DELFT UNIVERSITY OF TECHNOLOGY

Utilization of Generative AI for enabling knowledge contextualization among stakeholders for enhancing circularity in the construction industry

Final report

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Abstract

This thesis explores the potential of utilizing Generative AI to enhance knowledge contextualization among stakeholders to promote circularity in the construction industry. Circularity, essential for sustainable development, demands a shift from the linear "take-make-dispose" model to a regenerative approach that minimizes resource consumption and waste. The construction industry, a significant contributor to global material use and waste, faces unique challenges in implementing circularity due to its technical complexity and the wide range of stakeholders involved. Consultants, who play a crucial role in bridging the gap between technical knowledge and practical application, are central to overcoming these challenges. This study focuses on consultants and their ability to disseminate and contextualize knowledge, a process hindered by technical language, the varying expertise of stakeholders, and the multi-disciplinary nature of construction projects.

The research investigates the current applications of Generative AI, with a particular focus on ChatGPT, as a tool for knowledge contextualization in circular construction projects. Through a comprehensive literature review and qualitative data collection from semi-structured interviews with industry professionals, this thesis identifies both the barriers to effective knowledge-sharing stakeholders encounter in circular projects and the potential affordances of ChatGPT in overcoming these challenges. The state-of-the-art capabilities of ChatGPT include features such as contextual comprehension, few-shot learning, and coherent content generation, which allow it to process and present complex information in a user-friendly format tailored to the specific needs of stakeholders. Its affordances, such as knowledge retrieval, organization, and tailoring, enable ChatGPT as a powerful tool to create customized knowledge outputs, making it particularly suited for addressing the diverse and technical demands of the construction industry. The analysis of the interviews highlights that the limited understanding of circularity principles among stakeholders stems from the complexity of technical documentation, the information overload of the documents regarding circularity, and the lack of tailored information that adapts to the specific needs of different actors and projects in the construction process.

The thesis investigates the possibility of ChatGPT as a solution to these issues by dynamically tailoring technical information to match the expertise and tasks of diverse stakeholders. The research studies how ChatGPT's features and affordances in knowledge management can enhance the contextualization of circularity knowledge, improving the accessibility and usability of complex information for non-experts. This approach fosters better collaboration among stakeholders and accelerates the adoption of circularity practices, often slowed by misunderstandings and technical jargon.

The findings suggest that while the potential of ChatGPT in knowledge management is vast, its implementation is still in the early stages. The study proposes a framework for integrating Generative AI into the knowledge-sharing processes of the circular construction industry, aiming to optimize knowledge dissemination and improve stakeholder comprehension. The framework is based on tailoring the capabilities of AI to support consultants in their pivotal role of contextualizing knowledge. By addressing the identified barriers to the adoption of this tool, this thesis contributes to the ongoing discourse on sustainable construction practices and highlights the importance of technology in advancing the industry towards circularity.

This thesis concludes by offering practical guidelines for the integration of Generative AI in circular construction projects, underscoring the need for further research into its long-term implications. The proposed guidelines for integrating ChatGPT into the construction industry focus on three key phases: preparation, where stakeholders are trained to understand the AI's capabilities; pilot testing, where AI-assisted knowledge contextualization is trialed in a controlled setting; and deployment, where the AI is fully integrated into project workflows with ongoing monitoring to ensure its effectiveness in enhancing communication and knowledge sharing. The research lays the groundwork for future studies aimed at refining AI applications in this context and ensuring that the construction industry can meet its sustainability goals through improved knowledge management practices.

Content

1. Introduction 6
2. Research Methodology 8
2.1 Literature review 9
2.2 Interview Sampling 11
2.3 Data Acquisition 12
2.4 Data Analysis 13
3. Literature Review 15
3.1 Circularity in the Construction Industry 15
3.2 Knowledge management in the construction industry 21
3.3 Generative AI 26
4. Findings 38
4.1 Validation of limited understanding 38
4.2 Difficulties of Consultants 39
4.3 Difficulties of Collaborating Stakeholders 41
4.4 Resources for rectification 43
4.5 Effects on Circular Projects 44
4.6 Current use of ChatGPT 45
4.7 Concerns about ChatGPT 47
4.8 Difficulties for integration of ChatGPT 49
4.9 Willingness to adopt ChatGPT for knowledge contextualization 51
5. Discussions 53
5.1 Reasons for poor knowledge contextualization 53
5.2 Rectifying Resources and Produced Setbacks 57
5.3 Familiarity with ChatGPT and willingness for utilization 58
5.4 Concerns about ChatGPT 59
5.5 Difficulties for integration of ChatGPT 61
5.6 Rationale behind the need for the creation of the guidelines 62
5.7 Comparison of ChatGPT and other Generative AI tools 64
6. Guidelines development 66
6.1 Preparation Phase 67
6.2 Pilot Phase 72
6.3 Deployment Phase 74

7. Conclusions 76
7.1 Research Questions 76
7.2 Theoretical and Practical Contribution 79
7.3 Limitations 81
7.4 Future Research 82
References 83
Appendix A 96

List of Figures

FIGURE 1: RESEARCH DESIGN 10
FIGURE 2: STEPS OF THEMATIC ANALYSIS, SOURCE: WPTAMARA (2024) 14
FIGURE 3: CIRCULARITY IN THE CONSTRUCTION INDUSTRY, SOURCE: KUSCU (2021) 17
FIGURE 4: THE 9R FRAMEWORK, SOURCE: POTTING ET AL. (2017) 20
FIGURE 5: THE KMC MODEL, SOURCE: EVANS ET AL. (2014) 25
FIGURE 6: IMPLEMENTATION PHASES OF CHATGPT 30
FIGURE 7: GUIDELINES FOR SMOOTH INTEGRATION OF CHATGPT 68

TABLE 1: SEARCH STRATEGY 11
TABLE 2: INTERVIEW PARTICIPANTS 12
TABLE 3: THEMATIC DATA ANALYSIS 15
TABLE 4: QUOTES ON CONSULTANTS' DIFFICULTIES 44
TABLE 5: QUOTES ON COLLABORATING STAKEHOLDERS' DIFFICULTIES 46
TABLE 6: QUOTES ON RECTIFYING RESOURCES 47
TABLE 7: QUOTES ON THE EFFECTS ON CIRCULAR PROJECTS 49
TABLE 8: CURRENT CHATGPT APPLICATIONS 50
TABLE 9: QUOTES ON CONCERNS ABOUT CHATGPT 52
TABLE 10: QUOTES ON DIFFICULTIES OF INTEGRATION 54
TABLE 11: QUOTES ON WILLINGNESS TO UTILIZE CHATGPT 55
TABLE 12: SUMMARY OF FINDINGS 56
TABLE 13: GUIDELINES DEVELOPMENT 67

