environment and accurate criteria allocation throughout the project's design duration.

```
Sub SaveAndValidate()
    Dim ws As Worksheet
    Set ws = ThisWorkbook.Sheets("DGNB crit")

    Dim i As Long
    Dim j As Long
    Dim rowError As String
    Dim errorMessage As String

    ' Clear any existing error messages
    errorMessage = ""

    ' Loop through each row to check for errors
    For i = 2 To 245
        Dim countX As Integer
        countX = 0

        ' Count the number of "x" in each row
        For j = 17 To 20    ‘Columns corresponding to the 4 temporal phases
            If ws.Cells(i, j).Value = "x" Then
                countX = countX + 1
            End If
```

```
      Next j

      ' Record any errors
      If countX = 0 Then
         errorMessage = errorMessage & "Missing 'x' in row " & i & vbCrLf
      ElseIf countX > 1 Then
         errorMessage = errorMessage & "Multiple 'x' in row " & i & vbCrLf
      End If
   Next i

   ' If there are errors, display message and exit sub
   If errorMessage <> "" Then
      MsgBox "Errors found:" & vbCrLf & errorMessage, vbExclamation
      Exit Sub
   End If

   ' If no errors, proceed to fill in subsequent phases
   For i = 2 To 245
      For j = 17 To 20 ' Columns Q to T
         If ws.Cells(i, j).Value = "x" Then
            ' Fill subsequent phases
            Dim k As Long
            For k = j + 1 To 20
               ws.Cells(i, k).Value = "x"
            Next k
            Exit For   ' Exit the inner loop once the first "x" is found
         End If
      Next j
   Next i

   ' Confirmation message
   MsgBox "Data saved and validated successfully!", vbInformation
End Sub
```

Listing 1: Automated process for criteria allocation by user.

The result from the initial macro is that each temporal phase has a list of allocated criteria. These criteria need to be transformed to the database worksheet via an automated process. To achieve this, the macro from Listing 1 must be extended to automate the consolidation of the four phases into the database. This extension of the macro is provided in Listing 2. The extended macro ensures that for every "x" in columns Q, R, S, or T in the source worksheet containing the allocated DGNB criteria, the value in column M is transposed per temporal phase to rows 1, 5, 10, or 15 respectively in the database worksheet. To be able to label and link corresponding data throughout the model, a Globally Unique Identifier (GUID) has been developed. This GUID is a combination of the criterion label and the component number subsequent to that label (e.g. ENV2.4 and 5.1 respectively), which results in the GUID of Env2.4_5.1. For every component a GUID has been created and allocated to a certain column in the DGNB criteria worksheet, column M in this particular case. Automation is crucial for maintaining consistency and efficiency in handling the data across different phases of the project. The details filled in by the user are saved in the "database" worksheet, directly below the rows with the GUIDs of each temporal phase, specifically in rows 2, 6, 11, and 16 respectively.

```
Sub SaveAndValidate()
   Dim srcSheet As Worksheet
   Dim destSheet As Worksheet
   Dim lastCol As Long
   Dim colOffset As Long

   ' Set worksheets
```

```
    Set srcSheet = ThisWorkbook.Sheets("DGNB crit")
    Set destSheet = ThisWorkbook.Sheets("database")

    ' Clear the destination rows first
    destSheet.Rows(1).ClearContents
    destSheet.Rows(5).ClearContents
    destSheet.Rows(10).ClearContents
    destSheet.Rows(15).ClearContents

    ' Loop through each row in the source sheet
    For i = 2 To 245
        If srcSheet.Cells(i, "Q").Value = "x" Then
            ' Find the last column with data in the destination row
            lastCol = destSheet.Cells(1, destSheet.Columns.Count).End(xlToLeft).Column
            ' Copy the component label to the destination row 1, leave the first column blank
            destSheet.Cells(1, lastCol + 1).Value = srcSheet.Cells(i, "M").Value
        End If

        If srcSheet.Cells(i, "R").Value = "x" Then
            lastCol = destSheet.Cells(5, destSheet.Columns.Count).End(xlToLeft).Column
            destSheet.Cells(5, lastCol + 1).Value = srcSheet.Cells(i, "M").Value
        End If

        If srcSheet.Cells(i, "S").Value = "x" Then
            lastCol = destSheet.Cells(10, destSheet.Columns.Count).End(xlToLeft).Column
            destSheet.Cells(10, lastCol + 1).Value = srcSheet.Cells(i, "M").Value
        End If

        If srcSheet.Cells(i, "T").Value = "x" Then
            lastCol = destSheet.Cells(15, destSheet.Columns.Count).End(xlToLeft).Column
            destSheet.Cells(15, lastCol + 1).Value = srcSheet.Cells(i, "M").Value
        End If
    Next i
End Sub
```

Listing 2: Addition to code for the SaveAndValidate() macro for automated process to generate database.

The other two essential presets incorporated into the model are the Project Goals (PG) and Project Presets (PP). The PG module allows users to set and prioritize specific goals at the project's initiation, ensuring alignment with human-centric values and sustainability objectives. The PP module is crucial for specifying project attributes needed to calculate scores using the DGNB UD tool. These presets are vital for providing accurate feedback and enabling adjustments throughout the project's different stages.

For the PG module, it was concluded that users should have the option to choose between various specific dimensions, going beyond the generic five dimensions of the DGNB tool. Instead, the 11 criteria groups that build up the five dimensions corresponding to the “City” district have been incorporated. Although experts initially preferred a slider function for setting goals, VBA does not support this feature. Therefore, a Likert scale, as recommended by De Piante Henriksen & Palocsay (2008), has been implemented. This scale allows respondents to choose the option that best corresponds with their feelings about each criterion. A seven-point Likert scale was selected to capture a nuanced range of importance for the 11 criteria groups, allowing users to prioritize more accurately. This method ensures alignment of expectations and goals among all stakeholders, reducing the chance of dissatisfaction (Bhandari & Nikolopoulou, 2023). To facilitate understanding, each criteria group is accompanied by a brief explanatory text, and a button linking to the embedded PDF document of the DGNB tool has been added for additional insights. The details filled in by the users to answer each component are saved in a designated database in a separate worksheet.

For the PP module, all criteria from the DGNB UD tool were thoroughly analyzed to identify the necessary information required for accurate calculations, such as project size (ha) and top environmental risks. These details are also saved in a designated database in a separate worksheet. Both preset worksheets contain headers in the first row and user-filled information in the second row. To ensure data integrity and prevent interference, all three database worksheets are hidden and locked from user access, protecting the model from corruption.

4.2.3 Computational Method

It was determined that each temporal phase must have its own computational model, where each computational model has to deal with data from four sources. Each imports data from the PG database, PP database, the overall database, and the DGNB criteria worksheet. Each of these data inputs will be discussed in this chapter, this will be in order of the computational method appearance. First is the standardized setup of the calculation sheet. This is structured horizontally, showcasing every criteria that is in the DGNB handbook, and aligning with the horizontal structure of the databases, allowing for easy integration. Since the computational model is positioned horizontally, the labels of each row have been positioned in the first column. These labels and elaboration of the contents of these rows is provided in Table 5.

Table 5: Contents of the buildup of the computational model worksheet.

Row	Row label	Content elaboration
1	Topic	The five topics of the DGNB UD tool
2	Criteria group	The twelve criteria groups within the five topics
3	Project goals factor per criteria group	The Likert scale score imported from the PG database
4	Relevance factor criterion	As set in the DGNB UD tool per criterion
5	Component label	The GUID
6	Points per component	Maximum amount of point that can be achieved
7	Bonus point	Indicates with a “x” if this component is a bonus point
9	Input checklist	Imported data from the database containing the details filled in by the users to answer each component of the specific temporal phase corresponding to that computational model
11	Options	The answers options of the components as set in the DGNB UD tool
26	Points achieved per component	Points achieved based on the answer options set in the DGNB UD tool
28	Total points per criterion	Accumulation of all points scored per criterion
29	% Achieved per criterion	(Scored points/maximum achievable)
30	Total points per criteria group	Accumulation of all points scored per criteria group
31	% Achieved possible per criteria group	Accumulation of % achieved that is possible per criterion for that temporal phase
32	% Achieved per criteria group (incl relevance factor)	Accumulation of % achieved per criterion * weighted factor
33	Total points per topic	Accumulation of all points scored per topic

34	% Achieved per topic	Accumulation of % achieved per criteria group & with weighted factor scoring per criteria group

Some of the contents are directly derived and copied from the DGNB UD tool, thus will not be elaborated upon, the remaining contents will be elaborated upon per paragraph.

In the PG module, the user will indicate which topics are more important, using a seven-point Likert scale. The filled in data is imported into the computation worksheet in a numeric value. This is a simple formula that has been pre-set in every cell in this row, where only the column label of the linked worksheet changes (='database PG'!A2) up to (='database PG'!K2).

To automate the allocation and transfer of criteria from the "DGNB crit" worksheet to the "IP comp (!)" worksheet, a specific Excel formula was employed. This formula ensures that the maximum achievable criterion points are accurately copied based on two conditions. The formula of a cell in row 6 in the "IP comp (!)" worksheet checks the "DGNB crit" worksheet to find a row where the value in column M (GUID) matches the value in of a cell in row 5 and the corresponding cell in column Q (first temporal phase) contains an "x". Once such a row is found, it retrieves the value from column P (maximum component score) of that row and displays it in the designated cell in row 6. This process ensures that criteria labels are correctly transferred based on the matching GUID. The ranges in this formula are set to absolute references to make sure that these do not shift and the formula gets corrupted. There is one mixed reference preset “B5”, this has been done so that the cell could be dragged over the whole width of the computation worksheet so that it checks for every component whether or not the formula is true. In each computational model a range in this formula has been altered so that it can fit each computation model (*'DGNB crit'!$Q$2:$Q$245*), it is changed in to a different column in the criteria worksheet so that it imports each temporal phase, these columns (Q, R, S, T) are also incorporated in the code in Listing 2. The formula used to calculate the achieved points can be found in Listing 3 in Appendix 5.

To automate the allocation and transfer of the bonus point indicator from the “DGNB crit” worksheet to the “IP comp (!)” worksheet, the formula used in Listing 3 has been repurposed. Only the INDEX has been altered to retrieve data from column J (bonus indicator) in the DGNB criteria worksheet. The formula used to calculate the achieved points including bonus points can be found in Listing 4 in Appendix 5.

To automate the transfer of data based on specific criteria between worksheets, a precise formula was employed in the Excel model. This formula ensures that values are accurately copied from the "IP database" worksheet to the "IP comp (!)" worksheet based on matching conditions of the GUID. The formula in a cell in row 9 of the "IP comp (!)" worksheet checks the "IP database" worksheet to find the column where the value in row 1 matches the value of a cell in row 5 of the "IP comp (!)" worksheet. Once such a column is found, it retrieves the corresponding value from row 2 of that column and displays it in the designated cell in row 9. This automated process ensures accurate data transfer based on the matching GUID. The ranges in this formula are set to absolute references to make sure that these do not shift and the formula gets corrupted. There is one mixed reference preset “B$5”, this has been done so that the cell could be dragged over the whole width of the computation worksheet so that it checks for every component whether or not the formula is true. In each computational model the two ranges in this formula have been altered so that it can fit each computation model, they are both changed to different rows. As indicated in Listing 2, the data is saved on rows 2, 6, 11, and 16, and the GUID’s are saved on rows 1, 5, 10, and 15. Therefore the row numbers have been altered to these numbers in the formulas for each computational model. The formula used for automated user data import determined by the GUID can be found in Listing 5 in Appendix 5.

To be able to have a user-friendly interface, the determined most effective method has been incorporated. This method entails the use of checklist to facilitate a structured approach to data entry and this integration minimizes the risk of human error. For each component, the DGNB tool has predetermined answers with corresponding scorings. To eliminate the human error, the contents for a drop-down lists have been drafted up for these predetermined optional answers for each component. As mentioned in Chapter 4.1.2, some components might nog be applicable to a specific project or have not been performed yet during the development. Therefore the list has been expanded upon by implementing a 0-score called “Not performed” and a “Not applicable” equating a full-score to accommodate for these instances. Due to the three different types of component testing, some answers have been altered to fit the contents of a dropdown list.

As has been stated, row 9 imports the data filled in by the user. Row 26 automatically calculates, using a simple formula, the scores that match the filled in data by the user. The formula used for scoring each component by a matching approach can be found in Listing 6 in Appendix 5.

This formula works by first using the MATCH function to find the position of the value in the cell that imports the data filled in by the user within the range of options of the contents for the checklist. The MATCH function returns the relative position of this value, ensuring an exact match (denoted by 0). The resulting position index is then passed to the CHOOSE function, which selects a value from a list based on this index. The CHOOSE function's list contains the values 0, 2, 4, 6, 6, 8, B6, B6, corresponding to possible positions identified by the MATCH function. These values are based on the points that can be scored per content of the checklist derived from the DGNB tool, the first referenced cell in this list (B6) is the maximum obtainable score. This setup allows for flexible retrieval of values based on dynamic inputs, ensuring that each data import value maps to a specific outcome. For each component a custom formula has been made to fit the afore mentioned contents for the checklist, therefore no specific references are used in this formula. The first value of the MATCH function (0) reflects the “Not performed” option and the last value of the formula (B6) reflects the “Not applicable” option.

The calculation for the performance of the design in the designated temporal phase has been done in a stepwise manner. First the scores per criterion are calculated by summing the normal components (row 26), meaning that the components that are marked with a “x” in row 7 (bonus points) following Listing 4 are not taken into this summation. This process has been automated by means of a personalized formula for each criterion. The formula used for determining the obtained points per criterion excluding bonus points can be found in Listing 7 in Appendix 5.

This formula works by using the SUMIF function to evaluate the range with bonus point indicators within each criterion. The criterion ("<>x") in the formula instructs Excel to include only those cells that do not contain an "x". Consequently, the corresponding values in the range of points achieved per component are summed, effectively omitting the value in the column where "x" is found in row 7. This approach ensures that the summation operation dynamically adapts to the presence of an "x" in row 7, providing accurate and relevant results based on user inputs.

Subsequently, the achieved scores per component have been divided by the maximum obtainable score excluding the bonus points for that specific criterion. This has been done by taking example of Listing 7. The formula used for determining the achieved weighted score per criterion excluding bonus points can be found in Listing 8 in Appendix 5.

For the calculation of the achieved weighted score of the design in the designated temporal phase per criterion, multiple aspects have been taken into account. First it is crucial to take the relevance factor of each criterion into account, this determines the weighted factor of the criterion. Since these values are directly copied from the DGNB tool, it is important that only the relevance factors of the criteria that are present in a temporal phase are taken into the calculation. Therefore the relevance factors have been transformed to a percentage of the total amount of relevance factor points corresponding to that temporal phase. To have this function automated in each computational model, an extensive formula was used. The formula used to sum the relevance factor points per corresponding temporal phase can be found in Listing 9 in Appendix 5, where the choice of column can be altered to fit each temporal phase.

For the calculation of the achieved weighted score of the design in the designated temporal phase per criteria group including the achieved bonus points in percentage, multiple aspects have been taken into account. First the total points in the criteria group need to be summed, this is including the bonus. As stated, bonus points can make a criterion overflow, the overflowed points can be distributed within a criteria group. Therefore, the bonus points are credited in this row and not before. To credit the bonus points, the formula in Listing 7 has been heavily adapted so that it only sums the points achieved when they are marked as a bonus point over the entire width of the criteria group. Subsequently it is important that the maximum amount of points achieved will not exceed the maximum creditable points, which is 100 per criterion. Since each computational model has different criteria "activated" based on their temporal phase allocation, the computational model must be capable of calculating the maximum creditable points corresponding to these phases. This requires the model to dynamically adjust to the specific criteria relevant to each temporal phase. This has been solved by adapting the formula used in Listing 9 to the ranges of each criteria group. The full formula to count for each group whether it belongs to a certain phase can be found in Listing 10 in Appendix 5.

To be able to calculate the obtained score per criteria group whilst taking into account the weighted factor per criterion, the maximum of 100 obtainable points per criterion, and the possibility of abundant points overflowing to other criteria within their criteria group an excessive formula has been set up. This formula is only used for the criteria groups that facilitate the overflowing of abundant points, which is the case for 7 of the 11 groups. The formula starts by summing the points achieved within a specified range for each criterion. Each criterion group can score up to a maximum of 100 points. However, in cases where bonus points cause the total to exceed this limit, the formula calculates the excess points using the MAX-function. This calculation checks if the sum of points in the adjacent criterion group exceeds 100. If so, the excess points are added to the current criterion group. To ensure that only active criteria groups are considered, the formula uses the IF-function. This part of the formula checks if any criteria in the specified range are active (marked by "x"). If active, it sets the maximum achievable points for that criterion group to 1, which is subsequently multiplied by 100. The formula then normalizes the achieved points by taking the minimum of the adjusted total points or the maximum achievable points. This ensures that the total points for the criterion group do not exceed the maximum allowable points. The same calculations are repeated for the following criteria within the criteria group. Finally, the formula sums the normalized points for both criteria. This gives the total adjusted score, ensuring that any overflow points are correctly accounted for and that only active criteria contribute to the final score. The formula for each criteria group to calculate the obtained points per criteria group including the achieved bonus points can be found in Listing 11 in Appendix 5.

For the other 4 criteria groups that do not facilitate bonus points, thus the overflowing of points to other criteria, a simplified formula is used. The simplified formula can be found in Listing 12 in Appendix 5.

For the calculation of the achieved score of the design in the designated temporal phase per criteria group in percentage, a small adaption has been made to Listing 11. The first change is that the obtained scores are divided by the sum of the maximum obtainable scores per criterion in their significant temporal phase. Then in the addition at the end of the formula, to account for the result not being larger than 100%, another division is added that counts the activated criteria. The formula for each criteria group to calculate the achieved score per criteria group including the achieved bonus points can be found in Listing 13 in Appendix 5.

For the calculation of the achieved weighted score of the design in the designated temporal phase per criteria group in percentage, a small adaption has been made to Listing 11. What has been added are two factors, for each criterion the maximum obtainable score, as well as the weighted factor in percentage has been added. The adapted formula for each criteria group to calculate the achieved weighted score per criteria group including the achieved bonus points in percentage can be found in Listing 14 in Appendix 5.