1. Introduction

The world has experienced a huge depletion of natural resources during the last few decades. The construction industry is one of the leading sectors responsible for the depletion of natural resources, contributing to the unsustainable exploitation of the Earth's finite resources (Habert et al., 2010b). The rising demand for raw materials (wood, sand, minerals, rocks) poses a serious threat to preserving biodiversity and environmental sustainability. The risk of the continued growth of the linear model of production and consumption hinders any possibility of achieving a sustainable future (Turner, 2008). According to the Circularity Gap Report, the construction industry is accountable for 40% of material extraction, produces 33% of greenhouse emissions, and generates 40% of waste yearly (Fraser et al., 2023). The linear model that governs the construction industry is further deteriorating the depletion of natural resources, the rise of material consumption, and the increase in waste production (Oluleye et al., 2022). Evidently, the linear model of extract, produce, and dispose is incapable of sustaining the future needs of the construction industry (Esposito et al., 2018).

The need for sustainability in the construction industry necessitates the adoption of circularity, a process that involves multiple stakeholders at almost every stage of a project. Success in circularity is highly dependent on accurate knowledge dissemination and effective interaction between the actors, each contributing critical information (Fobbe & Hilletofth, 2022). This can be substantiated by the fact that circularity is a multifaceted concept that has recently gained attention from the construction sector. In combination with the proven slow adaption of the sector to changes, the new information around this concept needed to be comprehended by the stakeholders renders it even more difficult to attain a satisfactory level of circularity (Velte et al., 2016). Challenges in **accurately contextualizing** this knowledge to the specific needs and tasks of the stakeholders can lead to significant setbacks in the entire process. Some of these issues include limited implementation of circular practices, missed opportunities for resource optimization, less innovation, and sub-optimal solutions (Bilal et al., 2020b).

This thesis will focus specifically on consultants in circular construction projects, aiming to propose improvements to current knowledge-sharing practices. Consultants are currently producing detailed, extensive, and complex documents that are disseminated to all stakeholders without considering varying levels of expertise and knowledge (Kirkpatrick et al., 2018). The findings and recommendations are intended to enhance the knowledge-sharing practices of the consultants, particularly in the Netherlands, to ensure more effective communication tailored to the diverse needs of project participants. Investigating the role of consultants is crucial for the thesis because consultants play a pivotal role in coordinating various stakeholders and disseminating the necessary knowledge for successfully implementing circularity principles in construction projects. Consultants are responsible for processing and contextualizing highly technical documents and guiding different parties, including those who may lack technical expertise, through complex sustainability initiatives (Mathar et al., 2020). By focusing on consultants, the research offers more specific insights and actionable recommendations to address the common challenges faced by these professionals. Additionally, consultants are often the bridge between clients, regulatory bodies, project managers, architects, and other key stakeholders. Their role in translating policy documents, sustainability requirements, and technical data into actionable plans for other stakeholders makes their position central to project success (Morrison-Saunders & Bailey, 2009). This

research seeks to address these dissemination issues and improve circular projects' execution through targeted interventions. Attaining enhanced levels of circularity in the construction sector makes it imperative to facilitate the accurate contextualization of theoretical knowledge into practical information and tailor it effectively to the specific expertise, tasks, and roles of the stakeholders of a project to cope with the existing lack of awareness and knowledge about the process.

A promising solution enabling knowledge contextualization and tackling this persisting barrier can be found in Generative AI. The thesis will study the potential of Generative AI to address these challenges by leveraging its advanced features and affordances, enhancing stakeholders' comprehension levels and abilities to implement circularity practices effectively. Generative AI is a prominent example of Large Language Models (LLMs), which represent significant advancements in the field of Natural Language Processing (NLP) (Koubâa et al., 2023). Currently, this tool is not being utilized to its full potential, as few of its users have recognized its affordances (Retkowsky et al., 2024). However, a thorough examination of the capabilities will demonstrate that this emerging tool possesses significant additional capabilities. It presents an interface that allows employees to pose questions, seek advice, and utilize knowledge resources (Beerbaum, 2023). Through its enhanced features it can quickly analyze various documents, presenting each stakeholder the information relevant to his task. Moreover, by leveraging its affordances, it can adapt to sector-specific knowledge, and provide very precise knowledge to its users. Thus, Generative AI has the possibility of bridging the gap between the stakeholders and difficult-to-interpret information by influencing knowledge contextualization in the digital workplace.

The purpose of this thesis project is to explore how can Generative AI facilitate more effective knowledge contextualization through its integration into the construction industry to tackle the deficiency of lack of awareness and knowledge and establish an enhanced circular process. Throughout the implementation of the thesis, the term knowledge contextualization will be used as the adjustment of information to fit the recipient's expertise and tasks (Song et al., 2016). Therefore, the main research question to be investigated is:

"How can Generative AI enable knowledge contextualization among stakeholders for enhancing the circularity in the construction industry?"

Throughout the implementation of this project and to attain a definitive outcome, four sub-questions will be answered. Each of these will play a vital role in addressing the main research question:

- What is Generative AI's state of the art and its current affordances relating to knowledge management for enhancing circularity in construction projects?
- What are the reasons for poor knowledge contextualization among stakeholders and the produced setbacks in implementing circular projects?
- What are the concerns associated with the utilization of Generative AI to enable knowledge contextualization in the circular construction industry?
- How can Generative AI be integrated into the existing construction industry practices to facilitate knowledge contextualization?

2. Research Methodology

The research methodology to investigate the research questions was by the combination of an extensive literature review and conducting open-ended, semi-structured interviews. The detailed research methodology is illustrated in Figure 1. The first sub-question was explored through the review of the existing literature, which unveiled the state-of-the-art affordances of Generative AI relating to knowledge management, substantiating the utilization of Generative AI for knowledge contextualization by proving its capability to help in this specific domain. The literature review included a detailed exploration of Generative AI, its applications, and potential opportunities within the construction sector. The second and the third sub-questions was investigated through interviews with stakeholders in the construction industry, who enriched this thesis with their experiences and insights on the topic. The number of interviews was 10, aiming at reaching a saturation point, where the answers of the interviewees were repeated (Guest et al., 2006). Through the second sub- question, insights about the reasons behind poor knowledge contextualization were gathered, the produced setbacks, and the impact of these deficiencies on the efficiency and success of circular construction projects. By answering this question, the research demonstrated which of these problems Generative AI can tackle, enhancing this way knowledge transfer and ultimately circularity principles comprehension in the construction industry. The third sub-question delved into the concerns of the employees about the utilization of this tool in the everyday process of the circular sector. This feedback allowed for gaining better insights into issues that need to be addressed, stressing out the importance of creating guidelines for the safe integration of ChatGPT into the workflow process of the construction industry for enhanced knowledge contextualization. The qualitative data obtained from the interviewees were analyzed through a thematic data analysis. The second and third sub-questions cannot be answered through a literature review because they require specific, practical insights from industry stakeholders that are not readily available in existing academic sources. For the second sub-question, the issue is rooted in specific real-world experiences that vary across different projects and organizations. The existing literature lacks the context-specific details needed to understand these challenges in-depth, as the term knowledge contextualization has not been researched extensively. The third sub-question similarly demands input directly from stakeholders. Since the thesis studies a specific sector of the construction industry and Generative AI is a relatively new concept in that sector, there is limited literature on the practical concerns that circularity professionals might have regarding its implementation. Finally, the fourth sub-question which is also the output of this research, is the guidelines for the safe and smooth integration of Generative AI in the circular sector for knowledge contextualization. These guidelines were produced by the combination of knowledge gained through the literature review, researching effective integration guidelines to gain a first insight into essential steps for other technologies integration, and insights gathered through the interviews.

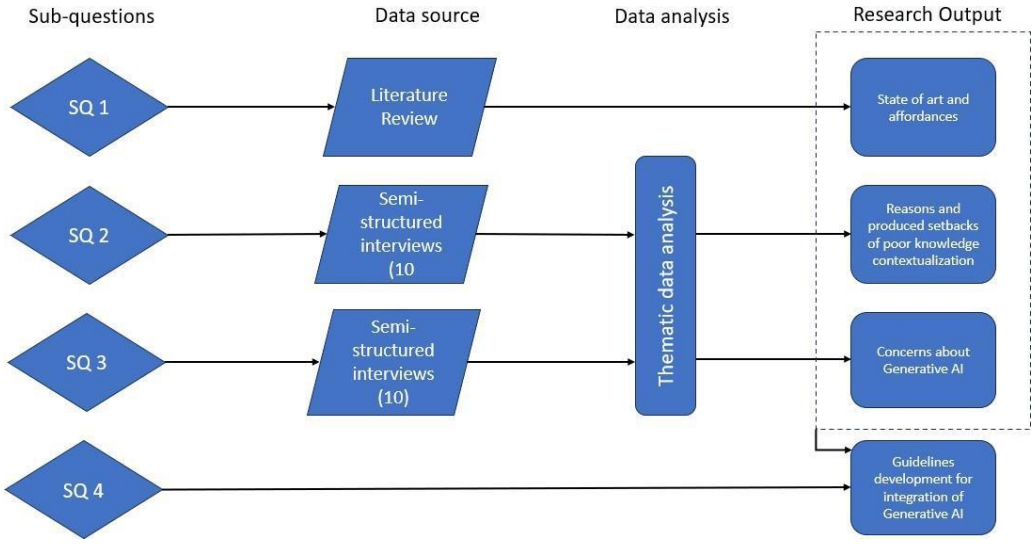

Figure 1: Research Design

2.1 Literature review

An extensive literature review was implemented to acquire preliminary knowledge of the current state of circularity in the construction industry and the knowledge contextualization process. Furthermore, the state-of-the-art generative AI and the affordances of ChatGPT were solely explored through the existing literature. To gather the necessary information for this project, a search plan was followed to locate the corresponding literature, which will be described below.

The first step in locating the necessary literature was to search through Google Scholar and ScienceDirect with two broad-term combinations: (Circularity) AND (Knowledge Management), and (Knowledge Management) AND (Generative AI). Additionally, the first sub-question of this thesis was answered through the exploration of combinations like: (ChatGPT Affordances) AND (Knowledge Management) and (State-of-the-art Generative AI). Affordance, in the context of knowledge management, refers to the potential actions or opportunities that a system, tool, or resource provides to users for managing and utilizing knowledge effectively (Chaves et al., 2017). For the concept of Generative AI, the research also included a thorough exploration of the articles uploaded in the arXiv database. This database was utilized for this purpose because it covers various topics within Generative AI, from theoretical foundations to practical applications, providing a comprehensive view of the field. This comprehensive search strategy allowed the identification and review of the most recent and relevant scientific papers regarding the topics explored in this research. During the second step of the literature review, search criteria were created to refine the initial search, utilizing only the up-to-date information, and implementing more precise research. The refined search criteria are illustrated in Table 1. In the keyword section, various keywords used are described for each concept. Only the concepts are listed in the truncation section, but the keywords within these concepts are utilized. The numbering in the Table indicates which additional criteria were applied to each truncation. The next step involves the review of the refined results and the selection of the most relevant papers based on their titles. The selection of the most useful papers is further narrowed down by examining the abstracts of the refined list, focusing on the current state and concepts of circularity and knowledge management, the affordances of ChatGPT for knowledge management, and state-of-the-art