The final two rows in the computational model indicate the scoring of the entire project design in points obtained and score achieved per topic, with all the aforementioned elements taken into account. The formulas used are simple summations, where for the points obtained from the criteria groups (row 30) are summed and for the achieved scores from the criteria groups (row 31) are summed and subsequently divided by the number of activated criteria groups. For the achieved weighted score, this division is not present in the formula, since the weighted score provides for the factor of the whole. These results are used to feed the feedback mechanism, which will be discussed in the next section.

4.2.4 Feedback Mechanism

To be able to provide feedback to the users of the DSS, the results from the computation model have to be interpreted. Most importantly, the preferences derived from the Likert scale have to be incorporated for proper personalized feedback. However, as stated, the users need to have the possibility to adjust their preferences throughout the development process, therefore an adaptive system has been developed, that update the feedback based on the made changes. All the elements of the feedback mechanism have been added to the same worksheet as the computational model, so that the overall model would not become too complicated or extensive.

The first element of the feedback mechanism is to check the overall score of the project. This has been done by creating an new table in the worksheet. This table consists out of three columns, the first one contains the five topics of mentioned in the DGNB handbook. The second column contains the achieved score in percentage. The third column contains the achieved weighted score in percentage. The second and third column are directly copied from row 34 of the computational model. Table 6 showcases the contents of the table when full scores are obtained for the initial phase. As can be seen in the bottom right cell, the overall score of the project for that temporal phase is at 100%, this score is used as feedback and is displayed in the interface for each specific temporal phase. For additional visual aid, the first two columns are loaded into a graph, which is also displayed in the interface of each specific temporal phase.

Table 6: Scoring result derived from computational model for feedback mechanism.

Topic	Score	Score
Environmental Quality	100%	32%
Economic Quality	100%	14%
Sociocultural And Functional Quality	100%	26%
Technical Quality	100%	17%
Process Quality	100%	12%
		100%

To be able to generate personalized feedback for the user, multiple steps have been taken to achieve this data. As stated before, the Likert scale that translates the personal preferences of the users is set per criteria group. To create an overview of the scores per criteria group, a simple formula was used, which can be found in Listing 15 in Appendix 5. Row 2 entails the abbreviations used for each criteria group by the DGNB handbook. The condition for the filter function is that it only returns the cells that contain a value. The exact same formula has been used to retrieve the scores per group and the Likert scale score per group, only now has the range be adjusted to the contents of row 31 and row 3 respectively. From this newly formed overview, a radar graph is generated that showcases the score per criteria group which will be displayed in the interface for each specific temporal phase.

The next step is to filter this table so that the groups labeled more important by the user return on top. The formula used to achieve this action can be found in Listing 16 in Appendix 5. This formula operates in two stages: First, it filters the data range E48:G58, excluding any rows where the corresponding cell in column F is empty. This ensures that only complete data entries are considered in subsequent analyses. Second, the filtered data is sorted based on the values in column F (number 2 in formula), arranged in descending order (number -1 in formula). The sorting mechanism prioritizes rows with the highest values in column F, bringing them to the top.

From the filtered results, there has been chosen to look at the top 5 returning criteria groups only. Since the user has indicated that for the development of their project, these criteria groups are most important, lower scoring groups via the Likert scale should not be taken into consideration for the direct feedback. From the top 5 returning groups, again a radar graph is generated that showcases the score per criteria group which will be displayed in the interface for each specific temporal phase.

Following the top 5 most important criteria groups, five analysis column-groups are generated, each consisting out of four subsequent columns. To label each analysis column-group, the label abbreviation of the criteria groups mentioned are copied from the top 5. In the first column of each group, the GUID of the components present in that specific temporal phase is loaded in by using the formula found in Listing 17 in Appendix 5. The formula functions by first applying the SEARCH function to the range with GUIDs, looking for any partial matches with the text contained in cell B64 (criteria group label). The SEARCH function returns the position of the match as a number if a match is found, and the ISNUMBER function then converts these results into a logical array of TRUE (indicating a match) or FALSE (indicating no match). Next, the FILTER function uses this logical array to filter out any cells in the range that do not contain the specified text from B64. The filtered results consist only of the cells that matched the search criteria. Finally, the TRANSPOSE function is applied to convert the filtered row of matching data into a vertical column format.

To facilitate feedback, the scoring per component has been imported into the second column of each column-group. The formula used for this action is more intricate. The formula operates by first using the MATCH function to identify the exact column in the range of component labels ($B$5:$CI$5) that corresponds to the value in cell $B65 (value in first column). This column index is then used by the

INDEX function to retrieve the corresponding value from row $B$26:$CI$26 (points achieved). Simultaneously, the formula retrieves the value from the same column in row $B$6:$CI$6 (maximum obtainable points) using another INDEX function. The two retrieved values are then divided, allowing for a direct comparison of the data from these rows based on the matching column. To ensure robustness, the IFERROR function is incorporated to handle cases where no match is found. If the MATCH function does not find the specified value from $B65 in the range $B$5:$CI$5, the formula returns "No Match" instead of an error. The formula used in the second column of the first column-group can be found in Listing 18 in Appendix 5. As a result, the first two columns are filled with "activated" GUIDs and their corresponding score based on the top 5 of most important criteria groups for each temporal phase.

The obtained first two columns are sorted in the third and fourth columns using an altered version of the formula used in Listing 16. Only now the sorting order is ascending, so that the lowest scoring components come out on top. This has been done to facilitate an easy overview of the components that still need to be changed and have the highest impact, since a component with a low score can easily be improved, but a component with an already high score is less likely to improve without a lot of effort. The formula used can be found in Listing 19 in Appendix 5.

This entire mechanism provides for direct adjustments, since all the cells are interlinked. If there is one change somewhere in the input, or in the project goals, the entire computational model and the feedback mechanism will adapt to these changes and give other outcomes. As mentioned, to providing feedback to the user on which aspects to improve before going to the next temporal phase, a smart but simple mechanism has been put in place. For each criteria group, the components that score less than 100% are imported and displayed on the interface of that specific temporal phase. This results in the user having direct feedback on which components to focus on if they want to improve the design in this temporal phase.

4.2.5 Iterative Development Process

To enhance user-friendliness, an iterative process was incorporated. As the DGNB tool adopted a holistic triple-bottom-line approach with numerous set criteria, it would be cumbersome if users had to repeatedly fill in the same criteria at different temporal phases. Thus, the model saves progress at each stage to make it more adaptable. As mentioned in the aforementioned chapters, the model is made adaptive to any changes made in each stage. Starting with the allocation of the components to the temporal phases, which are directly transferred to the database to facilitate an automated database (see Chapter 4.2.2). The database itself has been adapted to be iterative by means of a simple formula. On rows 6, 11, and 16, a formula is used to check if a phase is finished by checking one cell for a certain value. If true, the formula looks up the value of the cell above itself in the range belonging to the previous phase. When a match is found, it retrieves the corresponding input of the previous phase and returns it. If no match is found, it does not return anything, otherwise the computational models return errors. The formula that facilitates daisy-chaining can be found in Listing 20 in Appendix 5.

As visible in the listing above, a finalized phase is indicated with an "x". The user finalizes a phase by means of an automated process. Each worksheet belonging to a temporal phase is incorporated with a button "Finalize Phase" that has the macro assigned to it that puts an "x" in the database of that temporal phase. This is a simple recorded macro. The macro has been expanded upon by activating the button to go to the next phase which is in the navigation bar.

An additional button that has been added to this worksheet is the automated personalized feedback generation. As stated before, each temporal phase has its own worksheet that displays the quality of the design based on the input of the user. The worksheets are provided with the basic graphs. However, with this addition to the worksheet, the personal feedback based on the input by the user is loaded into the worksheet. Additionally, only when the last temporal phase has been finalized, thus marked with an “x” in the database, the result worksheet generates the final score for the user.

To facilitate a fully automated and iterative decision support system, the user forms of each temporal phase have been made adaptable as well. The allocation of components as discussed in Chapter 4.2.2 hinder the user form for each temporal phase to be pre-designed due to multiple factors. First, due to the fact that the components can be personally activated for each desired phase, the number of components that need to be dealt with in the user form needs to be adaptable. The direct linked next problem is the contents of the combo boxes, these need to correspond specifically with the activated components. Therefore this user form has been entirely made by means of code. The code sets the user form to a standard width, it provides a scroll bar, and it also incorporates two buttons that allows the user to open the DGNB handbook and to save their input. The code used for the development of this iterative user form can be found in Appendix 5, its contents will be further elaborated upon Chapter 4.3.2.

4.3 Graphical User Interface

The previous chapter deals with all the details about the backend of the model, to have the details worked out and interpretable for the user, DSSs are equipped with smart graphical user interfaces (GUIs), as has been elaborated upon in Chapter 2.2.3. Designing a user-centric interface and efficient navigation system was crucial for ensuring the DSS model's usability and accessibility. The interface was designed with the end-user in mind, prioritizing ease of use and intuitive interaction. Each worksheet within the model was carefully structured to present information clearly and logically, minimizing the learning curve for new users. The use of buttons and interactive elements allowed users to navigate between different sections of the DSS effortlessly, enhancing their overall experience. A key feature of the user interface was the navigation menu, which enabled users to move seamlessly between the Project Goals module, Project Presets module, and the various temporal phases. This menu was designed to be intuitive, allowing users to easily access and modify different parts of the model as their project progressed. The elements that make up the GUI of the DSS are elaborated upon in the following two sub-chapters.

4.3.1 Worksheets

As discussed in Chapter 4.2.1, the model is built up out of eleven worksheets. Out of which the user interacts with 6, being the welcome screen, the phase interfaces, the result worksheet, and the criteria allocation worksheet. In the sections of previous sub-chapter, the elements of these worksheets have been elaborated upon extensively. This section will showcase solely the sheets and give elaborations on them, command buttons or other VBA supported elements will be dealt with in the next chapter. The sheets will be dealt with in chronological order.

When the user opens the program, the “Start” worksheet automatically opens. This worksheet is provided with an elaborate text, explaining the goal of the system and how to use it. From the interviews it became clear that the model must not be used as a decision determining system, but rather to see where the possibilities for improvement lie. Therefore it is important to highlight this inside the system as well, this has been done by means of a disclaimer message that is visible when the excel file is opened. Next it has two buttons, “Start” opens a VBA supported UserForm via which the user fills in the Project Presets and the Project Goals. Additionally, the worksheet is provided with a “Next” button that allows the user to go to the first phase. The button has been provided with a VBA code that has been recorded, it resets the personalized feedback mechanism, so that the user has to mindful fill in the elements of the system, without taking false assumptions or misinterpretations. In general, the button provides the next interface of a clean start. The interface can be found in Figure 9.

The next interfaces the user has to interact with are the ones linked to each temporal phase. Each of these interfaces has a navigation menu with buttons for each phase, as well as two buttons that open up the preset user forms. The buttons linking to the temporal phases are only activated once the corresponding preceding databases have data in them. The general part of these interfaces are identical, they each have an explanatory text that explains how to use each specific interface. They each have a “Checklist”, “Generate Feedback”, “Component Explanation”, “Finalize Phase”, “Previous”, and “Next” buttons. The “Checklist” button opens up a VBA supported UserForm corresponding to that specific temporal phase. After filling in the checklist, the interface displays the scoring of the project design, as well as the scoring for the top five most important criteria groups, according to the project goals defined via the Likert scale. Then, via the “Generate Feedback” button, the user is provided with the badly performing components of each of the five criteria groups. The user can use the “Component Explanation” button to find the details of these components to improve on these components, via a hyperlink. Once the user has decided that the temporal phase has been finished and no additional changes will be made to the design, the “Finalize Phase” button can be clicked. This activates the recorded VBA macro, which copies the data from the current to the next phase, ensuring the iterative mechanism that has been described in Chapter 4.2.5. Lastly, the “Previous” and “Next” buttons allow the user to go back and forth between the phases. The worksheet of the Initial Phase, with generated feedback can be found in Figure 10.

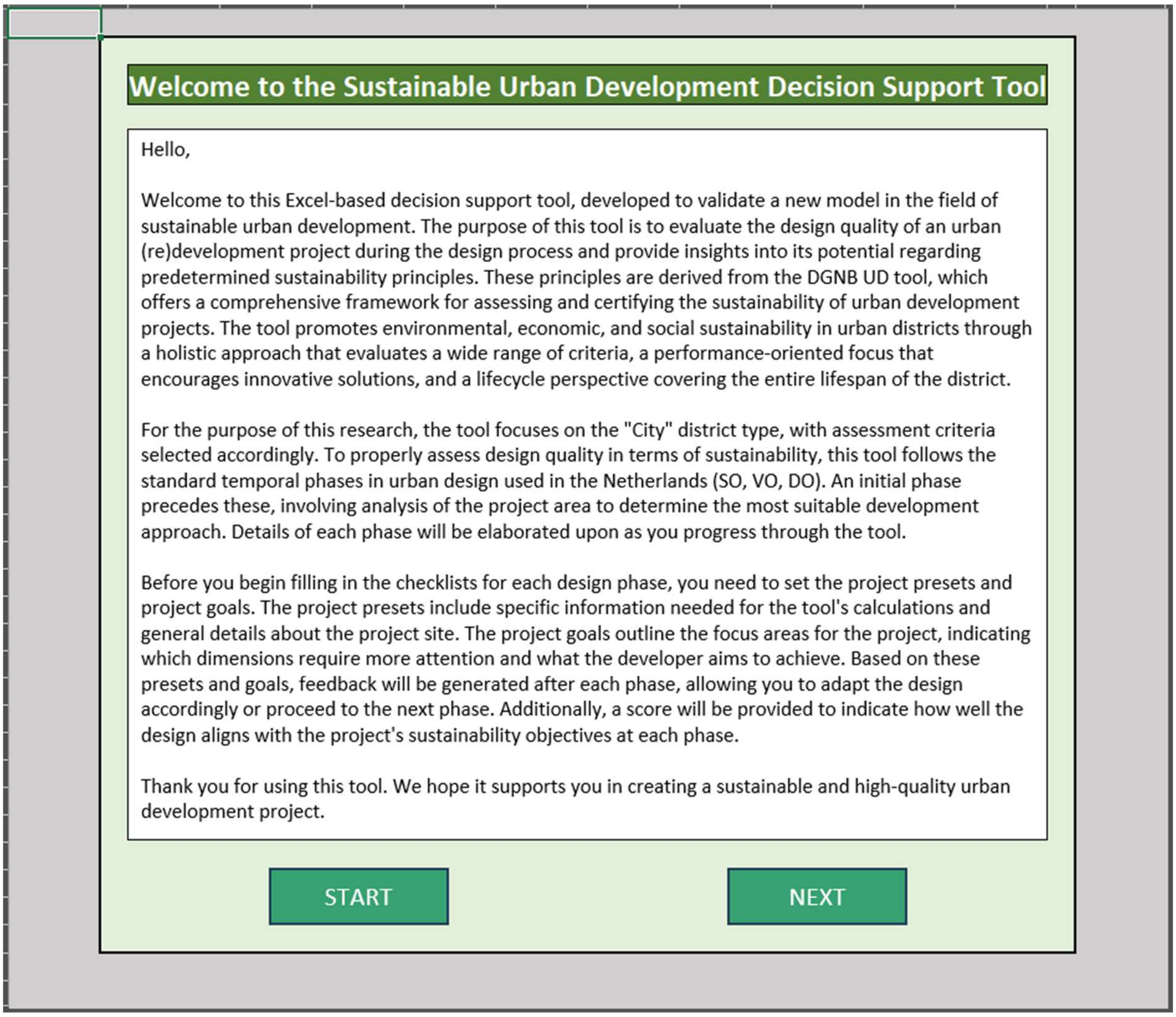


Figure 9: Excel worksheet "Start".

The final interface that indicates the performance of the project design is the “Result” interface. This interface is a simplified version of the previous interfaces. All the buttons on the right side of the interface have been left out, there is just one new button on this interface; “Computational Model”. This button is added to provide the user with a transparent overall DSS. In the computational model the user can see how the scores are derived and see in detail where additional potential is for the project design. Also the buttons that allow the user to change the presets of the project have been set to non-active, since for the final result, these do not change the outcome. Furthermore, this interface showcases the overall score of the project design in a grade, again, this score is not the actual score the project has, since the DSS is merely meant for indicative purposes. This final interface can be found in Figure 11.

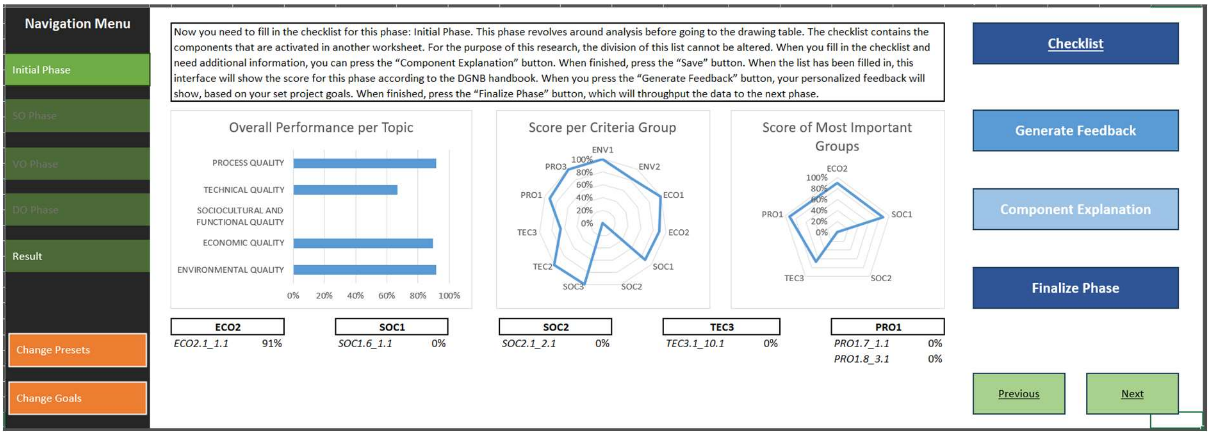


Figure 10: Excel worksheet "Initial Phase".

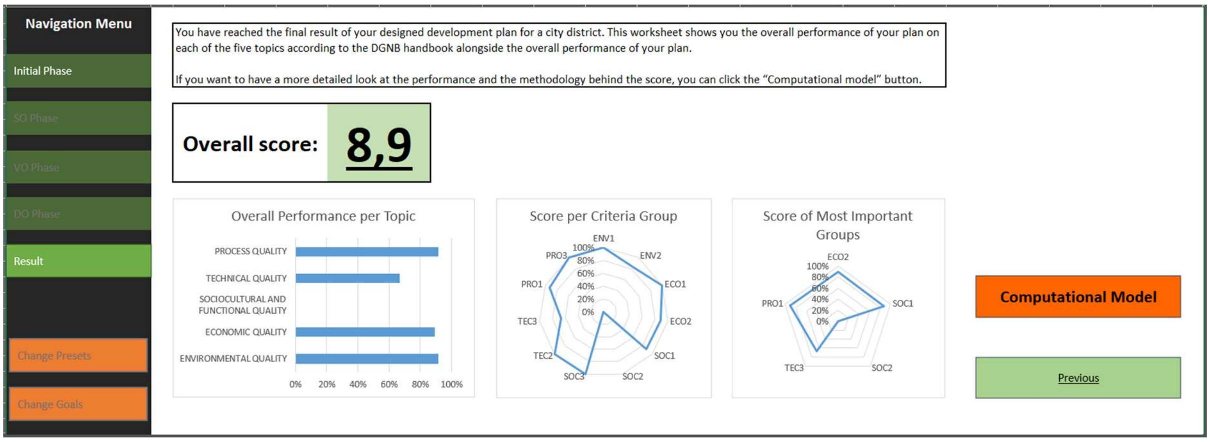


Figure 11: Excel worksheet "Result".

4.3.2 VBA

In total, the DSS has sixteen different macro's. Three are dedicated to the presets, three per temporal phase, and one that resets the feedback mechanism as described in previous chapter. Some of these macro's are recorded macros, whilst others are coded. As stated, the recorded macro's are used for the "Next" button in the "Start" worksheet, and for the "Generate Feedback" and "Finalize Phase" for each temporal phase. The code for these recorded macro's can be found in Appendix .

The VBA codes for the UserForms used in the DSS can all be found in Appendix . This chapter will show the UserForms themselves and describe what they entail and how the user will interact with them. The first user form the user sees and uses is called "frmFormStart", This userform is provided with a disclaimer, and three command buttons. The main message of the disclaimer is that the DSS must be used as a guiding method, and not as something to follow in every detail, the responsibility is still in the hand of the user. Two of the three buttons open another user form, one is dedicated to the project presets, and the other to the project goals. Once both user forms have been filled in, the third button is activated, allowing the user to be able to close this initial user form and start using the DSS. The "frmFormStart" user form can be found in Figure 12.

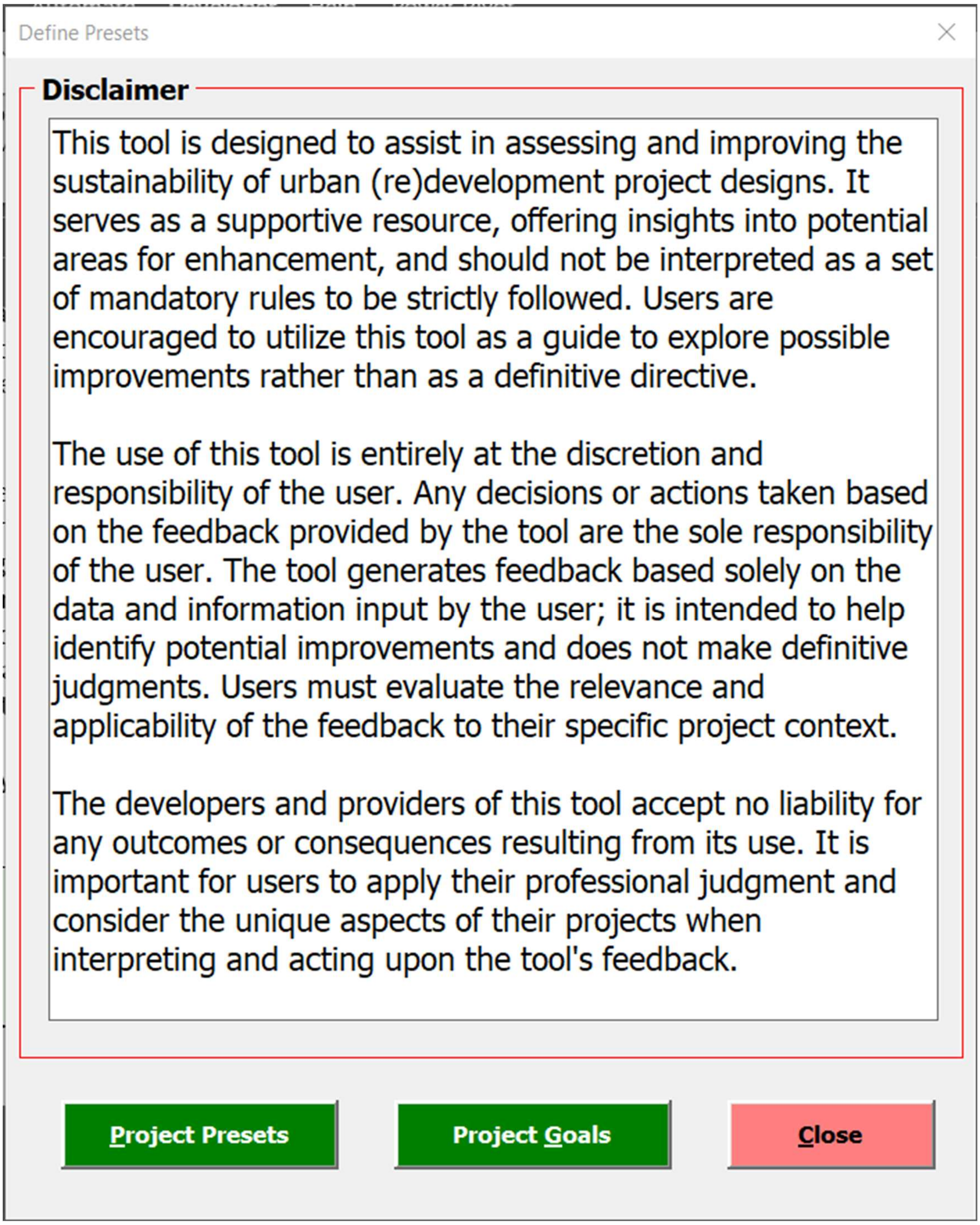
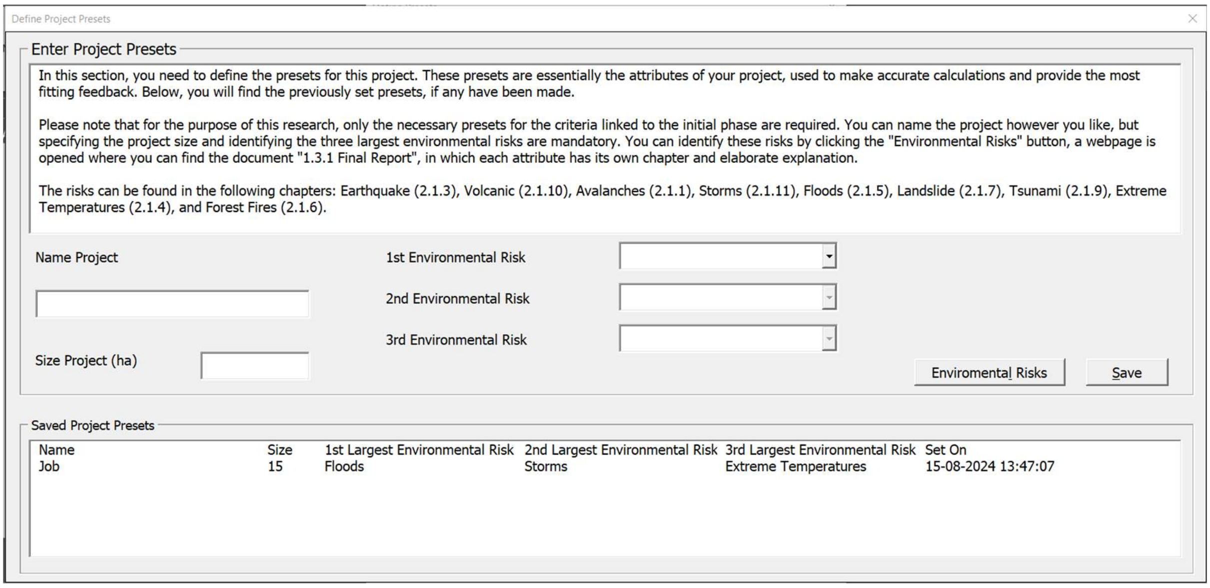


Figure 12: Excel UserForm "frmFormStart".

The first command button "Project Presets", opens the user form where the user needs to fill in specific details about the project, as discussed in Chapter 4.2.2. This user form explains to the user how to use and fill in this user form. Next to this, the saved data is showcased, providing insight into the database and when this data was saved. For additional information to fill in certain aspects, a command button is created that leads to a website that provides additional explanation, aiding the user in decision making. Lastly the presets can be saved by means of the "Save" button. When the user wants to save the data, a pop-up message is displayed asking the user if the data is correct and if the user is sure that the data must be saved. The "frmFormPP" user form can be found in Figure 13.



Define Project Presets

Enter Project Presets

In this section, you need to define the presets for this project. These presets are essentially the attributes of your project, used to make accurate calculations and provide the most fitting feedback. Below, you will find the previously set presets, if any have been made.

Please note that for the purpose of this research, only the necessary presets for the criteria linked to the initial phase are required. You can name the project however you like, but specifying the project size and identifying the three largest environmental risks are mandatory. You can identify these risks by clicking the "Environmental Risks" button, a webpage is opened where you can find the document "1.3.1 Final Report", in which each attribute has its own chapter and elaborate explanation.

The risks can be found in the following chapters: Earthquake (2.1.3), Volcanic (2.1.10), Avalanches (2.1.1), Storms (2.1.11), Floods (2.1.5), Landslide (2.1.7), Tsunami (2.1.9), Extreme Temperatures (2.1.4), and Forest Fires (2.1.6).

Name Project

1st Environmental Risk

2nd Environmental Risk

3rd Environmental Risk

Size Project (ha)

Enviromental Risks

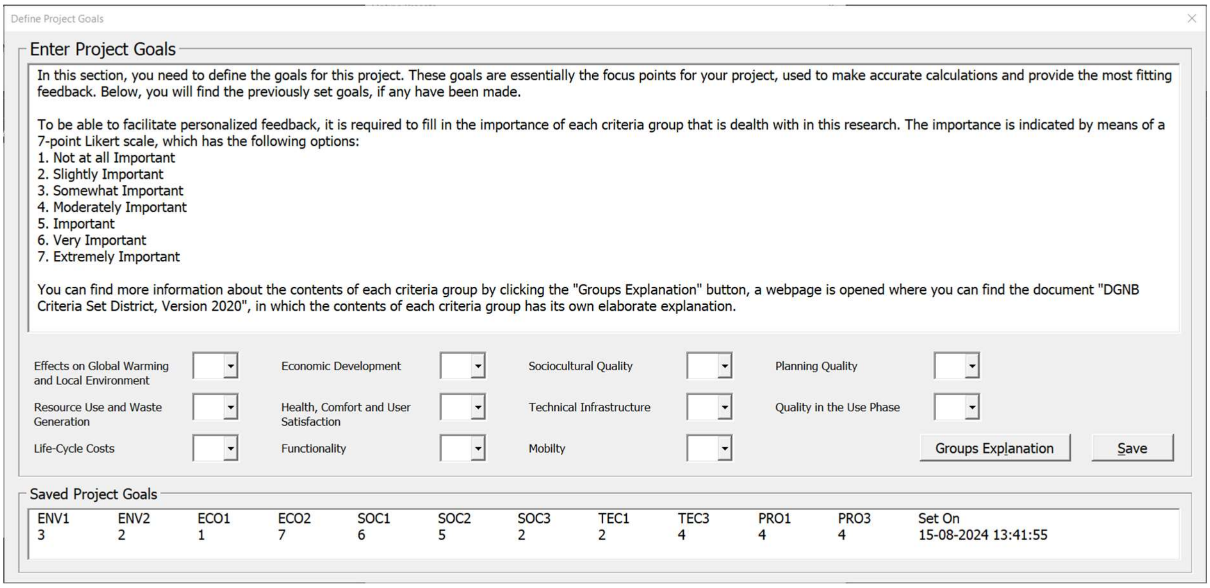
Save

Saved Project Presets

Name	Size	1st Largest Environmental Risk	2nd Largest Environmental Risk	3rd Largest Environmental Risk	Set On
Job	15	Floods	Storms	Extreme Temperatures	15-08-2024 13:47:07

Figure 13: Excel UserForm "frmFormPP".

The second command button “Project Goals”, opens the user form where the user needs to fill in the goals of the project, as discussed in Chapter 4.2.2. Again this user form explains how to use and fill in this user form. Next to this, the saved data is showcased, providing insight into the database alongside a timestamp for when this data was saved. For additional information to use the Likert scale, a command button is created that leads to the DGNB handbook, aiding the user in decision making. Lastly, the goals can be saved by means of the “Save” button. When the user wants to save the data, a pop-up message is displayed asking the user if the data is correct and if the user is sure that the data must be saved. The “frmFormPG” user form can be found in Figure 14.



Define Project Goals

Enter Project Goals

In this section, you need to define the goals for this project. These goals are essentially the focus points for your project, used to make accurate calculations and provide the most fitting feedback. Below, you will find the previously set goals, if any have been made.

To be able to facilitate personalized feedback, it is required to fill in the importance of each criteria group that is dealth with in this research. The importance is indicated by means of a 7-point Likert scale, which has the following options:
1. Not at all Important
2. Slightly Important
3. Somewhat Important
4. Moderately Important
5. Important
6. Very Important
7. Extremely Important

You can find more information about the contents of each criteria group by clicking the "Groups Explanation" button, a webpage is opened where you can find the document "DGNB Criteria Set District, Version 2020", in which the contents of each criteria group has its own elaborate explanation.

Effects on Global Warming and Local Environment

Economic Development

Sociocultural Quality

Planning Quality

Resource Use and Waste Generation

Health, Comfort and User Satisfaction

Technical Infrastructure

Quality in the Use Phase

Life-Cycle Costs

Functionality

Mobilty

Groups Explanation

Save

Saved Project Goals

ENV1	ENV2	ECO1	ECO2	SOC1	SOC2	SOC3	TEC1	TEC3	PRO1	PRO3	Set On
3	2	1	7	6	5	2	2	4	4	4	15-08-2024 13:41:55

Figure 14: Excel Userform "frmFormPG".

The last type of UserForm is the one belonging to the checklist of each temporal phase. However, since the components of the model can be changed by the user, it is not possible to make a fixed UserForm. Therefore the adaptiveness has been completely covered by means of an elaborate code, which can be found in Appendix . The form for the initial phase can be found in Figure 15.

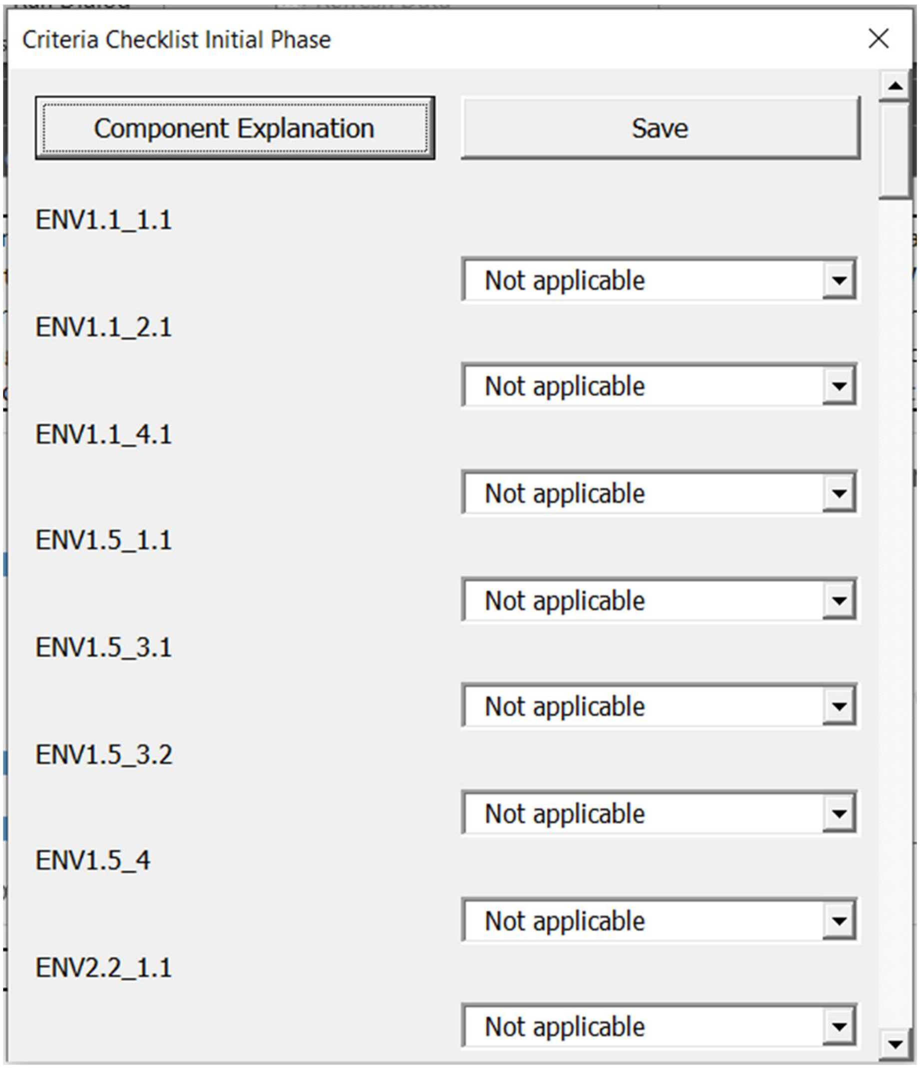


Figure 15: Excel UserForm "UserForm1"

The code looks up the values in the database corresponding to the temporal phase it belongs to, so for the initial phase these are the values in row 1 and row 2. The labels are copied for all the activated components. Subsequently, for each ComboBox, the code looks up the value of the label (GUID) in the computational model. When a match is found, it copies all the corresponding possible answers to the ComboBox. Additionally, the initial answer of each ComboBox is set to "Not applicable", meaning that in the computational model full marks are rewarded. For each phase, the code first looks in the database to see if there is already data there, if this is the case, it will load this value in the ComboBox, so that the user does not need to fill in every component again. With this mechanism, the user can fill in the user form spread over different times of the day or month. In the top of the user form, two command buttons are visible. Via "Component Explanation" the user can look up the component label in the DGNB handbook and is able to fill in the answer of the ComboBox. The "Save" button makes sure that the input data of the user is saved to the database.