Generative AI. By assessing the content of the articles from the abstract, the research is conducted by utilizing the most significant and relevant studies. The first step includes the employment of the standard 'backward snowballing' and 'forward snowballing' search techniques. This involves the examination of the citations within the relevant papers as well as the papers cited by these sources. These techniques were employed for all of the concepts studied in this thesis, enabling the discovery of additional significant literature and enhancing the comprehensiveness of the research. The fifth step of the search strategy pertains to the collection of all these papers in Mendeley to maintain an organized overview of all relevant literature for subsequent analysis. Within Mendeley, the papers are categorized by concept and annotated to highlight significant ideas. The final step focuses only on the circularity concept, where practical literature from sources like the Ellen MacArthur Foundation (Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition, n.d.) was incorporated. These articles offer practical insights that complement the scientific literature and are used to inform concepts and best practices in the circularity theme. To ensure the academic relevance and reliability of the research findings, some exclusion criteria were considered. Articles that lack peer review, such as opinion pieces or unverified sources, are excluded. This step is critical to maintain the credibility of the literature used, as peer-reviewed studies have undergone a rigorous evaluation process by experts in the field. Additionally, geographical relevance is considered, with studies focusing on regions or industries outside the construction sector or from areas with minimal adoption of circularity practices being excluded. This ensures that the research remains contextually relevant to the construction industry's specific challenges and advancements in circularity. Finally, only articles written in English are included to ensure the researcher can accurately interpret and analyze the content, avoiding potential misinterpretations due to language barriers. These exclusion criteria help narrow the focus to high-quality, relevant sources that contribute meaningfully to the research objectives. Throughout the thesis, 120 articles were leveraged for the acquisition of the necessary knowledge in researching the topic.

Table 1: Search strategy

Category	Concepts
Keywords	Circularity; Circular Economy; Circularity Strategies; Circular Themes; Circularity Barriers Knowledge Management; Categories of Knowledge; Knowledge Management Cycle; Knowledge contextualization Generative AI; ChatGPT workflow process; ChatGPT features; ChatGPT affordances; ChatGPT applications
Truncation	1. (Circularity) AND (Knowledge Management) 2. (Circularity) AND (Knowledge Contextualization) 3. (Knowledge Management) AND (Generative AI) 4. (Knowledge Management) AND (ChatGPT) 5. (Knowledge Management) AND (ChatGPT Affordances)
Additional criteria	The numbering of each criterion corresponds to a truncation 1. Published year > 2015 2. Published year > 2015 3. Published year > 2020 4. Published year > 2020 5. Published year > 2020

2.2 Interview Sampling

The target group was selected based on **non-probability sampling techniques**. More specifically, a **purposive sampling approach** was employed, aiming at eliminating people who may negatively affect the research findings. The purposive approach is a strategy of sampling that provides the opportunity to deliberately select individuals based on their relevance and potential contribution to the research question (Palinkas et al., 2013). It is purposefully designed to identify direct actors or groups pertinent to the research, in this case, actors that actively engage and have experience in circular construction projects and have the ability to provide crucial perspectives and insights into this thesis. Purposive sampling is a justified choice for this research study because it can capture stakeholders' diverse experiences and perspectives who have encountered similar problems. This approach will enrich the study with different insights, enabling the development of a comprehensive understanding of the current deficiencies in knowledge contextualization within the circular construction industry. This method will also substantiate the thesis' proposition of employing ChatGPT to address these deficiencies. It allows the collection of detailed context-based information in this study, offering a chance to discover new themes and patterns that could lead to new findings significant in the existing body of knowledge (Maxwell, 2013).

The participants for this research were identified and selected through LinkedIn. The thesis concentrated specifically on circularity practices and their shortcomings in the Netherlands. Consequently, all the participants interviewed are currently employed in the circular construction sector within the country. The selection criteria were based on the relevance of their professional experience, years of experience, and knowledge of the circularity sector. The interviewees that were selected had at least three years of experience in the circularity sector. This thesis focused on the aspects of one stakeholder of circular projects, the consultants. The decision to focus on consultants is justified by the fact that they have to coordinate with many stakeholders, making their role pivotal in the process and dissemination of necessary knowledge for the successful integration and implementation of circularity principles. Additionally, focusing on one stakeholder will offer a deeper and more detailed analysis of the problem, leading to a richer understanding of the specific issues, needs, and perspectives of consultants involved in these projects. Furthermore, by concentrating on consultants, the research produces findings that are highly relevant and specific, leading to more actionable recommendations and practical applications tailored to this group. Each participant was assigned an interviewee ID to cite their quotes more clearly during the thesis. This ID, together with the job title, years of experience, and the duration of the interview can be seen in Table 2.

Table 2: Interview participants

Interviewee ID	Job Title	Years of experience	Duration of the interview
1	Sustainability Project Manager	20 years	30 Minutes
2	Sustainability Project Manager	3 years	37 Minutes
3	Circularity Consultant	3 years	41 Minutes
4	Senior Consultant in Circular Buildings and Infrastructure	20 years	33 Minutes

5	Circular Economic Consultant	10 years	32 Minutes
6	Senior Sustainability Specialist	6.5 years	35 Minutes
7	Sustainability Consultant	4 years	25 Minutes
8	Sustainable Building Consultant	4 years	28 Minutes
9	Circularity Consultant	5 years	26 Minutes
10	Sustainability Consultant	5 years	21Minutes

2.3 Data Acquisition

To gather the necessary data for this research project, **semi-structured interviews** were conducted. This research aims to investigate the possibility of employing Generative AI for knowledge contextualization within the circular construction sector with a set of specific, yet open, questions deployed. The semi-structured format allows asking probing questions and seeking clarification, so that although the majority of the issues are covered across all respondents, new issues and perspectives may be introduced by both the interviewee and interviewer. For example, questions such as 'What are the challenges when implementing circularity practices?' or 'What difficulties do you encounter in understanding technical documents and how do you solve them?' provide deeper insights. Through this approach, a deeper understanding of the topic is facilitated, providing at the same time room for flexibility to guide conversations back on track if they diverge too far from the core research question (Wilson, 2014). Consequently, it is expected that this method would provide rich, in-depth qualitative data of valuable perspectives regarding how this AI technology can support and further enable such multi-method collaborations for circular practice within the construction sector.

The interviews were arranged through email and held on Microsoft Teams. Before each interview, participants were provided with an informed consent form. With the participant's approval, the calls were recorded and securely saved on the TU Delft OneDrive. The researcher reviewed and corrected the automatic transcriptions generated by Microsoft Teams to maintain the data's accuracy and integrity.