4.4 Conclusion

The development of this DSS represents a significant innovation in the integration of the DGNB Urban District sustainability assessment tool within a structured framework, aimed at improving the sustainability and quality of urban development projects. By leveraging expert insights and the robust features of the DGNB UD tool, the DSS enables project designers to embed sustainability considerations throughout all phases of project development.

Expert input was integral to shaping the DSS' design, particularly in establishing the importance of a phased approach. Experts emphasized the need for structured temporal phases, which begin with a context analysis and progress through detailed design stages. Their feedback led to the incorporation of PG and PP modules, enabling users to define and dynamically adjust sustainability objectives and project attributes as the project evolves. Additionally, experts highlighted the importance of human-centric values and the flexibility to prioritize different sustainability goals, ensuring the system supports holistic, value-driven urban planning.

The integration of the DGNB UD sustainability assessment tool brings comprehensive, multi-dimensional evaluation criteria into the DSS, covering Environmental, Social, Economic, Technical, and Process Quality aspects. By associating DGNB criteria with specific temporal phases, the system ensures that sustainability assessments are relevant to each stage of project development, preventing skewed representations of progress. The system's ability to calculate scores using DGNB's predefined weighting systems and methods (such as addition, interpolation, and selection) allows for accurate and nuanced project evaluations.

The DSS's computational model is designed for efficient data management and calculation, with scores dynamically adjusted based on user input. Central to its functionality is the automation enabled by VBA macros, which streamline key processes such as data entry, feedback generation, and the iterative updating of project scores. This automation not only ensures immediate insights but also empowers users to make informed adjustments throughout each phase of the design process. Additionally, the inclusion of checklists and an integrated database helps capture and preserve critical project details, providing targeted feedback and enabling continuous refinement of sustainability goals at each stage of development.

A user-friendly GUI enhances the DSS' accessibility, making the complex sustainability assessments intuitive for its users. The GUI's design includes interactive elements such as buttons and user forms that simplify navigation between modules and project phases, while also protecting the system's underlying data integrity. The DSS's interface ensures that a complex assessment tool has been reduced to a easily interpretable checklist, which the user can fill in with ease. Additionally, it provides clear focused personalized suggestive feedback and scores per set goal. All aiding in the possibility of early integration, resulting in a better scoring and sustainable development projects.

In conclusion, the DSS developed in this project offers a comprehensive, expert-informed solution for integrating DGNB UD sustainability assessments into urban development projects. With its phase-specific assessments, adaptability, and suggestive feedback, the DSS empowers designers to enhance project sustainability and quality dynamically. The iterative, adaptable structure, combined with expert-backed methodologies, ensures that the DSS will be a valuable resource for achieving more sustainable and successful urban projects in the long term.

5 MODEL VALIDATION

This chapter deals with the preparation of the developed methodology for model validation. The contents in afore mentioned chapters are all incorporated or simplified for this validation, since the scope of this research is to test whether this new methodology is a step towards better SUD, the model has been simplified so that the purpose can be tested. The two subchapters will discuss how the model is altered and how the validation process has been carried out together with its outcomes respectively.

5.1 Model Preparation for Testing

To develop a functional model, all elements discussed in previous chapters have been thoroughly tested. The most efficient testing method was through integration into the Excel environment, which has been developed to a sophisticated level to effectively test the proposed methodology. However, the intricate model presented in previous chapter was too complicated to develop within this short time frame for validation. Therefore a simplified version has been developed. This version was developed in such a way that the possibilities of suggestive feedback and general use of the DSS was possible, which is in line with the scope of this research regarding this new methodology. Again it is meant to see if it might aid the decision making process during the design development in SUD. The intricate elements that the user of the DSS did not see or interact with had therefore been simplified. This chapter details the elements that were either excluded or modified during the DSS validation preparation process.

The proposed model relies on a checklist that users must complete, it would require end users to fill in the same checklist four times, once for each temporal phase. Moreover, the component allocation required users to manually go through the DGNB handbook and allocate each of the 232 components to a specific phase. Both steps require significant amount of participation time. To make a feasible testing version, these two steps have been eliminated. The first temporal phase was selected as the focus of the testing version, with the pre-allocated component, as described in Chapter 4.1.2.

This decision directly impacted the computational models, as only the model corresponding to the first temporal phase was generated using the automated process outlined in Chapter 4.2.1. With the exclusion of the remaining temporal phases, the navigation menu's significance was also reduced. The menu, which contained hyperlinks to each phase, the results section, and user forms for adjusting project goals and presets, were modified to deactivate and darken the links to the unavailable phases. Only the functional elements were activated for the interviews.

A final preparatory step for model validation involved setting the checklist contents to "Not applicable." During the expert validation interviews, interviewees were asked to complete the checklist. However, with 86 components already activated for the first temporal phase, this would have taken too much time. Instead, interviewees were only required to fill in a few components at the start. When these initial components are completed, the DSS' feedback would normally assign a low score, labeling all unchecked components as insufficient (scoring below 100%). This occurs because the model automatically assigns a score of zero to components marked as "Not performed." By changing this to "Not applicable," the model assigned a default score of 100%, providing more realistic and interpretable results for the interviewees.

5.2 Expert Validation

During the expert validation, it was important to make sure the purpose of the interview did not go astray. The validation interviews are set up as follows: first there was an introduction of what had been performed within this thesis and why. For the experts that already involved in the first round of interviews, this served as a cognitive refreshment. In this refreshment, the contents of the DGNB tool were shown as well as a general introduction as to how this topic was chosen and what the purpose was of this graduation project. Subsequently the purpose and setup of the interview was explained, together with its expectations; first the interviewees used the DSS by means of a guided user manual. The interviewer acted as a user manual in a sense that if the users of the DSS had questions, they could ask those questions to help them in the process of using the DSS. Just as a user guide, help would only be provided for when the situation was really not clear by itself. The available steps as described in the previous chapter had been walked through with care. A fictional case study was provided in the validation stage. The case study encompassed four elements; project characteristics, goal of the project, criteria group explanations, and efforts made per component for a small selection of components that the interviewee needed to fill in in the checklist. All of the given information had been set up in such a way that the user could not directly copy the information, but rather needed to figure out by using all the elements of the system what the answers to the checklist were. Just like a project specialist that would use this model will have to. The case study can be found in Appendix . After the case study had been completed, the interviewee was asked questions in regards to the developed DSS.

As stated in Chapter 3.3, the methodology for conducting the second round of interviews differed from the first round of interviews. This second round employed a structured format to obtain precise answers necessary for properly validating the developed model. The short interview time precluded a semi-structured approach. During the interviews, questions addressed four domains of the model: user experience, user-friendliness, functionality, and performance. Additionally, questions sought user suggestions for further development of the model. This structured approach ensured that responses aligned with the research questions, providing comprehensive insights for the model's validation. The list of questions can be found in Appendix . The results are discussed below, with each goal addressed in its own paragraph.

The interviewees generally recognized the DSS' structured approach and its potential to guide sustainability assessments effectively. They appreciated the intuitive start screen, although some felt that it contained excessive text, which might not be necessary for users familiar with the DSS. As users gained experience, navigation became smoother, but initially, the need for greater clarity in the presentation of project presets and environmental risk allocations was highlighted. All experts emphasized the critical role of project goals, suggesting that adding a logbook feature would help track why specific criteria were assigned certain scores, especially in long-term projects where goals might evolve over several years. The idea of making environmental risk allocation more automated was well-received, as this would streamline the setup and improve the overall ease of use.

Concerns about the DSS' user-friendliness were consistent, especially for those without deep expertise in sustainability. The abundance of abbreviations and technical language was seen as a barrier for non-experts, who might struggle to understand how to move through the DSS' sections. The layout, while functional, was sometimes overwhelming due to the uniform appearance of buttons, which did not reflect the hierarchical nature of their functions. A clearer visual distinction between elements could make the interface more intuitive. In addition, users mentioned that more detailed explanations within the interfaces would be beneficial for user-friendliness, such as hover-over descriptions or an onboarding tutorial. There was a clear consensus that improving the accessibility of the system would allow for broader adoption, with suggestions to simplify interfaces by reducing textual clutter and introducing visual aids like radar diagrams to display criteria scores more clearly.

The DSS' functionality was widely praised, particularly its ability to manage complex sustainability assessments and offer detailed insights into project performance. However, some users felt that the DSS could benefit from a "quick-win" option for faster decision-making in smaller projects or those with tight deadlines. The DSS' adaptability to different project sizes and sectors was also a positive topic of conversation. The DSS appeared well-suited for large-scale public sector projects, moreover, flexibility in allowing selection between personalized or standardized criteria lists was a recognized addition. Some saw the potential for the model to be used in collaborative settings, where multiple stakeholders could work together to assign criteria and make decisions, which would promote collective project ownership. This idea tied into suggestions for making the DSS useful in democratic settings like public consultations, where it could foster transparency and collective decision-making.

Regarding future improvements, the need for better distinction between the model's potential uses—whether as a detailed sustainability guide or a quick DSS—was a recurring theme. Simplifying the interface was again emphasized, with specific recommendations such as reworking the button hierarchy, integrating additional project management tools, and improving navigation. Users also suggested offering different versions for each design phase within the DSS, particularly for projects spanning several years. This would enable better traceability and adaptability as project goals shift over time, making the DSS more applicable across various stages of urban development. The possibility of incorporating features that allow for collaborative input from diverse expert teams was also noted as a way to enhance the model's utility in more complex projects.

The overall performance of the DSS was viewed positively, though its complexity and the time required to master its features were concerns. While the detailed metrics were appreciated for larger projects, particularly those involving government tenders or extensive sustainability requirements, smaller projects or those needing quick, high-level decisions found the DSS somewhat cumbersome. Scalability was seen as a necessary improvement, with users recommending an option to choose between in-depth analysis or quicker assessments, depending on the project's needs. Long-term adoption was another concern, with suggestions for institutional support, such as training sessions and community-building initiatives, to foster regular use. The model's strong justification of decisions was also seen as a key asset, particularly in professional environments where sustainability outcomes need to be clearly demonstrated.

5.3 Conclusion

This chapter presented the comprehensive validation process for the developed decision support system for assessing sustainability during urban development design phases. The process included functional model evaluation, which informed a simplified, user-focused testing version, prioritizing suggestive feedback and usability within a constrained timeframe. Structured expert interviews, combined with a fictional case study provided insights into various DSS domains: user experience, interface accessibility, functionality, and overall performance.

The validation highlighted key strengths, including the DSS's structured assessment approach and adaptability across different project sizes and stages. At the same time, the expert feedback underscored potential areas for improvement, particularly in interface clarity, accessibility for non-experts, and automation features to streamline usability. Recommendations suggest that enhancing simplicity, incorporating visual aids, and automating elements like environmental risk presets could broaden the DSS's applicability and support rapid decision-making for smaller or complex projects.

In conclusion, while the DSS demonstrates strong potential to facilitate collaborative, transparent decision-making in sustainability-driven projects, refining its adaptability across varied project phases and enhancing user-friendliness would maximize its utility. With these improvements, the DSS could serve as a valuable resource for both technical specialists and collaborative, inclusive decision-making in urban development.

6 DISCUSSION

6.1 Model Development Evaluation

The development of the decision support system proceeded with relative ease, although certain aspects presented more complexity and effort than others. The overarching aim was to integrate the DGNB UD sustainability assessment method into a user-friendly, Excel-based decision support system tailored for urban development projects. While the process was smooth, some challenges required more in-depth problem-solving. Throughout the development process, testing was conducted continuously within the Excel environment using an iterative design strategy, ensuring that each component was rigorously tested as it was developed. This method of rapid prototyping allowed for adjustments and refinements based on real-time testing, leading to a smoother development cycle, more efficient troubleshooting of issues, and ultimately the successful creation of a prototype that aligns with the research objectives.

One of the major achievements of the development process was the successful creation of an automated, iterative system. The interlinkage of different elements ensured that any changes made by the user were automatically reflected throughout the model. This meant that updates to any one part of the model would be carried through to all other sections, allowing for seamless suggestive feedback. This automation was crucial in maintaining usability and reducing the risk of errors, making it a reliable resource for users. The iterative nature of the model, which was central to its design, allowed users to make adjustments at each design phase of their project, supporting the overall goal of enhancing decision-making. By ensuring that feedback was continually generated based on user inputs, a process of continuous refinement and improvement was facilitated. This was particularly important in the context of urban development projects, where decisions made in one phase can have significant impacts on later stages. The methodology behind the development, particularly the use of the design science research framework, was key to the model's success. This iterative, feedback-driven approach ensured that the model was not only theoretically robust but also responsive to practical challenges. Expert feedback played an essential role in shaping both the user interface and the overall functionality of the system. The decision to incorporate user-friendly features such as a graphical user interface and automated feedback mechanisms was informed by insights gained during expert interviews, ensuring that the system was intuitive and accessible to its target users.

Despite the achievements, there are several significant challenges during the DSS development. One of the most significant challenges in the development process was translating the DGNB handbook into usable digital data. This task required not only a technical understanding of the handbook's components but also the ability to simplify its contents for effective use in an Excel environment. A key aspect of this translation was the allocation of different components to the relevant phases of urban development. Each component of the DGNB tool had to be linked to specific temporal phases, such as the conceptual, preliminary, and final design stages. This was critical to ensuring that the DSS provided relevant feedback at the appropriate stages in the project lifecycle.

Additionally, simplifying the content of the DGNB handbook posed its own difficulties. The handbook, being comprehensive and elaborate, had to be distilled into a form that would not overwhelm users but still capture the essential details. This process ensured that the DSS remained practical while providing enough detail to support decision-making. The score allocation mechanism also needed careful adaptation, requiring a balance between maintaining the integrity of the handbook's scoring system and making it manageable within the confines of the Excel environment. These issues were addressed by adjusting the weightings and simplifying the scoring methods, allowing the DSS to function effectively without compromising on the handbook's core elements.

Several challenges arose during the development of the model's structure and user interaction. One of the more complex problems was organizing the DSS multiple worksheets in a way that users could easily navigate. Given the phased nature of urban development projects, the model required a clear and intuitive structure to allow users to move seamlessly between different parts of the decision-making process. Another hurdle was the incorporation of Visual Basic for Applications (VBA) code and user forms. These elements were necessary to automate feedback generation and manage user interactions, but the unfamiliarity with VBA initially made this task challenging. However, through online tutorials and a trial-and-error approach, these components were quickly mastered. The automation provided by VBA reduced the risk of human error and made the DSS more efficient, allowing users to interact with the DSS without needing to understand the underlying code or data structures.

Despite the successes, there were limitations imposed on the scope of the model's development. One such limitation was the decision to focus on just one of the five urban district types outlined in the DGNB handbook. The goal of the research was to investigate the benefits of early integration of a sustainability assessment tool into the design phase of development projects, and expanding the scope to include all five district types would have been beyond the time and resource limits of the study. By focusing on a single district type, the model could be more deeply developed and tested within a manageable scope. Similarly, certain criteria from the handbook, such as scheme-specific information and bonus point mechanisms, were excluded from the DSS. These elements were considered too elaborate to be included within the timeframe of the research and would have added unnecessary complexity to the model. The simplification allowed the DSS to retain its core functionality while remaining practical and user-friendly. Another limitation was in the validation of the DSS. The expert prototype validation process, while thorough, did not encompass all four phases of the design process. Instead, the prototype focused on only one phase to assess whether early integration of the DGNB tool would benefit decision-makers. Expanding the prototype to all four phases would have resulted in double work, without providing significantly more insight into the present functions. However, other problems or suggestions could be gathered due to this more complex prototype.

In summary, the development of the model successfully addressed the core research objectives, overcoming challenges related to the translation of the DGNB handbook, structural organization, and user interaction. While limitations were necessary to keep the scope of the project manageable, the iterative, automated system that emerged was a significant achievement, providing a user-friendly and practical DSS for urban development stakeholders. Through continuous testing, refinement, and expert validation, the DSS proved to be both functional and adaptable, ensuring its effectiveness in real-world applications.

6.2 Validation Evaluation

The evaluation of the developed model was carried out through a series of interviews with experts from the field of urban development. The process of conducting these validation interviews was structured, but not without challenges. Initially, the plan was to reconnect with the four experts that had participated in the first round of interviews. However, not all of them were available for the second round of interviews. As a result, an open invitation was sent to several other companies within Eindhoven involved in urban development. Despite this broader outreach, only four companies responded and were able to participate in the interviews. While the limited number of participants was unfortunate, the diverse specializations of the involved companies meant that a broad range of perspectives was still captured during the evaluation process.

The companies that participated in the validation interviews came from different specializations within the urban development sector. This diversity allowed the evaluation to benefit from varied perspectives, though the limited number of participants posed a challenge in terms of breadth. The decision to focus on companies within Eindhoven also limited the validation to one region of the Netherlands. While proximity made coordination and scheduling more feasible, it introduced a potential bias in the results, as all participants were working within the same regional context. Ideally, a broader geographical spread of participants, including experts from other cities or even international perspectives, would have enriched the evaluation by highlighting different approaches to the design phase of urban development and sustainability assessment. Time constraints and practical considerations limited this possibility.