The interviews began with a discussion to explore which R-strategies are currently utilized in the construction industry and validate the literature findings which outline a limited understanding of circularity practices among stakeholders. The interviews also delved into knowledge contextualization, focusing on practical strategies for adapting and communicating complex technical information to diverse stakeholders. Participants were asked about their experiences and problems that they encountered in contextualizing complex knowledge into actionable tasks, ensuring comprehensive understanding among all stakeholders, and overcoming challenges in knowledge contextualization. Additionally, the interviews aimed to explore not just current implementations, which were rare, but predominantly the interests, expectations, and plans for future circularity practices and the potential role of advanced tools like Generative AI in enhancing these efforts. The transcript of the questions asked during the interviews can be in Appendix A. After the completion of each interview, the transcripts were auto-generated and downloaded from the Teams platform. Each interview was reviewed to fix inconsistencies between the audio and the transcript and to eliminate stutters, repeated phrases, filler words, and non-relevant information like greetings or casual conversation before or after the interview. Any sensitive

or personal details, including participant names, their organizations, and competitors, were removed.

2.4 Data Analysis

This qualitative research was conducted using **thematic analysis**. This approach allows for the decoding and interpreting complex qualitative data gathered from semi-structured interviews with various stakeholders in the construction sector. The thematic analysis contributes to this research by identifying, analyzing, and reporting patterns (themes) within the data, offering insightful perceptions, experiences, and insights of key actors of the industry regarding AI's role in circularity practices. This process includes 6 key steps (Clarke & Braun, 2013) which can be identified in Figure 2:

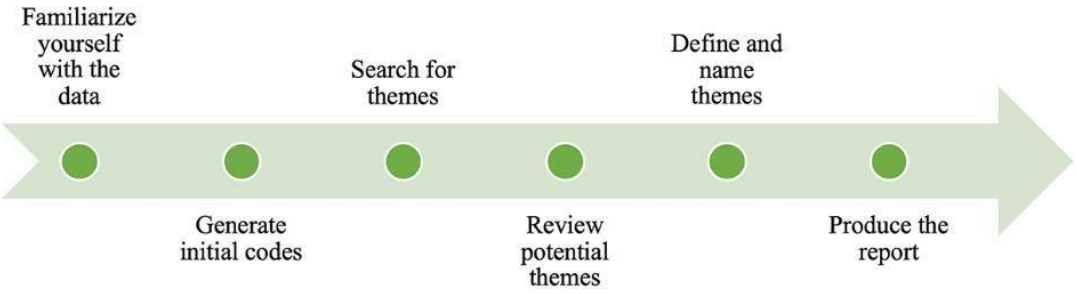

Figure 2: Steps of Thematic Analysis, Source: Wptamara (2024)

The process started with a thorough reading of the interview transcripts to familiarize myself with the depth and breadth of the content. This step involved noting down initial observations and getting a sense of repeated topics and key points discussed by the interviewees. The next step was a systematic coding of data to highlight important and repeated insights and perceptions about the thesis topic. In this step, a thorough review of all ten transcripts was conducted to identify significant features and key points relevant to the research questions. This involved extracting repeated topics and important insights from the interviews (Javadi & Zarea, 2016). The initial codes were derived from various aspects discussed by the interviewees, such as their roles and experience in circularity practices, the application of different R-strategies, and the challenges they face in implementing these strategies. Solutions to these challenges were also coded. Additionally, the impact of deficiencies on project efficiency and success was a key area, with codes related to project delays, suboptimal reuse of materials, and the need for continuous communication and training to mitigate these impacts. Another significant area of coding focused on the use of AI and ChatGPT in their work processes, highlighting both the benefits (such as task automation and information verification) and concerns (like security, data privacy, and ethical issues). These initial codes captured the essential features of the data and provided a foundation for identifying broader themes, ensuring a comprehensive understanding of the key issues and patterns discussed across all transcripts.

The codes produced in step two were grouped into potential themes that capture the essence of the interviews with the stakeholders, leading to five themes:

1. Circularity Practices and Strategies
2. Circularity Barriers and Knowledge Gap
3. Knowledge Issues and Solutions
4. Impact of Deficiencies on Projects and Rectifying Resources
5. Generative AI and Technology Integration

Each theme was reviewed and refined to produce an accurate representation of the greater ideas in the dataset (Neuendorf, 2018), maintaining a clear and detailed comprehension of the complex interaction of AI technologies and circularity practices in the construction industry. Adjustments were made to merge similar themes, split complex themes, and discard unsupported themes. Finally, clearly defined aggregate categories for each theme were created that conveyed the essence of each theme (Peel, 2020). The themes were described in detail, highlighting the key points and supporting evidence from the transcripts. This approach allowed for a thorough analysis of the main research question, contributing significantly to the creation of knowledge on enabling stakeholders to more sustainable practices within the construction sector. The produced themes, their descriptions, and answers from the transcripts can be seen in Table 3.

Table 3: Thematic data analysis

Themes	Description	Answers from Transcripts
Circularity Practices and Strategies	Focus on various R-strategies and how they are applied in different projects. Evolution from simple recycling to more complex practices like refurbishing and reusing materials	Reuse strategy in dismantling buildings and salvaging materials. Reducing carbon footprint with bio-based materials. Transition from recycling to refurbishing and repurposing in projects
Circularity Barriers and validation of Lack of Awareness and Knowledge	Issues related to stakeholders' understanding and adaptation to circular practices.	Lack of understanding of circularity among stakeholders. Need for training and workshops to bridge knowledge gaps. Misalignment of expertise and difficulty comprehending technical documents
Reasons for poor Knowledge Contextualization and Solutions	Problems related to the complexity and volume of technical documents. Effective solutions such as simplified guides, direct communication, and workshops.	Complexity and technical language of documents. The volume of information and lack of contextualization. Solutions include simplified guides, checklists, flowcharts, and direct communication
Impact of Deficiencies on Projects and Rectifying Resources	Effects of deficiencies on project efficiency and success. Strategies to mitigate these impacts, including time investment, communication, and training.	Project delays and suboptimal reuse due to knowledge gaps. Organizational disconnection and inefficiency. Strategies include time investment, continuous communication, and providing training.
Generative AI and Technology Integration	Use of AI and ChatGPT for various tasks, along with concerns about security, reliability, and ethical issues. Challenges in adopting new technologies and the need for management approval and user adaptation.	Use of ChatGPT for text generation, coding, presentations, and abstracts. Concerns about security, data privacy, and ethical issues. Challenges include knowledge gaps, the rapid evolution of AI capabilities, familiarization of personnel with the technology, and the need for management approval.