The validation process itself involved detailed interviews, each initially scheduled to last around one hour. However, explaining the complexity of the DSS and the decisions made throughout its development often took longer than anticipated. The interviews required substantial preparation to ensure the participants understood the DSS' purpose and how it fit into the context of urban development. Although this exceeded the allotted time, the participants were generally accommodating and willing to extend their availability. This flexibility was crucial, as it allowed the evaluation process to unfold more thoroughly, ensuring that each aspect of the DSS was properly explored and evaluated by the interviewees.

A key challenge during the interviews was managing the expectations and focus of participants who were not familiar with the project. The companies that had been involved in the first round of interviews were better prepared and had a clearer understanding of the DSS' objectives, which made the evaluation process more streamlined in their case. In contrast, the experts that were new to the process often interpreted the generated feedback based on their own organizational practices, rather than the specific context of the interview, leading to a misunderstanding of the interview's intended focus. This occasionally led to a misalignment with the broader goal of assessing the DSS' general applicability in the field of urban development. To address this, the interviewer had to carefully guide the conversation back to the model's intended purpose, ensuring that the feedback focused on its potential use across the industry rather than within a specific company. This additional guidance helped align the responses and made it possible to collect more relevant insights, though it did require more effort and time than originally anticipated.

One of the logistical decisions made during the validation was to use a simplified the model for the purposes of the interview. The full functionality of the model, particularly the component allocation across multiple phases, was deemed too complex and time-consuming for the interview setting. As a result, a simplified version was presented with only the first temporal phase fully developed, allowing participants to focus on that aspect without being overwhelmed by the entire system. A hypothetic case was presented for the validation. This simplification proved effective in managing the interviewees' time and attention, though it also meant that certain elements of the model were not fully explored. To further streamline the process, the checklist components were pre-set to "Not applicable," reducing the amount of manual data entry required during the interviews and allowing the participants to focus on interacting with the DSS itself rather than becoming bogged down in data entry.

While the validation process yielded valuable feedback, it also highlighted several limitations and areas for improvement. The decision to use a simplified version of the model, while practical for managing time constraints, meant that certain features of the DSS were not thoroughly tested, limiting the evaluation's depth. This raises questions about the representativeness of the feedback, as the full functionality of the DSS was not explored by the participants. Furthermore, the limited number of participants, while ensuring manageable data collection, restricted the diversity of perspectives, as only four companies from the Eindhoven region were involved. Ideally, a broader geographical and organizational range would have provided a more comprehensive understanding of the DSS's applicability across different contexts and project scales. Additionally, while the interviewees' insights were valuable, the varying levels of familiarity with the project meant that some participants may have struggled to align their feedback with the model's intended objectives, leading to a slight misalignment in the evaluation focus. Despite these challenges, the interviewees' willingness to engage and provide constructive feedback ensured that the evaluation process still produced useful insights. However, these factors should be considered when interpreting the results, as they may have influenced the feedback's relevance and generalizability.

In summary, the validation process was successful in gathering valuable feedback, but it also revealed several areas for improvement and limitations. While the simplified DSS allowed for focused feedback within the time constraints, it also limited the scope of the evaluation, as certain features of the DSS were not fully explored. The relatively small number of participants and the regional focus of the evaluation constrained the breadth of the insights gathered, which could affect the generalizability of the results. Nevertheless, the process provided useful and actionable insights into the functionality and user experience of the DSS, confirming its potential value for urban development projects. Despite the limitations, the feedback from experts has provided a solid foundation for further refinement and improvement of the DSS, ensuring its relevance and applicability for future research and practical applications in urban sustainability assessments.

7 CONCLUSION

Having developed and evaluated the proposed methodology, this research aims to determine whether sustainability assessment tools can be effectively integrated into the design phase of (re)development projects. Throughout this process, several key research questions have been addressed in earlier chapters. In this conclusion, the research sub-questions are answered in a consolidated manner to provide a comprehensive response to the main research question.

Sub-question 1: What are the current state-of-the-art sustainability-focused assessment tools, and how do these tools enable pre-emptive adjustments?

The current state-of-the-art sustainability assessment tools include globally recognized systems such as BREEAM, LEED, DGNB, CASBEE, and SBTool. These tools are designed to evaluate projects across multiple dimensions of sustainability: environmental, economic, and social aspects. They offer frameworks to assess urban development projects on criteria like energy efficiency, resource management, social inclusivity, and economic viability.

However, while these tools provide comprehensive post-project evaluations, their ability to make pre-emptive adjustments during the design phase is often limited. Typically, tools like BREEAM and LEED assess a project after substantial portions of the design have been finalized. This retrospective nature creates challenges in implementing feedback that could improve sustainability outcomes during the early, flexible stages of design.

The DGNB tool, among the most holistic, does incorporate elements that allow for adjustments earlier in the process, such as scoring projects based on their adherence to sustainability goals like circular economy principles and Sustainable Development Goals. Nevertheless, the proactive integration of sustainability adjustments within the design phase remains a challenge across the board. Current tools need further development to integrate dynamic feedback mechanisms that allow for suggestive feedback regarding modifications to design strategies, leading to better sustainability outcomes.

Sub-question 2: How do sustainability assessment tools evaluate projects and what are their limitations?

Sustainability assessment tools evaluate projects by using a multi-criteria framework, where they measure a project's performance across several sustainability indicators. For instance, tools like DGNB assess projects based on ecological quality (e.g., resource efficiency, biodiversity impact), socio-cultural quality (e.g., comfort, health, and inclusivity), and economic quality (e.g., lifecycle costs and financial viability). These tools use scoring systems to rank projects and assign certification levels (e.g., Bronze, Silver, Gold, Platinum in DGNB), depending on how well the projects align with sustainability benchmarks.

Despite their widespread use, tools like BREEAM and LEED have significant limitations in their application for influencing design decisions. Primarily functioning as post-project evaluators, they assess projects after many critical design choices have been made, which limits their ability to guide adjustments that could enhance sustainability. Additionally, the complexity and time-consuming nature of their assessment processes can deter smaller-scale projects from fully adopting these tools, as the resources required may outweigh the perceived benefits.

Moreover, some tools fall short in addressing the full complexity and evolving demands of urban sustainability. For example, BREEAM and LEED tend to place a stronger emphasis on environmental factors, such as energy consumption and material selection, while providing less comprehensive frameworks for assessing social and economic sustainability dimensions, such as inclusivity, community impact, and lifecycle cost analysis. This focus can result in a more limited view of sustainability, where critical socio-cultural and economic factors receive insufficient attention. DGNB, in contrast, was selected for its balanced approach, which includes ecological, economic, and socio-cultural criteria, allowing for a more holistic evaluation of sustainability that better aligns with the diverse needs of urban development projects. This broader scope is essential for projects aiming to achieve sustainability across multiple dimensions throughout the design phase and beyond.

Sub-question 3: How can a decision support system be effectively designed to incorporate a broad range of sustainability criteria from an established assessment tool, ensuring ease of use and adaptability while preserving the tool's integrity?

An effective decision support system (DSS) can be designed to integrate comprehensive sustainability criteria from an established assessment tool by maintaining a balance between adaptability and adherence to the original framework. Achieving this requires translating complex, multi-dimensional criteria—such as those from DGNB's five key areas of ecological, economic, socio-cultural, technical, and process quality—into an accessible, user-friendly format. By leveraging an Excel-based environment with automated calculations and interactive scoring features, the DSS can offer intuitive navigation and suggestive feedback to support iterative decision-making. Clear visual representations, like radar diagrams and scoring charts, enable users to understand and optimize their project's sustainability performance. Maintaining the integrity of the assessment tool is essential, achieved by aligning the DSS's scoring methods with the original criteria while enhancing usability through dynamic features that allow for flexible adjustments. This approach ensures that the DSS serves as a valuable, adaptable method for sustainability-focused planning without compromising the rigor of the underlying assessment framework.

Sub-question 4: How can the temporal aspects of a development plan be effectively integrated, considering diverse time frames and criteria with an ongoing project plan?

Incorporating the temporal aspects of a development plan into a decision support system is critical for long-term project success. Development projects, particularly urban (re)development projects, evolve over time, with criteria such as energy performance, environmental impact, and social inclusivity changing as the project progresses.

A decision support system must account for these evolving factors by allowing users to update inputs and reassess sustainability performance across different phases of the project—e.g., initial design, conceptual planning, and final design. This can be done by dividing the project into temporal phases, with criteria weights and benchmarks changing to reflect the priorities of each phase.

For example, in the early phases, ecological and technical quality criteria might take precedence, as these are critical in shaping the physical design of the project. As the project moves into later stages, socio-cultural and economic factors may become more prominent. The DGNB tool, with its detailed life-cycle assessment approach, provides a useful framework for integrating temporal factors into decision-making by scoring projects in different phases.

Sub-question 5: How can the design and functionality of a decision support system be influenced by stakeholder input while accommodating their diverse needs to ensure a user-friendly and universally applicable solution?

To design a decision support system that is both shaped by stakeholder input and adaptable to diverse needs, it is essential to integrate stakeholder insights into every phase of the model's development. Stakeholder input directly influences the design and functionality of the DSS, ensuring that it reflects a range of perspectives and priorities relevant to urban development projects. By incorporating feedback from key stakeholders—such as urban planners, environmental scientists, and developers—the DSS can be tailored to address practical needs and adapt to different geographical and project-specific contexts. This adaptability is crucial in creating a system that remains relevant across diverse urban development scales and settings.

The system's functionality must support user-friendliness, allowing users with varying expertise to effectively engage with it. Stakeholder input is particularly valuable in refining this aspect, as it can reveal usability challenges and highlight preferences for interface features, evaluation criteria, and overall system flow. Features such as customizable dashboards, interactive visualizations like radar diagrams, and direct feedback mechanisms emerged from this input as essential components for enhancing accessibility. These elements allow users to not only navigate the DSS intuitively but also to interpret results that align with their specific project needs.

To accommodate diverse stakeholder requirements, the DSS must also offer flexibility in how evaluation criteria are selected and weighted, as different projects will prioritize sustainability criteria in unique ways. For example, stakeholders may wish to emphasize environmental impact or lifecycle costs differently based on local project goals or community expectations. This flexibility ensures that the DSS can be adjusted to fit the unique demands of any urban (re)development project.

Overall, designing a DSS that is responsive to stakeholder input and accommodates varied needs leads to a system that is both universally applicable and user-friendly. By prioritizing stakeholder-driven adaptability, the DSS not only achieves its sustainability goals but also aligns with the social, economic, and environmental objectives of the communities it serves.

With these sub-questions answered, the main research question can be answered.

Main research question: How can a decision support system be designed to evaluate and guide (re)development projects during the design phase to result in higher quality sustainability assessment?

To design a decision support system that can evaluate and guide (re)development projects during the design phase and lead to higher-quality sustainability assessments, the system must be grounded in a comprehensive methodology that incorporates expert insights, sustainability criteria, and flexibility throughout the project lifecycle. The design cycle applied in this research, which follows a structured approach of model design, model development, and model validation, forms the foundation of the DSS's creation. This cycle ensures that sustainability considerations are integrated into the project from the outset, and that decisions can be guided with clarity, agility, and precision.

Model design, the first step of the design cycle, begins by setting a knowledge baseline that outlines the requirements for the DSS and captures essential external knowledge through expert interviews. These interviews focus on understanding the key sustainability dimensions—ecological, economic, socio-cultural, and technical—that should guide the design process, as well as stakeholders' preferences and feedback on existing assessment tools like DGNB. The Knowledge Baseline also analyzes the strengths of the DGNB tool and identifies opportunities for adaptation and integration into the DSS. This sets the groundwork for a system that is both informed by external standards and tailored to meet the needs of urban redevelopment projects.

In the next phase of model design, the technical aspects of the DSS are defined. Here, it is outlined how the system will process data, handle user inputs, and provide feedback. The DSS is built in Microsoft Excel using the effectuation methodology, leveraging its accessibility and user-friendly nature to develop an adaptable platform. Through automated calculations, interactive scoring features, and clear visualizations, the DSS allows for the real-time evaluation of various sustainability aspects such as material choices, energy systems, and layout designs. The system enables users to see the implications of their design choices and adjust them accordingly to optimize sustainability outcomes. The feedback provided by the DSS is actionable, enabling project teams to make timely changes that align with sustainability goals throughout the design process.

One of the key advantages of the DSS is its ability to offer temporal flexibility. Urban (re)development projects unfold in stages, each with evolving sustainability challenges. The DSS adjusts its feedback to reflect the priorities and criteria relevant to each project phase. For example, early stages may prioritize ecological and technical factors, while later stages focus more on socio-cultural and economic dimensions. By adjusting criteria weighting and evaluation benchmarks as the project progresses, the DSS helps ensure that sustainability is integrated as a continuous, iterative design objective, rather than a final requirement that only appears toward the end of the project.

The graphical user interface design step focuses on ensuring the system's usability, using user-centered design methodology. This step ensures that the DSS interface is intuitive and meets the needs of various stakeholders. Key features such as customizable dashboards, radar diagrams, and performance indicators allow users to track sustainability metrics in a clear, visual format. The input fields and interactive features ensure that users can easily modify and reassess their decisions at any time. The system is designed to be flexible, allowing users to tailor the DSS to their project's specific requirements while ensuring that the feedback remains grounded in established sustainability criteria.

In the model development phase, the focus shifts to preparing the DSS for testing. The system is developed as a minimum viable product, focusing on core functionalities like the feedback mechanism, scoring system, and data processing. This MVP approach allows the system to be tested early, ensuring that experts can evaluate its essential components in the time available. User feedback from the MVP testing is essential for further refinement and ensuring the system's reliability in real-world applications.

Finally, in model validation, the system undergoes user testing with stakeholders from various disciplines to assess its usability, functionality, and impact on decision-making. By interacting with the DSS, these users provide insights into its effectiveness in guiding design choices and supporting high-quality sustainability assessments. The feedback garnered from these tests is used to validate the system's performance and identify areas for further development. The insights gained from expert feedback also provide an opportunity to improve the system's adaptability to different urban contexts and project scales.

7.1 Scientific and Societal Relevance

The research presented in this thesis holds substantial scientific and societal relevance, especially in the context of urban (re)development and sustainability. From a scientific perspective, this research contributes to Sustainable Urban Development by addressing gaps in current decision support system methodologies, particularly in proactive and dynamic sustainability assessment during the design phase of urban projects. Existing literature frequently highlights a need for tools that offer not only retrospective evaluations but also real-time guidance and feedback, allowing for proactive and personalized adjustments as projects evolve. By focusing on the integration of sustainability assessment criteria directly into the design phase, this research responds to this gap, moving beyond post-project evaluations and offering a method for continuous, iterative decision-making.

Additionally, insights from the first round of interviews pointed to critical design needs for DSS, such as enhancing user interaction, delivering quick and timely feedback, and automating aspects of data integration and stakeholder input analysis. Incorporating these elements addresses gaps identified in both literature and practice, where many tools still lack responsiveness and the flexibility to adjust based on stakeholder needs or evolving project requirements. This research demonstrates how a third-party sustainability tool, like the DGNB UD system, can be embedded into a decision support framework to not only meet the scientific need for proactive, adaptable assessment tools but also support real-time interaction across ecological, socio-cultural, economic, and technical domains.

Ultimately, this study advances the scientific discourse by showing how an integrated, adaptable DSS can influence sustainable urban development in a more responsive and interactive way. By allowing for personalized feedback and dynamic adjustments based on project input, this research paves the way for future studies that aim to create user-centered DSS models capable of shaping sustainable urban spaces throughout the design process.

From a societal perspective, this research addresses some of the most pressing challenges in urban development, particularly those related to sustainability, stakeholder inclusion, and long-term resilience. With global initiatives like the United Nations SDGs and the European Union's Green Deal, urban development projects are increasingly required to meet rigorous sustainability standards. The model developed in this research allows urban planners, developers, and other stakeholders to evaluate the sustainability performance of projects during their formative stages, ensuring that environmental goals, economic viability, and social inclusivity are balanced. This approach encourages urban projects to prioritize not only environmental considerations but also broader social goals, such as accessibility, community involvement, and public health.

Additionally, the research demonstrates how stakeholder engagement can be integrated into the design and decision-making process, helping to ensure that the diverse needs and objectives of urban residents, local governments, and developers are considered from the outset. In this way, the model supports more democratic and collaborative decision-making, fostering urban spaces that reflect the values and needs of the communities they serve. This aligns with the increasing global focus on inclusive, participatory planning processes that address social equity and environmental justice.

In summary, this research is scientifically relevant because it advances the field of decision support systems and sustainable urban development by integrating proactive assessment tools into the design phase. Societally, it provides a practical framework for creating more resilient, inclusive, and sustainable urban spaces, contributing to the broader goals of environmental stewardship and social well-being in cities worldwide.

7.2 Future Directions of Research

This research opens several avenues for future studies, which can further refine and expand upon the findings presented in this thesis. First, while the current research successfully demonstrates the integration of a third-party sustainability tool like DGNB UD into a decision support system, future research could explore the scalability of this system across different types of urban projects. One potential direction is to investigate how the DSS can be tailored to fit small-scale local developments as well as large-scale metropolitan projects, ensuring that its functionality remains effective regardless of the project's size or complexity. This would help bridge the gap between localized urban interventions and large, strategic urban regeneration efforts.

Another area for future research is the temporal dimension of urban projects. While this research acknowledges the importance of incorporating temporal aspects into the decision-making process, further studies could delve deeper into how dynamic, long-term sustainability criteria can be applied as projects progress through various stages. For example, research could focus on how the model can evolve to track and respond to changing sustainability benchmarks over a project's lifecycle, from conceptual design to post-construction and operational phases. This would involve developing more sophisticated temporal feedback mechanisms that allow for sustainability performance tracking over time, ensuring that the model remains relevant as urban projects grow and evolve.

Additionally, integrating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML) into decision support systems offers a promising research direction. By incorporating AI and ML algorithms, the model could be enhanced to predict the outcomes of different design scenarios more accurately and provide data-driven recommendations. AI could also support automated integration of stakeholder feedback, enabling analysis of large datasets of input and adaptive adjustment of design criteria. Furthermore, generative AI offers the potential for a dialogue-based interface, which could simplify interactions, reduce the use of complex terminology, and make the tool more accessible to a broader range of users. These advancements would facilitate dynamic, data-driven decision-making, allowing planners and developers to respond quickly and effectively to real-time insights.

Moreover, future research could examine how the decision support system can be adapted to different regulatory contexts and sustainability frameworks beyond DGNB UD. For instance, further studies could investigate the system's applicability in regions where LEED, BREEAM, or other sustainability certifications are the norm, creating a more flexible system that can incorporate various international standards. This would make the model adaptable for use in global urban projects, extending its relevance to a broader audience and fostering greater international cooperation on sustainability goals.

Lastly, there is significant potential for future research to explore how the decision support system can facilitate multi-user participation in urban development projects. Research could focus on developing features within the model that enable public engagement platforms, allowing community members to provide input on sustainability criteria and design preferences. This would support more inclusive urban planning processes, ensuring that the voices of local residents are integrated into the sustainability assessments and design decisions. This line of research would not only improve the social legitimacy of urban projects but also align with growing trends toward participatory governance in urban development.

In conclusion, future research should explore the scalability of the model, its integration with advanced technologies, its adaptability to different sustainability standards, and its role in enhancing public participation in urban development. These areas of study will further refine the decision support system's capacity to create sustainable, inclusive, and adaptable urban spaces, ensuring that it remains relevant in an evolving global urban landscape.

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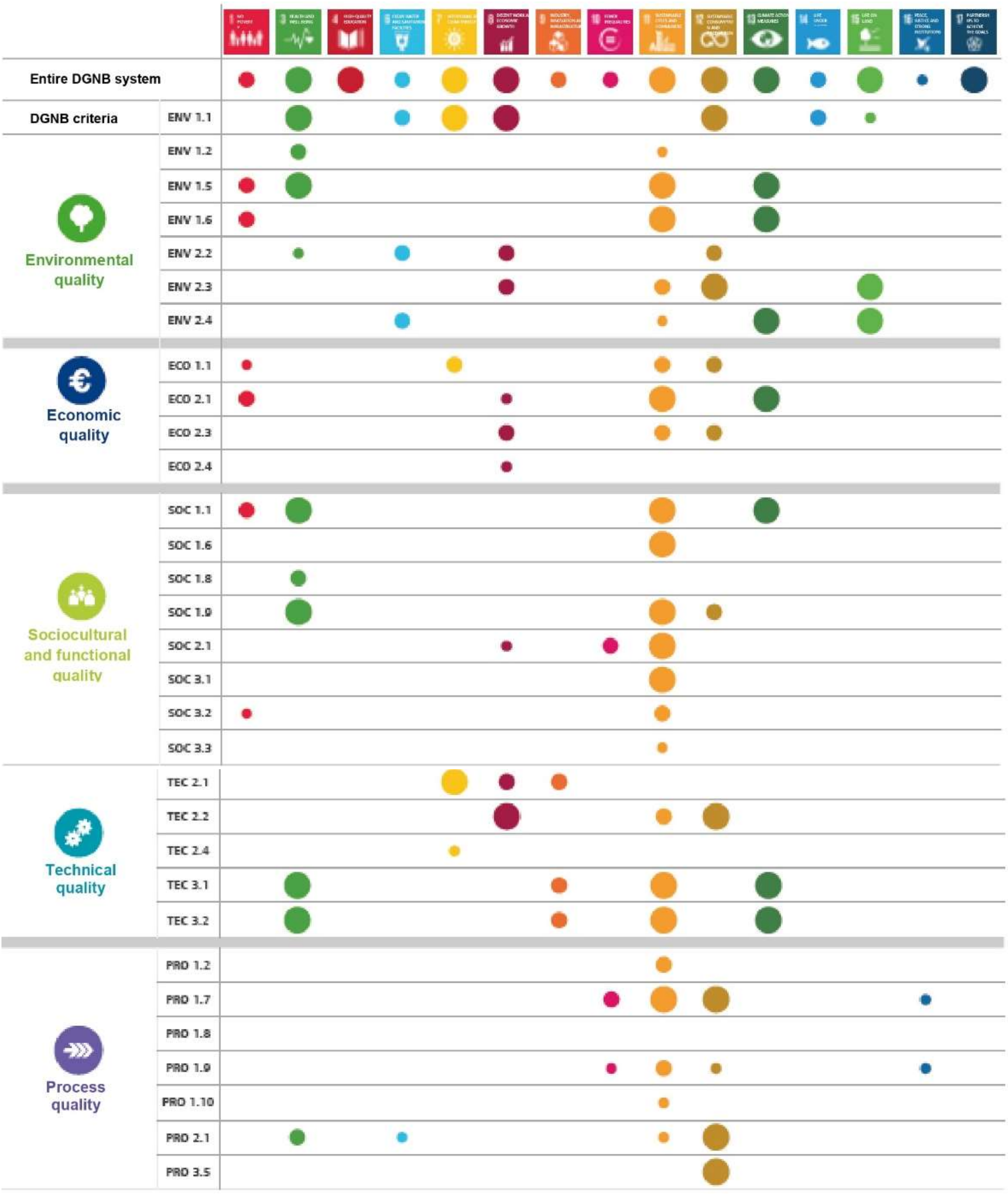
9 APPENDICES

Appendix 1

Contribution of the DGNB system to the SDGs for Urban Districts



Appendix 2

Weighting of the criteria of the DGNB system

Topic	Criteria group	Criterion	Urban districts / Business districts		Event areas		Commercial areas		Industrial sites	
Environmental quality (ENV)	Effects on global and local environment (ENV1)	ENV1.1	8	6.4%	8	6.2%	10	6.5%	9	5.8%
		ENV1.2	-	-	-	-	-	-	4	2.6%
		ENV1.5	5	4.0%	5	3.8%	7	4.5%	4	2.6%
	Resource use and waste generation (ENV2)	ENV2.2	4	3.2%	5	3.8%	5	3.2%	5	3.2%
		ENV2.3	4	3.2%	4	3.1%	5	3.2%	4	2.6%
		ENV2.4	4	3.2%	4	3.1%	4	2.6%	5	3.2%
Economic quality (ECO)	Life-cycle costs (ECO1)	ECO1.1	4	5.7%	4	6.7%	3	5.0%	4	5.0%
	Economic development (ECO2)	ECO2.1	3	4.3%	3	5.0%	3	5.0%	4	5.0%
		ECO2.3	3	4.3%	3	5.0%	2	3.3%	3	3.8%
		ECO2.4	2	2.9%	-	-	2	3.3%	3	3.8%
		ECO2.5	2	2.9%	2	3.3%	2	3.3%	2	2.5%
Sociocultural and functional quality (SOC)	Health, comfort and user satisfaction (SOC1)	SOC1.1	3	2.6%	3	2.6%	2	1.8%	3	2.7%
		SOC1.6	4	3.5%	4	3.5%	4	3.6%	3	2.7%
		SOC1.8	-	-	-	-	-	-	3	2.7%
		SOC1.9	3	2.6%	3	2.6%	3	2.7%	3	2.7%
	Functionality (SOC2)	SOC2.1	3	2.6%	3	2.6%	2	1.8%	3	2.7%
	Sociocultural quality (SOC3)	SOC3.1	3	2.6%	3	2.6%	3	2.7%	4	3.6%
		SOC3.2	4	3.5%	4	3.5%	5	4.5%	-	-
		SOC3.3	3	2.6%	3	2.6%	3	2.7%	3	2.7%
Technical quality (TEC)	Technical infrastructure (TEC2)	TEC2.1	4	4.4%	4	4.7%	5	5.3%	5	5.6%
		TEC2.2	2	2.2%	2	2.4%	3	3.2%	3	3.3%
		TEC2.4	2	2.2%	2	2.4%	3	3.2%	3	3.3%
	Mobility (TEC3)	TEC3.1	5	5.6%	5	5.9%	4	4.2%	4	4.4%
		TEC3.2	5	5.6%	4	4.7%	4	4.2%	3	3.3%
Process quality (PRO)	Planning quality (PRO1)	PRO1.2	3	5.0%	3	4.0%	2	3.3%	3	5.5%
		PRO1.7	2	3.3%	2	2.7%	3	5.0%	3	5.5%
		PRO1.8	2	3.3%	2	2.7%	2	3.3%	-	-
		PRO1.9	2	3.3%	2	2.7%	2	3.3%	-	-
		PRO1.10	-	-	2	2.7%	-	-	-	-
	Quality in the use phase (PRO3)	PRO2.1	1	1.7%	2	2.7%	1	1.7%	2	3.6%
		PRO3.5	2	3.3%	2	2.7%	2	3.3%	3	5.5%

Relevance factor
Share of the total score

Appendix 3

Interview questions before the development of the model

1. *Would you be comfortable with this meeting being recorded to ensure no exchanged information is lost?*
2. *How does the company participate in urban development projects?*

Goal 1: Getting to know the different stages in the design process of urban development projects and the level of detail related to each stage.

1. *Does your company currently implement phasing during the design process of urban development plans?*
2. *How many phases does your company usually have in this process?*
3. *What are these phases, how are they defined?*
4. *To what level of detail do the design plans need to be for these different stages?*

5. *What criteria or key indicators does your company consider when determining the appropriate level of detail for each phase of an urban development project?*
6. *From your experience, how does the level of detail in the design phase impact the overall success and sustainability of urban development projects?*

Goal 2: Predetermined preference per project

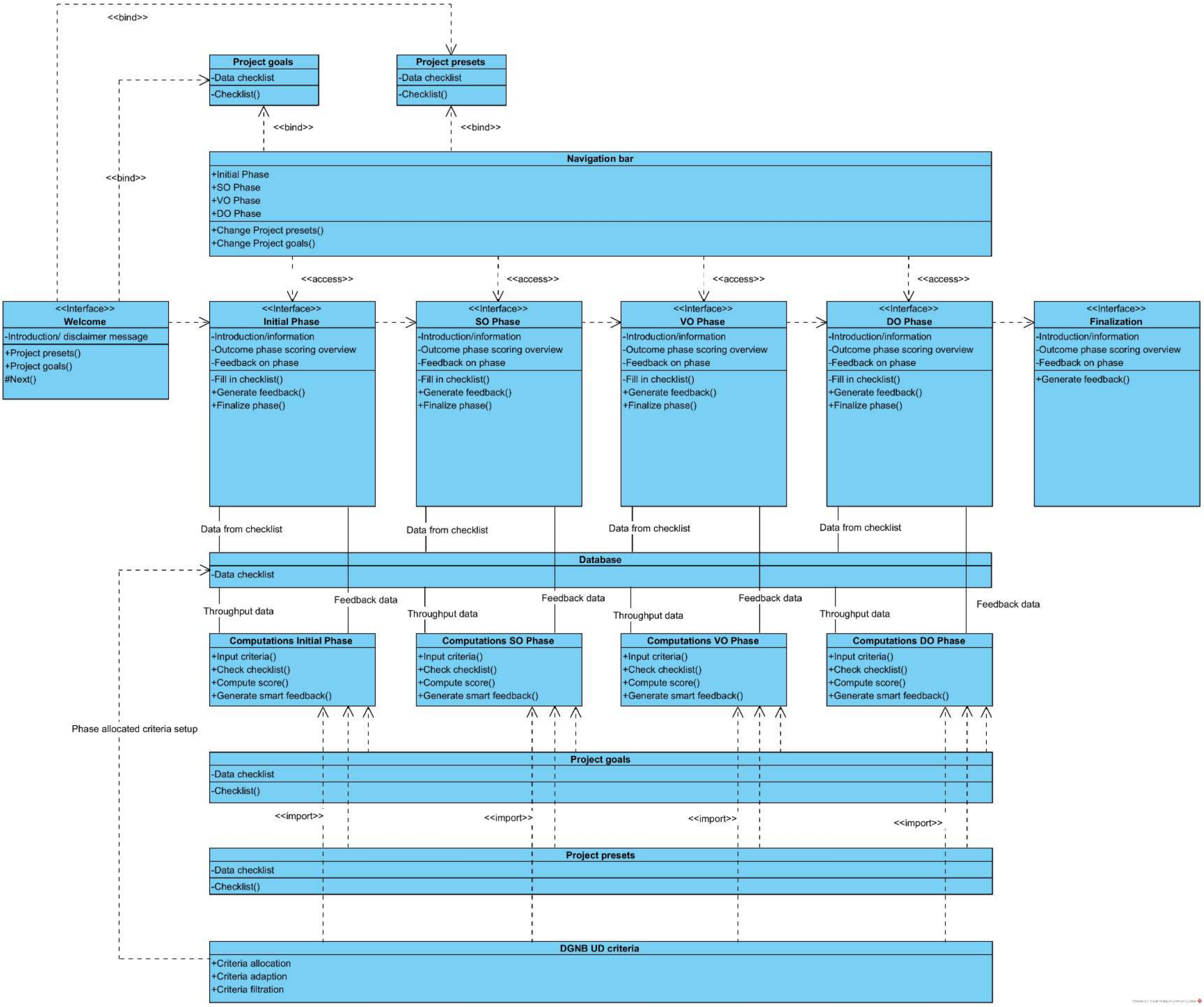
7. *What are the primary goals or is the primary focus of the company when considering urban development?*
8. *What specific information, criteria, or presets would you prefer to be included in a tool supporting decision making in development plans?*
9. *How do you envision the user interface of the tool accommodating predetermined preferences for each project?*

Goal 3: Useability of the tool

10. *In which way would you like to gain feedback that the tool will suggest?*
11. *Do you see opportunities for integrating technological solutions or decision support systems to streamline and enhance the phasing process in urban development projects?*
12. *Do you think that early feedback on the design could aid in developing more profound urban development projects?*

Appendix 4

System architecture of the proposed model



Appendix 5

Formulas used throughout the Technical Aspects chapter in chronological order of appearance.

```
=INDEX('DGNB crit'!$P$2:$P$245; MATCH(1; ('DGNB crit'!$M$2:$M$245=B$5) * ('DGNB crit'!$Q$2:$Q$245="x"); 0))
```

Listing 3: Excel formula for automated maximum criterion point import determined by the GUID.

```
=INDEX('DGNB crit'!$J$2:$J$245; MATCH(1; ('DGNB crit'!$M$2:$M$245=B$5) * ('DGNB crit'!$Q$2:$Q$245="x"); 0))
```

Listing 4: Excel formula for automated bonus indicator import determined by the GUID.

```
=INDEX('IP database'!$B$2:$IK$2; MATCH(TRUE; 'IP database'!$B$1:$IK$1=B5; 0))
```

Listing 5: Excel formula for automated user data import determined by the GUID.

```
=CHOOSE(MATCH(B9; B11:B18; 0); 0; 2; 4; 6; 6; 8; B6; B6)
```

Listing 6: Excel formula for scoring each component by a matching approach.

```
=SUMIF(B7:D7; "<>x"; B26:D26)
```

Listing 7: Excel formula for determining the obtained points per criterion excluding bonus points.

```
=B28/(SUMIF(B7:D7; "<>x"; B6:D6))
```

Listing 8: Excel formula for determining the achieved weighted score per criterion excluding bonus points.

```
=SUM(
 IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x"); 'DGNB crit'!$E$2; 0);
 IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x"); 'DGNB crit'!$E$7; 0);
 IF(COUNTIF('DGNB crit'!Q$12:Q$14; "x"); 'DGNB crit'!$E$12; 0);
 IF(COUNTIF('DGNB crit'!Q$15:Q$18; "x"); 'DGNB crit'!$E$15; 0);
 IF(COUNTIF('DGNB crit'!Q$19:Q$24; "x"); 'DGNB crit'!$E$19; 0);
 IF(COUNTIF('DGNB crit'!Q$25:Q$28; "x"); 'DGNB crit'!$E$25; 0);
 IF(COUNTIF('DGNB crit'!Q$29:Q$40; "x"); 'DGNB crit'!$E$29; 0);
 IF(COUNTIF('DGNB crit'!Q$41:Q$42; "x"); 'DGNB crit'!$E$41; 0);
 IF(COUNTIF('DGNB crit'!Q$43:Q$56; "x"); 'DGNB crit'!$E$43; 0);
 IF(COUNTIF('DGNB crit'!Q$57:Q$79; "x"); 'DGNB crit'!$E$57; 0);
 IF(COUNTIF('DGNB crit'!Q$80:Q$86; "x"); 'DGNB crit'!$E$80; 0);
 IF(COUNTIF('DGNB crit'!Q$87:Q$102; "x"); 'DGNB crit'!$E$87; 0);
 IF(COUNTIF('DGNB crit'!Q$103:Q$109; "x"); 'DGNB crit'!$E$103; 0);
 IF(COUNTIF('DGNB crit'!Q$110:Q$116; "x"); 'DGNB crit'!$E$110; 0);
 IF(COUNTIF('DGNB crit'!Q$117:Q$127; "x"); 'DGNB crit'!$E$117; 0);
 IF(COUNTIF('DGNB crit'!Q$128:Q$137; "x"); 'DGNB crit'!$E$128; 0);
 IF(COUNTIF('DGNB crit'!Q$138:Q$140; "x"); 'DGNB crit'!$E$138; 0);
 IF(COUNTIF('DGNB crit'!Q$141:Q$150; "x"); 'DGNB crit'!$E$141; 0);
 IF(COUNTIF('DGNB crit'!Q$151:Q$160; "x"); 'DGNB crit'!$E$151; 0);
 IF(COUNTIF('DGNB crit'!Q$161:Q$167; "x"); 'DGNB crit'!$E$161; 0);
 IF(COUNTIF('DGNB crit'!Q$168:Q$181; "x"); 'DGNB crit'!$E$168; 0);
 IF(COUNTIF('DGNB crit'!Q$182:Q$188; "x"); 'DGNB crit'!$E$182; 0);
 IF(COUNTIF('DGNB crit'!Q$189:Q$195; "x"); 'DGNB crit'!$E$189; 0);
 IF(COUNTIF('DGNB crit'!Q$196:Q$215; "x"); 'DGNB crit'!$E$196; 0);
 IF(COUNTIF('DGNB crit'!Q$216:Q$220; "x"); 'DGNB crit'!$E$216; 0);
 IF(COUNTIF('DGNB crit'!Q$221:Q$229; "x"); 'DGNB crit'!$E$221; 0);
 IF(COUNTIF('DGNB crit'!Q$230:Q$236; "x"); 'DGNB crit'!$E$230; 0);
```

```
  IF(COUNTIF('DGNB crit'!Q$237:Q$245; "x"); 'DGNB crit'!$E$237; 0)
)
```

Listing 9: Excel formula for maximum amount relevance factor points obtainable per temporal phase.