3. Literature Review

The subjects explored in this project involve definitions and topics that are continuously developing in their meanings. Therefore, to determine the scope and the objectives of this thesis it is important to clarify the key definitions of these concepts. This section aims to scrutinize the existing literature to find relevant definitions and features of these terms, identifying concurrently the gap in theory and establishing the foundation for the upcoming research.

3.1 Circularity in the Construction Industry

The circularity represents a contrasting approach to the persisting linear model that promotes sustainable development. This aims to swift the development from resource consumption to reducing and recycling natural resources (Corona et al., 2019). The concept of circularity has been the focus of scientific research, producing a large number of different definitions from various scholars. Kirchherr et al. (2017) identified during their research 144 definitions of circularity, highlighting the necessity of creating a coherent interpretation of the concept. The prevailing definition among the scholars is the one proposed by the Ellen MacArthur Foundation (Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition, n.d.), defining circularity as "*an approach that is restorative and regenerative by design that aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles*", which will be employed throughout this thesis project. To have a clear insight into what exactly circularity represents, this section will delve into this concept and the way that it is currently implemented in the construction sector.

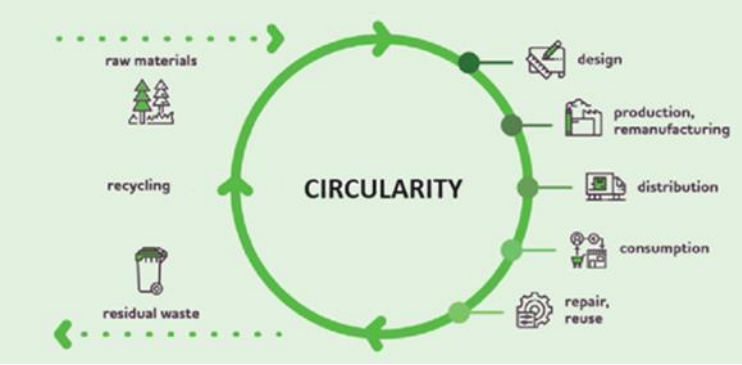

Figure 3: Circularity in the construction industry, Source: Kuscu (2021)

3.1.1 Goal of Circularity

Many principles of circularity have been proposed over the years, but three of them are the most prominent. The first principle is about conserving and increasing natural capital, which includes managing the stocks of finite resources and regulating the upsurge of renewable resources utilization, aiming at the regeneration of nature. The second principle regards the maximization of resource efficiency of products, components, and materials, maintaining them at the highest utility in technical and biological cycles (Suárez-Eiroa et al., 2021). Technical cycle refers to the process by which products and materials are managed to preserve their maximum value consistently. Suitable materials for these processes include those that do not degrade through use, such as metals, plastics, and wood. This can be achieved through refurbishing, remanufacturing, and recycling. On the other hand, the

biological cycle refers to the methods, including composting and anaerobic digestion, that collectively contribute to the regeneration of natural resources. Only materials that can be safely reintroduced to the biosphere are appropriate for these processes (Navare et al., 2021). Finally, the third principle involves the improvement of system efficiency by investigating and minimizing negative externalities from the design phase, eliminating waste production and pollution (Suárez-Eiroa et al., 2021).

Given the high material input of construction, the quantities of waste it generates, and especially the long-term environmental impact induced by buildings, implementation of these circularity principles is even more important in this sector. Thus, the goal of circularity in the construction industry is to create a more sustainable future by enlarging the lifespan of structures, minimizing waste, and exploiting the 'secondary' materials (Upadhyay et al., 2021). This approach incorporates the end-of-life phase of a structure in the design, aiming at the optimization of the building's endurance, and considering the materials as temporally deposited in a structure, from where they can be retrieved after the end of the structure's lifespan (Leising et al., 2018). The anticipated outcome of these features involves reduced demand for new materials, the substitution of primary raw materials for secondary ones in the manufacturing process, increasing the importance of the secondary sector, improved product durability, and repairability (Agrawal et al., 2021).

The minimization of waste is another central goal identified across various sources (Haas et al., 2015; De Jesús et al., 2018). The circularity approach, particularly influenced by the Cradle-to-Cradle model, underscores the importance of categorizing outputs into biological and technical wastes due to their distinct lifecycle treatments (McDonough and Braungart, 2010). Biological wastes, which are biodegradable and flow through biogeochemical cycles, should be emitted at rates that do not exceed the ecosystem's natural assimilation capacities, aligning with Daly's (1990) sustainability criteria. These wastes are designed to return value to the environment by re-entering the biosphere. On the other hand, technical wastes, which comprise non-renewable materials, should be managed to avoid entering the biosphere due to their non-biodegradable nature. Such materials require innovative processing to be reincorporated into the economic system, either by maintaining or enhancing their quality for reuse, thus ensuring that industrial cycles remain closed and sustainable. This approach necessitates those technical components to be designed for easy disassembly and optimal reusability, aiming for the reduction or elimination of technical waste (Favi et al., 2019).

Furthermore, since circularity goals are derived from sustainability goals, it is crucial to draw a line between renewable and non-renewable resources. Renewal resources have a semi-quantitative goal formulated in Daly 1980's operational criteria (Daly, 1990), according to which the utilization of renewable resources must "*not exceed the physical capacity of the environment to restore their abundance at current quality levels*". This measure is achievable and is stated in the Planetary Boundary Framework (Rockström et al., 2009), which defines a safe operational space for human activities on Earth and is continually being refined (Jaramillo & Destouni, 2015). Meanwhile, since non-renewable resources are finite, a sustainable rate implies that their use must be less than the rate of the development and utilization of a replacement. Usman et al. (2021) highlight that the ideal scenario is using non-renewable resources at the slowest rate possible with a transition to renewables.

In summary, circularity principles aim to balance the preservation of natural systems, maximize resource efficiency, and minimize waste, particularly in resource-intensive

industries like construction. The following section on strategies explores how these principles can be practically implemented to achieve a more sustainable and regenerative future.

3.1.2 Strategies towards circularity

The incorporation of the three principles in the construction sector illustrates and clarifies the goal of circularity. However, proceeding to a circular industry necessitates a clear understanding of transforming these principles into actionable outcomes. Understanding the incorporation of the R-strategies in projects helps identify the specific knowledge gaps and communication barriers that must be addressed, facilitating more effective stakeholder collaboration and resource management in construction projects. The next section delves into the strategies that help integrate these principles into the construction industry, exploring various methodologies that enable the efficient reuse and regeneration of resources within this sector.

Several strategies have been developed to reach these goals and achieve high rates of circularity, commonly referred to as R-strategies. The number of Rs may differ in the literature, but the most complete illustration is the one proposed by Potting et al. (2017) using a 9Rs model, which can be illustrated in Figure 3. The Rs are prioritized, so that the initial focus is on smarter usage and production, followed by the attempts to extend their lives, and then the practical application of the materials. Recycling or incineration should only be further consideration options. Recycling is deemed suitable only when it is critical to recover the material's value, and incineration is a significant challenge since while it provides energy recovery, the materials will not be reused (De Oliveira & Oliveira, 2023). Enhancing the circularity of materials in a product chain increases the duration for which those materials are in use. After they are discarded, they can be reused without any significant deterioration in their affordances. Generally, this translates to a reduced need for new natural resources. Thus, there is a reduction in resource extraction and material production. This has obvious benefits to the environment. However, it is crucial to note that this is not always the case, and enhancing the circularity of a given product chain may increase the pace at which natural resources are consumed, most of which are in the form of fossil fuels. Rebound or secondary effects need keen consideration. In most cases, higher circularity of a product chain will translate to lower natural resource and material consumption, and subsequently lower the associated environmental impact, as well as that of related chains (Potting et al., 2017).

The strategies from R0 to R2 aim to minimize or avoid using raw materials in production within the construction industry. These strategies include R0 (Refuse), where the need for certain construction materials or methods is eliminated because the benefits they provide can be achieved through alternative, more sustainable means. R1 (Rethink) and R2 (Reduce) focus on increasing the efficiency and intensity of material use, such as designing buildings requiring less material by optimizing architectural plans or employing innovative construction techniques that minimize waste. Strategies R3 to R7 aim to keep materials within the economy for as long as possible. For instance, R3 (Reuse) might involve the repurposing of building materials in new constructions or the sale of reusable fixtures and fittings through platforms like Material Marketplace. If building components are defective, they can be repaired (R4) to restore functionality, or refurbished (R5) to meet current

standards and aesthetics. R6 (Remanufacturing) could involve using components from demolished buildings in new constructions, and R7 (Repurpose) might see creative reuses such as turning old beams into furniture. When these strategies are not applicable, R8 (Recycle) and R9 (Recover) come into play, which involves the destruction of building materials to recover resources. Recycling aims to reclaim raw materials, thereby reducing the need for new extractions from the environment. However, if recycling results in lower-quality materials, this process is known as downcycling (Di Maria et al., 2018). The goal is to maximize the content of recycled materials in new constructions, thereby extending the lifecycle of raw materials and reducing environmental impact. This comprehensive approach highlights the importance of considering the entire lifecycle of construction materials, from initial design to final disposal, to ensure maximum material efficiency and sustainability. Finally, since the recover strategy does not imply any recycling of materials, it cannot be considered part of the traditional circular strategies for value creation and is thus prioritized last. The recover strategy is the most widely used modern approach and is applied in the situation when the recycling of some raw materials is not financially viable or technically possible. As a result, recovering implies the destruction of raw materials and the recovery of usable energy from waste.

These strategies are essential for the enhancement of circularity, as long as they are effectively linked with the core themes that govern their application and effectiveness. The following section will investigate these themes and their interconnection with the circularity process.

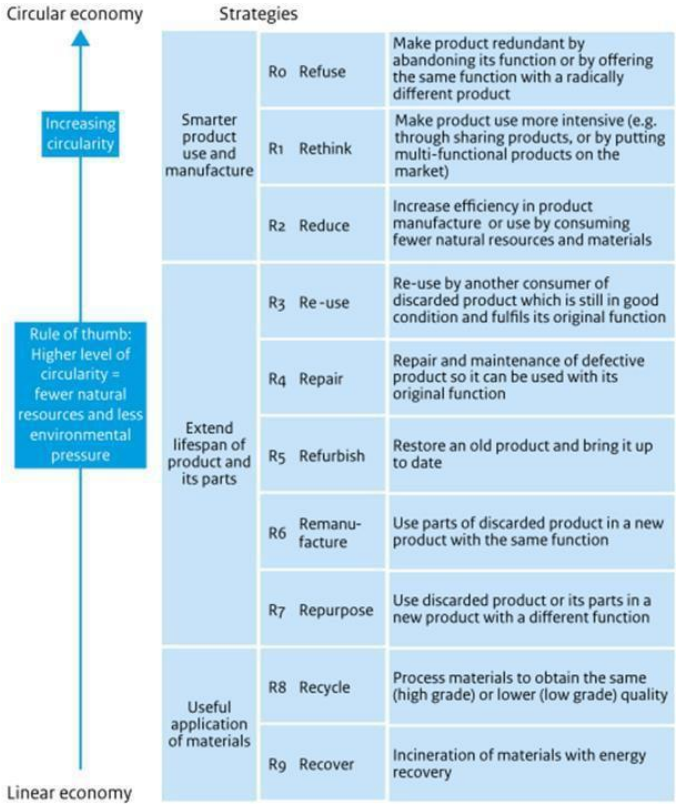

Figure 4: The 9R framework, Source: Potting et al. (2017)

This thesis will focus on the Reuse strategy, as this strategy is one of the most critical approaches to accomplishing the goal of circularity by reducing material consumption, lowering greenhouse gas (GHG) emissions, minimizing waste production, and eventually reaching high rates of circularity. This can be substantiated by the fact that reuse extends the useful life of materials, thereby minimizing environmental impacts and conserving resources. Reusing structural elements is a more sustainable option than other strategies, as it avoids the need for new industrial cycles and the associated energy consumption and emissions (Bertin et al., 2019).

However, the reuse strategy not only benefits the environment but also provides various opportunities for companies to adopt it, making it a more desirable strategy and easier to implement. This includes the development of new skills and competencies, which can lead to expansion into new business areas. This approach not only results in direct cost savings by reusing materials but also provides a competitive edge as companies position themselves as leaders in sustainability (Minunno et al., 2020). Additionally, it enhances branding and marketing opportunities by attracting environmentally conscious customers. Moreover, employees experience greater job satisfaction and engagement, boosting overall productivity. Together, these benefits contribute to long-term sustainability and profitability for companies embracing reuse in their operations (Harala et al., 2023).