	=SUM(
ENV1.1	IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x") > 0; 1; 0);
ENV1.5	IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x") > 0; 1; 0);
ENV2.2	IF(COUNTIF('DGNB crit'!Q$12:Q$14; "x") > 0; 1; 0);
ENV2.3	IF(COUNTIF('DGNB crit'!Q$15:Q$18; "x") > 0; 1; 0);
ENV2.4	IF(COUNTIF('DGNB crit'!Q$19:Q$24; "x") > 0; 1; 0);
ECO1.1	IF(COUNTIF('DGNB crit'!Q$25:Q$28; "x") > 0; 1; 0);
ECO2.1	IF(COUNTIF('DGNB crit'!Q$29:Q$40; "x") > 0; 1; 0);
ECO2.3	IF(COUNTIF('DGNB crit'!Q$41:Q$42; "x") > 0; 1; 0);
ECO2.4	IF(COUNTIF('DGNB crit'!Q$43:Q$56; "x") > 0; 1; 0);
ECO2.5	IF(COUNTIF('DGNB crit'!Q$57:Q$79; "x") > 0; 1; 0);
SOC1.1	IF(COUNTIF('DGNB crit'!Q$80:Q$86; "x") > 0; 1; 0);
SOC1.6	IF(COUNTIF('DGNB crit'!Q$87:Q$102; "x") > 0; 1; 0);
SOC1.9	IF(COUNTIF('DGNB crit'!Q$103:Q$109; "x") > 0; 1; 0);
SOC2.1	IF(COUNTIF('DGNB crit'!Q$110:Q$116; "x") > 0; 1; 0);
SOC3.1	IF(COUNTIF('DGNB crit'!Q$117:Q$127; "x") > 0; 1; 0);
SOC3.2	IF(COUNTIF('DGNB crit'!Q$128:Q$137; "x") > 0; 1; 0);
SOC3.3	IF(COUNTIF('DGNB crit'!Q$138:Q$140; "x") > 0; 1; 0);
TEC2.1	IF(COUNTIF('DGNB crit'!Q$141:Q$150; "x") > 0; 1; 0);
TEC2.2	IF(COUNTIF('DGNB crit'!Q$151:Q$160; "x") > 0; 1; 0);
TEC2.4	IF(COUNTIF('DGNB crit'!Q$161:Q$167; "x") > 0; 1; 0);
TEC3.1	IF(COUNTIF('DGNB crit'!Q$168:Q$181; "x") > 0; 1; 0);
TEC3.2	IF(COUNTIF('DGNB crit'!Q$182:Q$188; "x") > 0; 1; 0);
PRO1.2	IF(COUNTIF('DGNB crit'!Q$189:Q$195; "x") > 0; 1; 0);
PRO1.7	IF(COUNTIF('DGNB crit'!Q$196:Q$215; "x") > 0; 1; 0);
PRO1.8	IF(COUNTIF('DGNB crit'!Q$216:Q$220; "x") > 0; 1; 0);
PRO1.9	IF(COUNTIF('DGNB crit'!Q$221:Q$229; "x") > 0; 1; 0);
PRO2.1	IF(COUNTIF('DGNB crit'!Q$230:Q$236; "x") > 0; 1; 0);
PRO3.5	IF(COUNTIF('DGNB crit'!Q$237:Q$245; "x") > 0; 1; 0)
	)

Listing 10: Excel formula for counting the criteria groups that belong to each temporal phase.

```
=SUM(
  (MIN(SUM(B26:D26) + MAX(0; SUM(E26:H26) - 100); (100 * IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x") > 0; 1; 0))));
  (MIN(SUM(E26:H26) + MAX(0; SUM(B26:D26) - 100); (100 * IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x") > 0; 1; 0))))
)
```

Listing 11: Excel formula for determining the obtained points per criteria group including bonus points facilitating overflow.

```
=SUM(
(MIN(SUM(BZ26);(100*IF(COUNTIF('DGNB crit'!Q$189:Q$195;"x")>0;1;0))));
(MIN(SUM(CA26:CB26);(100*IF(COUNTIF('DGNB crit'!Q$196:Q$215;"x")>0;1;0))));
(MIN(SUM(CC26:CG26);(100*IF(COUNTIF('DGNB crit'!Q$216:Q$220;"x")>0;1;0))))
)
```

Listing 12: Excel formula for determining the obtained points per criteria group including bonus points without overflow.

```
=SUM(
  (MIN(SUM(B26:D26) + MAX(0; SUM(E26:H26) - 100); (100*IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x") > 0; 1; 0))) / (SUM(B6:D6)));
  (MIN(SUM(E26:H26) + MAX(0; SUM(B26:D26) - 100); (100*IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x") > 0; 1; 0))) / (SUM(E6:H6)))
) / (SUM(
```

```
  IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x") > 0; 1; 0);
  IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x") > 0; 1; 0)))
```

Listing 13: Excel formula for determining the achieved score per criteria group including bonus points.

```
=SUM(
  (MIN(SUM(B26:D26) + MAX(0; SUM(E26:H26) - 100); (100*IF(COUNTIF('DGNB crit'!Q$2:Q$6; "x") > 0; 1; 0))) / (SUM(B6:D6)) * (B4/$CJ$4));
  (MIN(SUM(E26:H26) + MAX(0; SUM(B26:D26) - 100); (100*IF(COUNTIF('DGNB crit'!Q$7:Q$11; "x") > 0; 1; 0))) / (SUM(E6:H6)) * (E4/$CJ$4))
)
```

Listing 14: Excel formula for determining the achieved weighted score per criteria group including bonus points.

```
=TRANSPOSE(FILTER(B2:CI2; B2:CI2 <> ""))
```

Listing 15: Excel formula for generating a scoring list per criteria group.

```
=SORT(FILTER(E48:G58; F48:F58 <> ""); 2; -1)
```

Listing 16: Excel formula for sorting the scoring list based on personal preference.

```
=TRANSPOSE(FILTER(B5:CI5; ISNUMBER(SEARCH(B64; B5:CI5))))
```

Listing 17: Excel formula for loading in the components activated per specific temporal phase.

```
=IFERROR(INDEX($B$26:$CI$26; MATCH($B65; $B$5:$CI$5; 0)) / INDEX($B$6:$CI$6; MATCH($B65; $B$5:$CI$5; 0)); "No Match")
```

Listing 18: Excel formula for loading in the score per component activated and mentioned per specific temporal phase.

```
=SORT(FILTER(B65:C71; C65:C71 <> ""); 2; 1)
```

Listing 19: Excel formula for sorting the components of a criteria group by their scoring performance.

```
=IF($A2="x"; IFERROR(INDEX($B2:$IK2; MATCH(B5; $B1:$IK1; 0)); "" ); "")
```

Listing 20: Excel formula for daisy-chaining the input data in the database.

Appendix 6

Code for automated user form generation for the initial phase.

```
' Declare WithEvents variable at the top of your UserForm code module
Private WithEvents critExplButton As MSForms.CommandButton
Private WithEvents saveButton As MSForms.CommandButton

Private Sub UserForm_Initialize()
    Dim ws As Worksheet
    Dim dbWs As Worksheet
    Dim rng As Range
    Dim cell As Range
    Dim labelTop As Long
    Dim comboBoxTop As Long
    Dim lbl As MSForms.Label
    Dim cmb As MSForms.ComboBox
    Dim colIndex As Long
    Dim lastColumn As Long
    Dim headerCell As Range
    Dim existingValue As String

    ' Set the worksheets
    Set ws = ThisWorkbook.Worksheets("IP Comp (!)")
    Set dbWs = ThisWorkbook.Worksheets("IP database")
    lastColumn = ws.Cells(6, ws.Columns.Count).End(xlToLeft).Column

    ' Initialize positions for controls
    labelTop = 50
    comboBoxTop = 70

    ' Set the initial size of the form
    Me.Width = 350
    Me.Height = 400

    ' Enable scrolling
    Me.ScrollBars = fmScrollBarsVertical
    Me.ScrollHeight = 0  ' Initialize scroll height
    Me.ScrollTop = 0

    ' Create the "Component Explanation" button
    Set critExplButton = Me.Controls.Add("Forms.CommandButton.1")
    With critExplButton
        .Caption = "Component Explanation"
        .Left = 10
        .Top = 10
        .Width = 150
        .Font.Size = 10
    End With

    ' Create the "Save" button
    Set saveButton = Me.Controls.Add("Forms.CommandButton.1")
    With saveButton
        .Caption = "Save"
        .Left = 170
        .Top = 10
        .Width = 150
        .Font.Size = 10
    End With

    ' Loop through the columns in the range B6:CI6
    For colIndex = 2 To lastColumn
```

```
        Set cell = ws.Cells(6, colIndex)

        If cell.Value <> "" Then
            ' Create a new Label
            Set lbl = Me.Controls.Add("Forms.Label.1")
            lbl.Caption = ws.Cells(5, colIndex).Value
            lbl.Left = 10
            lbl.Top = labelTop
            lbl.Width = 150
            lbl.Font.Size = 10

            ' Create a new ComboBox
            Set cmb = Me.Controls.Add("Forms.ComboBox.1")
            cmb.Left = 170
            cmb.Top = comboBoxTop
            cmb.Width = 150
            cmb.MatchRequired = True
            cmb.Font.Size = 10
            cmb.Tag = colIndex

            ' Populate ComboBox with items from B11:CI24 for the current column
            For Each headerCell In ws.Range(ws.Cells(11, colIndex), ws.Cells(24, colIndex))
                If headerCell.Value <> "" Then
                    cmb.AddItem headerCell.Value
                End If
            Next headerCell

            ' Check if there's an existing value in the "IP database" sheet in row 2
            existingValue = dbWs.Cells(2, colIndex).Value
            If existingValue <> "" Then
                ' Set the ComboBox value to the existing data
                cmb.Value = existingValue
            Else
                ' Set the first item as the default selected item if no existing value
                If cmb.ListCount > 0 Then
                    cmb.ListIndex = 0
                End If
            End If

            ' Increment positions for the next Label and ComboBox
            labelTop = labelTop + 40
            comboBoxTop = comboBoxTop + 40

            ' Update the scroll height dynamically
            Me.ScrollHeight = Me.ScrollHeight + 40
        End If
    Next colIndex

    ' Adjust the form's scroll height to fit all controls
    If labelTop > Me.Height Then
        Me.ScrollHeight = labelTop + 20
    End If
End Sub

Private Sub SaveButton_Click()
    Dim ws As Worksheet
    Dim i As Integer
    Dim cmb As MSForms.ComboBox
    Dim colIndex As Long

    ' Set the worksheet where the data will be saved
    Set ws = ThisWorkbook.Worksheets("IP database")
```

```
    ' Loop through all the controls on the UserForm
    For i = 0 To Me.Controls.Count - 1
        If TypeName(Me.Controls(i)) = "ComboBox" Then
            Set cmb = Me.Controls(i)
            colIndex = cmb.Tag

            ' Check if colIndex is valid
            If IsNumeric(colIndex) And colIndex >= 2 Then
                ' Save the selected value to the corresponding column in the "IP database" sheet
                If cmb.ListIndex <> -1 Then
                    ws.Cells(2, colIndex).Value = cmb.Value
                Else
                    ws.Cells(2, colIndex).ClearContents
                End If
            End If
        End If
    Next i

    ' Confirm save operation
    MsgBox "Data saved successfully!", vbInformation, "Save"
End Sub


Private Sub critExplButton_Click()
    Dim url As String
    url = "https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/certification-schemes/urban-
districts"
    ThisWorkbook.FollowHyperlink Address:=url
End Sub
```

Appendix 7

Code of the recorded macro's for the "Next" button in the "Start" worksheet, feedback generation and phase finalization.

```
Sub StartNext()

    Sheets("IP database").Select
    Columns("A:A").Select
    Selection.ClearContents
    Sheets("Initial Phase").Select
    Range("H24").Select
    Cells.Replace What:="63", Replacement:="64", LookAt:=xlPart, SearchOrder _
        :=xlByRows, MatchCase:=False, SearchFormat:=False, ReplaceFormat:=False _
        , FormulaVersion:=xlReplaceFormula2
    Cells.Replace What:="64", Replacement:="63", LookAt:=xlPart, SearchOrder _
        :=xlByRows, MatchCase:=False, SearchFormat:=False, ReplaceFormat:=False _
        , FormulaVersion:=xlReplaceFormula2
    Cells.Replace What:="65", Replacement:="100", LookAt:=xlPart, _
        SearchOrder:=xlByRows, MatchCase:=False, SearchFormat:=False, _
        ReplaceFormat:=False, FormulaVersion:=xlReplaceFormula2
End Sub

Sub IP_Generate_Feedback()

    Cells.Replace What:="100", Replacement:="65", LookAt:=xlPart, _
        SearchOrder:=xlByRows, MatchCase:=False, SearchFormat:=False, _
        ReplaceFormat:=False, FormulaVersion:=xlReplaceFormula2
    Cells.Replace What:="63", Replacement:="64", LookAt:=xlPart, SearchOrder _
        :=xlByRows, MatchCase:=False, SearchFormat:=False, ReplaceFormat:=False _
        , FormulaVersion:=xlReplaceFormula2
End Sub

Sub IP_Finalize_Phase()

    Sheets("IP database").Select
    Range("A2").Select
    ActiveCell.FormulaR1C1 = "x"
    Range("A3").Select
    Sheets("Initial Phase").Select
    ActiveSheet.Shapes.Range(Array("Rectangle 5")).Select
    With Selection.ShapeRange.TextFrame2.TextRange.Font.Fill
        .Visible = msoTrue
        .ForeColor.ObjectThemeColor = msoThemeColorBackground1
        .ForeColor.TintAndShade = 0
        .ForeColor.Brightness = 0
        .Transparency = 0
        .Solid
    End With
    ActiveSheet.Hyperlinks.Add Anchor:=Selection.ShapeRange.Item(1), Address:=""

End Sub
```

Appendix 8

VBA code of UserForm frmFormStart.

```
Private Sub cmdGoals_Click()
  frmFormPG.Show
End Sub


Sub cmdPresets_Click()
    frmFormPP.Show
End Sub


Private Sub UserForm_Initialize()
   Me.Width = 430
   Me.Height = 530

   cmdClose.Enabled = False
   CheckEnableCloseButton
End Sub

Public Sub CheckEnableCloseButton()
   Dim wsPP As Worksheet
   Dim wsPG As Worksheet
   Dim countPP As Long
   Dim countPG As Long
   Dim cell As Range

   Set wsPP = ThisWorkbook.Sheets("database PP")
   Set wsPG = ThisWorkbook.Sheets("database PG")

   ' Debugging output for initial state
   Debug.Print "Initializing CheckEnableCloseButton..."
   Debug.Print "Data in wsPP (database PP):"
   For Each cell In wsPP.Range("A2:F2")
      Debug.Print cell.Address & ": " & cell.Value
   Next cell

   Debug.Print "Data in wsPG (database PG):"
   For Each cell In wsPG.Range("A2:E2")
      Debug.Print cell.Address & ": " & cell.Value
   Next cell

   countPP = Application.WorksheetFunction.CountA(wsPP.Range("A2:F2"))
   countPG = Application.WorksheetFunction.CountA(wsPG.Range("A2:E2"))

   ' Debugging output for counts
   Debug.Print "Count of non-empty cells in database PP: " & countPP
   Debug.Print "Count of non-empty cells in database PG: " & countPG

   ' Check if data exists in both ranges
   If countPP > 0 And countPG > 0 Then
      cmdClose.Enabled = True
      Debug.Print "Both ranges have data. Close button enabled."
   Else
      cmdClose.Enabled = False
      Debug.Print "One or both ranges are empty. Close button disabled."
   End If
End Sub
```

```
Private Sub cmdClose_Click()
   Me.Hide
End Sub


Private Sub UserForm_Resize()
   Me.Width = 430
   Me.Height = 530
End Sub
```

VBA code of UserForm frmFormPP.

```
Sub Reset()
   Dim ws As Worksheet
   Dim data As Variant
   Dim headerRow As Variant
   Dim iRow As Long

   iRow = [counta("database PP!A:A")]

   Set ws = ThisWorkbook.Worksheets("database PP")

   data = ws.Range("A1:F2").Value
   headerRow = Array("Name", "Size", "1st Largest Environmental Hazard", "2nd Largest Environmental Hazard", "3rd
Largest Environmental Hazard", "Set On")

   With frmFormPP
      .txtName.Value = ""
      .txtSize.Value = ""
      .cmbEnvR1.Clear
      .cmbEnvR2.Clear
      .cmbEnvR3.Clear

      ' Initialize the ListBox
      .lstDatabasePP.Clear
      .lstDatabasePP.ColumnCount = 6
      .lstDatabasePP.ColumnHeads = False
      .lstDatabasePP.ColumnWidths = "200;50;175;175;175;100"

      ' Populate the ListBox using the List property
      .lstDatabasePP.List = data

   End With
End Sub

Sub ShowForm()
   frmFormPP.Show
End Sub

Sub submit()

   Dim ws As Worksheet
   Dim iRow As Long

   Set ws = ThisWorkbook.Sheets("database PP")

   iRow = [counta(database PP!A:A)] + 1

   With ws
```

```
        .Cells(iRow, 1) = frmFormPP.txtName.Value
        .Cells(iRow, 2) = frmFormPP.txtSize.Value
        .Cells(iRow, 3) = frmFormPP.cmbEnvR1.Value
        .Cells(iRow, 4) = frmFormPP.cmbEnvR2.Value
        .Cells(iRow, 5) = frmFormPP.cmbEnvR3.Value
        .Cells(iRow, 6) = [text(now(),"DD-MM-YYYY HH:MM:SS")]

    End With
End Sub

Private Sub cmdEnvR_Click()
    Dim url As String
    url = "https://archive.espon.eu/programme/projects/espon-2006/thematic-projects/spatial-effects-natural-and-
technological-hazards"
    ThisWorkbook.FollowHyperlink Address:=url
End Sub


Private Sub cmdSavePP_Click()
    Dim msgValue As VbMsgBoxResult

    msgValue = MsgBox("Do you want to save the presets?", vbYesNo + vbInformation, "Confirmation")

    If msgValue = vbNo Then Exit Sub

    Call submit
    Call Reset
End Sub

Private Sub UserForm_Initialize()
    Me.Width = 1060
    Me.Height = 510

    Call Reset

    Dim ws As Worksheet
    Dim rng As Range
    Dim cell As Range

    ' Set the worksheet
    Set ws = ThisWorkbook.Worksheets("DGNB crit")
    ' Set the range containing the list
    Set rng = ws.Range("AB59:AB67")

    ' Populate cmbEnvR1
    For Each cell In rng
        Me.cmbEnvR1.AddItem cell.Value
    Next cell

    ' Disable cmbEnvR2 and cmbEnvR3 initially
    Me.cmbEnvR2.Enabled = False
    Me.cmbEnvR3.Enabled = False
End Sub

Private Sub UserForm_Resize()
    Me.Width = 1060
    Me.Height = 510
End Sub


Private Sub cmbEnvR1_Change()
    Dim ws As Worksheet
    Dim rng As Range
```

```
    Dim cell As Range
    Dim selectedItem As String

    ' Get the selected item from cmbEnvR1
    selectedItem = Me.cmbEnvR1.Value

    ' Set the worksheet and range again
    Set ws = ThisWorkbook.Worksheets("DGNB crit")
    Set rng = ws.Range("AB59:AB67")

    ' Clear and populate cmbEnvR2 excluding the selected item
    Me.cmbEnvR2.Clear
    For Each cell In rng
        If cell.Value <> selectedItem Then
            Me.cmbEnvR2.AddItem cell.Value
        End If
    Next cell

    ' Enable cmbEnvR2
    Me.cmbEnvR2.Enabled = True
End Sub

Private Sub cmbEnvR2_Change()
    Dim ws As Worksheet
    Dim rng As Range
    Dim cell As Range
    Dim selectedItem1 As String
    Dim selectedItem2 As String

    ' Get the selected items from cmbEnvR1 and cmbEnvR2
    selectedItem1 = Me.cmbEnvR1.Value
    selectedItem2 = Me.cmbEnvR2.Value

    ' Set the worksheet and range again
    Set ws = ThisWorkbook.Worksheets("DGNB crit")
    Set rng = ws.Range("AB59:AB67")

    ' Clear and populate cmbEnvR3 excluding the selected items
    Me.cmbEnvR3.Clear
    For Each cell In rng
        If cell.Value <> selectedItem1 And cell.Value <> selectedItem2 Then
            Me.cmbEnvR3.AddItem cell.Value
        End If
    Next cell

    ' Enable cmbEnvR3
    Me.cmbEnvR3.Enabled = True
End Sub
```

VBA code of UserForm frmFormPG.

```
Sub Reset()

    Dim ws As Worksheet
    Dim data As Variant
    Dim headerRow As Variant
    Dim iRow As Long

    iRow = [counta("database PG!A:A")]
```

```
    Set ws = ThisWorkbook.Worksheets("database PG")

    data = ws.Range("A1:L2").Value
    headerRow = Array("ENV1", "ENV2", "ECO1", "ECO2", "SOC1", "SOC2", "SOC3", "TEC2", "TEC3", "PRO1", "PRO3")

    With frmFormPG
        .cmbEnv1.Clear
        .cmbEnv2.Clear
        .cmbEco1.Clear
        .cmbEco2.Clear
        .cmbSoc1.Clear
        .cmbSoc2.Clear
        .cmbSoc3.Clear
        .cmbTec2.Clear
        .cmbTec3.Clear
        .cmbPro1.Clear
        .cmbPro3.Clear

        ' Initialize the ListBox
        .lstDatabasePG.Clear
        .lstDatabasePG.ColumnCount = 12
        .lstDatabasePG.ColumnHeads = False
        .lstDatabasePG.ColumnWidths = "70;70;70;70;70;70;70;70;70;70;70;105"
        ' Populate the ListBox using the List property
        .lstDatabasePG.List = data

    End With
End Sub

Sub ShowForm()
    frmFormPG.Show
End Sub

Sub submit()
    Dim ws As Worksheet
    Dim iRow As Long

    Set ws = ThisWorkbook.Sheets("database PG")

    iRow = [counta(database PG!A:A)] + 1

    With ws

        .Cells(iRow, 1) = frmFormPG.cmbEnv1.Value
        .Cells(iRow, 2) = frmFormPG.cmbEnv2.Value
        .Cells(iRow, 3) = frmFormPG.cmbEco1.Value
        .Cells(iRow, 4) = frmFormPG.cmbEco2.Value
        .Cells(iRow, 5) = frmFormPG.cmbSoc1.Value
        .Cells(iRow, 6) = frmFormPG.cmbSoc2.Value
        .Cells(iRow, 7) = frmFormPG.cmbSoc3.Value
        .Cells(iRow, 8) = frmFormPG.cmbTec2.Value
        .Cells(iRow, 9) = frmFormPG.cmbTec3.Value
        .Cells(iRow, 10) = frmFormPG.cmbPro1.Value
        .Cells(iRow, 11) = frmFormPG.cmbPro3.Value
        .Cells(iRow, 12) = [text(now(),"DD-MM-YYYY HH:MM:SS")]

    End With
End Sub

Private Sub cmdCritExpl_Click()
    Dim url As String
```

```
    url = "https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/certification-schemes/urban-
districts"
    ThisWorkbook.FollowHyperlink Address:=url
End Sub


Private Sub cmdSavePG_Click()
    Dim msgValue As VbMsgBoxResult

    msgValue = MsgBox("Do you want to save the goals?", vbYesNo + vbInformation, "Confirmation")

    If msgValue = vbNo Then Exit Sub

    Call submit
    Call Reset
End Sub


Private Sub UserForm_Initialize()
    Me.Width = 1060
    Me.Height = 510

    Call Reset

    Dim ws As Worksheet
    Dim rng As Range
    Dim cell As Range

    Set ws = ThisWorkbook.Worksheets("DGNB crit")
    ' Set the range containing the list
    Set rng = ws.Range("AD59:AD65")

    ' Populate combiboxes
    For Each cell In rng
        Me.cmbEnv1.AddItem cell.Value
        Me.cmbEnv2.AddItem cell.Value
        Me.cmbEco1.AddItem cell.Value
        Me.cmbEco2.AddItem cell.Value
        Me.cmbSoc1.AddItem cell.Value
        Me.cmbSoc2.AddItem cell.Value
        Me.cmbSoc3.AddItem cell.Value
        Me.cmbTec2.AddItem cell.Value
        Me.cmbTec3.AddItem cell.Value
        Me.cmbPro1.AddItem cell.Value
        Me.cmbPro3.AddItem cell.Value
    Next cell
End Sub

Private Sub UserForm_Resize()
    Me.Width = 1060
    Me.Height = 510
End Sub
```

VBA code of UserForm UserForm1, which is used for the checklist of the Initial Phase.

```
' Declare WithEvents variable at the top of UserForm code module
Private WithEvents critExplButton As MSForms.CommandButton
Private WithEvents saveButton As MSForms.CommandButton
```

```
Private Sub UserForm_Initialize()
    Dim ws As Worksheet
    Dim dbWs As Worksheet
    Dim rng As Range
    Dim cell As Range
    Dim labelTop As Long
    Dim comboBoxTop As Long
    Dim lbl As MSForms.Label
    Dim cmb As MSForms.ComboBox
    Dim colIndex As Long
    Dim lastColumn As Long
    Dim headerCell As Range
    Dim existingValue As String

    Set ws = ThisWorkbook.Worksheets("IP Comp (!)")
    Set dbWs = ThisWorkbook.Worksheets("IP database")
    lastColumn = ws.Cells(6, ws.Columns.Count).End(xlToLeft).Column

    ' Initialize positions for controls
    labelTop = 50
    comboBoxTop = 70

    ' Set the initial size of the form
    Me.Width = 350
    Me.Height = 400

    ' Enable scrolling
    Me.ScrollBars = fmScrollBarsVertical
    Me.ScrollHeight = 0
    Me.ScrollTop = 0

    ' Create the "Component Explanation" button
    Set critExplButton = Me.Controls.Add("Forms.CommandButton.1")
    With critExplButton
        .Caption = "Component Explanation"
        .Left = 10
        .Top = 10
        .Width = 150
        .Font.Size = 10
    End With

    ' Create the "Save" button
    Set saveButton = Me.Controls.Add("Forms.CommandButton.1")
    With saveButton
        .Caption = "Save"
        .Left = 170
        .Top = 10
        .Width = 150
        .Font.Size = 10
    End With

    ' Loop through the columns in the range B6:CI6
    For colIndex = 2 To lastColumn
        Set cell = ws.Cells(6, colIndex)

        If cell.Value <> "" Then
            ' Create a new Label
            Set lbl = Me.Controls.Add("Forms.Label.1")
            lbl.Caption = ws.Cells(5, colIndex).Value  ' Caption from B5:CI5
            lbl.Left = 10
            lbl.Top = labelTop
            lbl.Width = 150
            lbl.Font.Size = 10
```

```
        ' Create a new ComboBox
        Set cmb = Me.Controls.Add("Forms.ComboBox.1")
        cmb.Left = 170
        cmb.Top = comboBoxTop
        cmb.Width = 150
        cmb.MatchRequired = True
        cmb.Font.Size = 10
        cmb.Tag = colIndex

        ' Populate ComboBox with items from B11:CI24 for the current column
        For Each headerCell In ws.Range(ws.Cells(11, colIndex), ws.Cells(24, colIndex))
            If headerCell.Value <> "" Then
                cmb.AddItem headerCell.Value
            End If
        Next headerCell

        ' Check if there's an existing value in the "IP database" sheet in row 2
        existingValue = dbWs.Cells(2, colIndex).Value
        If existingValue <> "" Then
            ' Set the ComboBox value to the existing data
            cmb.Value = existingValue
        Else
            ' Set the first item as the default selected item if no existing value
            If cmb.ListCount > 0 Then
                cmb.ListIndex = 0
            End If
        End If

        ' Increment positions for the next Label and ComboBox
        labelTop = labelTop + 40
        comboBoxTop = comboBoxTop + 40

        ' Update the scroll height dynamically
        Me.ScrollHeight = Me.ScrollHeight + 40
    End If
  Next colIndex

  ' Adjust the form's scroll height to fit all controls
  If labelTop > Me.Height Then
    Me.ScrollHeight = labelTop + 20
  End If
End Sub

Private Sub SaveButton_Click()
  Dim ws As Worksheet
  Dim i As Integer
  Dim cmb As MSForms.ComboBox
  Dim colIndex As Long

  ' Set the worksheet where the data will be saved
  Set ws = ThisWorkbook.Worksheets("IP database")

  ' Loop through all the controls on the UserForm
  For i = 0 To Me.Controls.Count - 1
    If TypeName(Me.Controls(i)) = "ComboBox" Then
        Set cmb = Me.Controls(i)
        colIndex = cmb.Tag

        ' Check if colIndex is valid
        If IsNumeric(colIndex) And colIndex >= 2 Then
            ' Save the selected value to the corresponding column in the "IP database" sheet
            If cmb.ListIndex <> -1 Then
```

```
              ws.Cells(2, colIndex).Value = cmb.Value
            Else
              ws.Cells(2, colIndex).ClearContents
            End If
          End If
        End If
    Next i

    ' Confirm save operation
    MsgBox "Data saved successfully!", vbInformation, "Save"
End Sub


Private Sub critExplButton_Click()
    Dim url As String
    url = "https://www.dgnb.de/en/certification/important-facts-about-dgnb-certification/certification-schemes/urban-
districts"
    ThisWorkbook.FollowHyperlink Address:=url
End Sub
```

Appendix 9

Case validation Decision Support System

For the validation of the developed Decision Support System (DSS) by Job Jansen for his graduation project the following fictional case is drafted. Its main purpose is to provide the tester of the DSS with the information necessary to test it, no real-life related links are present.

Name of the project: Walkwartier

Location of the project: Oss

Size of the project: 11 ha

Goal of the development of Walkwartier

The Walkwartier project in Oss represents a significant urban redevelopment effort, spanning 11 hectares in the heart of the city. As part of this project, careful consideration must be given to various aspects that will shape the long-term sustainability, functionality, and livability of the area. The following topics are crucial in ensuring the success of this development and will require your input to gauge their importance in the planning and design phases. Your feedback will help guide the Decision Support System (DSS) in aligning project priorities with sustainable development goals.

<u>Effects on Global Warming and Local Environment</u>
The environmental impact of the project, including its contribution to global warming and effects on the local ecosystem, is a critical concern. The development must strive to minimize carbon emissions, promote biodiversity, and mitigate any negative environmental effects.

<u>Resource Use and Waste Generation</u>
Efficient use of resources and effective waste management are essential in reducing the environmental footprint of the project. Consider the importance of minimizing resource consumption and optimizing waste handling processes.

<u>Life-Cycle Costs</u>
Beyond initial investment, the long-term costs associated with the project, including maintenance, energy consumption, and operational expenses, play a vital role in its sustainability. The assessment should consider the balance between upfront costs and long-term financial efficiency.

<u>Economic Development</u>
The project's potential to stimulate local economic growth, create jobs, and attract investment is a key factor. Consider how the development can contribute to the economic vitality of Oss.

<u>Health, Comfort, and User Satisfaction</u>
Ensuring that the development promotes health, comfort, and satisfaction for its users is a priority. This includes access to green spaces, indoor air quality, thermal comfort, and overall user experience.

<u>Functionality</u>
The project must meet its intended functional requirements effectively. This includes the usability of spaces, adaptability to future needs, and overall operational efficiency of the area.

Sociocultural Quality
The development should respect and enhance the sociocultural fabric of Oss. This involves integrating cultural heritage, fostering community engagement, and supporting social cohesion.

Technical Infrastructure
Reliable and modern infrastructure, including water supply, energy systems, and communication networks, is essential for the project's success. The importance of robust infrastructure that meets current and future demands cannot be understated.

Mobility
Effective transportation solutions that facilitate movement within and around Walkwartier are crucial. Consider the importance of public transit, pedestrian pathways, and cycling routes in creating a connected and accessible urban area.

Planning Quality
The quality of the planning process itself, including stakeholder involvement, transparency, and adherence to regulations, plays a pivotal role in the project's outcome. Reflect on how the planning process can be optimized to ensure the best possible results.

Quality in the Use Phase
Finally, the long-term success of Walkwartier depends on its performance during the use phase. This includes how well the development meets the needs of its users over time and its ability to adapt to changing conditions and demands.

Project development

Below there are certain aspects that are known of the project thus far. This data need to be put in the DSS via the checklist embedded. Make sure all the data is properly filled in.

ENV1.1_1.1
From an early planning phase, district variables have been compared in detail. There are 2 areas of action (strategies) defined that are relevant to the life cycle assessment.

ENV1.1_2.1
Optimization of the LCA accompanying the planning was performed in a partial manner but carried throughout the development process.

ENV1.1_4.1
For this project there has been decided that there will be focus on the ambition to achieve carbon neutrality.

ENV1.5_1.1
A profound analysis on urban climate has been performed, covering 3 different areas of analysis.

ENV1.5_3.1
During analysis, there has been looked at the effects of the ventilation within the city, however, no digital model has been used or developed.

ENV1.5_3.2
Experts were not consulted for the ventilation analysis

ENV1.5_4.1
A specially tailored climate adaption strategy has been put together for this development.

ENV2.2_1.1
A water overarching concept has been investigated.

ENV2.3_3.1
The soil of the site is not contaminated.

ENV2.4_1.1
This has not been performed yet.

ENV2.4_2.1
In the plan the developers have implemented two active targeted measures to implement new native species for the biodiversity within the city.

ENV2.4_5.1
There has been made sure that there are no invasive plant species in the development plan.

Appendix 10

Interview questions for the evaluation of the developed model

1. *Would you be comfortable with this meeting being recorded to ensure no exchanged information is lost?*
2. *How does the company participate in urban development projects?*
3. *Would you like to be able to start using the tool right away, or would you like to first determine (together with a team) to which temporal phase each criteria should belong in your development project?*

Use of the tool

1. *How do you experience the starting window when you open the tool?*
2. *What do you think of the disclaimer message?*
3. *Is in this window clear what is expected from the user?*
4. *How do you experience filling in the Project Presets?*
5. *How do you experience filling in the Project Goals?*
6. *How do you experience filling in the checklist for the initial phase?*
7. *What are your thoughts of the visualization of the interface?*
8. *Is the feedback generated by the tool insightful to you?*
9. *What are your comments on the feedback presented?*

User friendliness of the tool

10. *How user-friendly did you find the tool overall?*
11. *Was the navigation menu intuitive for changing project goals or revisiting earlier design phases?*
12. *Did you find the tool's scoring and feedback mechanisms transparent and easy to understand?*
13. *How well does the tool support prioritizing sustainability goals and adapting to different types of development projects?*

General functionality of the tool

14. *Do you think this new tool is a smart adaption to answer difficult sustainability questions for development projects?*
15. *Do you think the system can provide universally applicable answers based on what you have experienced while working with the tool?*
16. *In what ways do you think the tool could improve the sustainability assessment process in development projects?*
17. *How do you see the tool enhancing communication and collaboration among different stakeholders in a project?*
18. *Do you think a system like this one would aid decision makers in development projects in making informed decisions?*

Future improvements of the tool

19. *What would you like to see different in this developed system?*
20. *Which additional improvements do you think this system needs?*
21. *Are there any particular features or functionalities that you feel are missing from the tool?*
22. *In what ways do you think the tool could be improved to better accommodate diverse stakeholder needs?*
23. *Do you have any suggestions for improving the user experience when navigating through different phases of the tool?*

Performance of the tool

24. *How does the tool compare to other sustainability assessment tools in terms of functionality, ease of use, and holistic assessment?*
25. *How effective is the tool in supporting iterative design, facilitating pre-emptive adjustments, and integrating stakeholder input throughout the project lifecycle?*
26. *How well does the tool handle temporal aspects and the integration of DGNB UD criteria within development plans?*
27. *How do you perceive the tool's potential to impact the quality of urban spaces in terms of sustainability?*