The choice to focus on this strategy extends also to the lack of knowledge and awareness concerning this strategy. This deficiency is evident in several areas, including insufficient expertise on how to implement reuse practices, a scarcity of successful case studies that could serve as benchmarks, and widespread uncertainty about the quality and reusability of construction materials (Gerhardsson et al., 2020). Furthermore, there is a general lack of awareness regarding the potential environmental and economic benefits of reuse, such as waste reduction and lower greenhouse gas emissions. To conclude, although the importance of this strategy is well recognized, it remains underutilized due to the lack of awareness and knowledge necessary to implement it. This issue will be analyzed in the next section in depth.

3.1.3 Lack of awareness/ knowledge of reuse in the circular sector

The theory of circularity is an area that has only recently begun to develop in the construction sector at a practical level, which was previously bordered by linear economic models focused on “take, make, and dispose”. Although studies on the concept of circularity date back to the 1970s (Thibaut Wautelet, 2018) and continuously developed, the construction industry has not yet adopted these practices extensively (Yang et al., 2022). The literature acknowledges various reasons to elucidate this situation. One important reason is the lack of awareness and knowledge of effectively integrating and utilizing the R-strategies, both on an organizational and industry level (Gerding et al., 2021b). Bilal et al. (2020) validated this as a prominent barrier in their research, concluding that the construction industry stakeholders exhibited a restricted understanding of circularity strategies. This knowledge gap is attributed to many inefficiencies, such as knowledge silos that impede the free flow of valuable information, information overload that makes it challenging to identify, utilize and comprehend relevant data effectively, and barriers to knowledge discovery that prevent easy access to necessary information, which are critical obstacles to the adoption and implementation of circularity practices in the construction industry (Fahad et al., 2024). The barrier to the necessary knowledge complicates the implementation of circular

strategies, as industry stakeholders may not fully understand or agree on foundational principles and objectives.

This gap of knowledge proceeds into the strategic application needed to facilitate circularity, especially in the construction industry, a complicated system of resource flows and lifecycles. While circularity principles, as discussed by researchers such as the three circular goals identified in Suárez-Eiroa et al. (2021) overview, ultimately suggest demand for resources to shift from a linear to a circular application, through the utilization of R-strategies, the construction sector proves slow in realizing this transition. This is attributed to the industry's characteristics, such as long periods of the building's life or the heterogeneity of materials applied, demand strategies sensitive to the sector's environmental, economic, and technical peculiarities, which are very difficult to comprehend by stakeholders that haven't familiarized themselves with this process.

Finally, the limited knowledge among the stakeholders has prevented circularity from achieving its full potential in changing the waste management dynamics in construction. The need to minimize waste and enhance the efficiency of resource use has been advocated for a long time. However, the measures for achieving these broad conditions for circularity have not been fully developed. A future-oriented industry should research to address this gap and move away from theoretical models to practical measures that account for the broader issues of a circular industry. To tackle these barriers there is a necessity to establish a clear knowledge management framework for the easy identification, storage, dissemination, and utilization of the necessary information within an organization, that can translate theoretical knowledge into practical information and contextualize it in the specific needs and tasks of the different stakeholders.

3.2 Knowledge management in the construction industry

Knowledge Management is critical for the most basic business operations. According to Breznik (2018), knowledge management is a comprehensive way to define, create, assess, recover, and distribute all types of knowledge, including databases, paperwork, legislation, procedures, and even formerly undocumented knowledge of the job and employee experience (Bueno et al., 2010). A framework for knowledge management should contain a standard understanding of knowledge activities and the support that carries out these activities. Knowledge management is a process that relies on identifying and utilizing the knowledge of the collective firm, but integrating at the strategic level remains an issue. The failure to integrate knowledge management is the main reason for the slow development of companies (Del Junco et al., 2010), as many companies cannot recognize, formulate, and utilize their knowledge base as a strategic method to enhance performance and competitive advantage. For this reason, Strategic Knowledge Management should be created as a strategic plan within a firm.

Knowledge management that occurs in the context of circularity plays an influential role in sustainable development and belongs to the sphere of organizational learning. This term means that organizations must have easy access to data and should give necessary information to stakeholders, or facilitate a reliable transfer of information between groups or organizations (Paulin & Suneson, 2015). For example, information about the circularity reuse strategy should be widely distributed among industries. Also, detailed information about the composition of new materials should be provided to understand social behaviors and make a valuable impact on circular practices (De Los Rios & Charnley, 2017). Companies need to develop policies that would promote effective and understandable sharing of knowledge about circularity and sustainability.

Circularity needs knowledge management to effectively and efficiently store, process, visualize, and share vast amounts of data and information about all stakeholders, processes, products, and materials participating in circular businesses. Suitable tools for these tasks are required. Such assertion is supported, for example, by a research study on enhancing institutional capacity through industrial symbiosis as an approach to promoting the development of a circularity (De Abreu & Ceglia, 2018). Knowledge management eliminates uncertainties and fosters a standalone and trustworthy business environment. It is an important source of information that allows companies to find potential new business opportunities and supplement them by creating synergies. Moreover, powerful tools that promote access to knowledge outside traditional domains are useful for innovation, as stated in the research on Swedish waste management sector managers (Aid et al, 2017). A deeper understanding of knowledge and its categories is imperative for employing this concept for a circular transition in the construction industry. This section will delve into this concept.

3.2.1 Categorization of knowledge

The following section of the thesis delves into knowledge categorization, which is a fundamental element in ensuring that the management and dissemination of information are efficient in organizations. Considering the size and diversity of knowledge present in the current era, which cuts across various fields and sectors of the industry, systematic organization and classification of this information is necessary. This classification not only makes it easier to access and retrieve but also simplifies the comprehension and application of the knowledge in professional practice.

To achieve high rates of circularity, a clear distinction between tacit and explicit knowledge has to be implemented. Explicit knowledge refers to information or educational content in a documented form, such as text, audio, video recordings, and graphics formats that are readily available for retrieval, distribution, and critical updates of the conceptual and operational framework (Dalkir, 2013). The updates of explicit knowledge are integrated to suit the circular demands. These materials are readily available in printed copies, such as textbooks and encyclopedias, or in e-learning platforms. Knowledge coordination includes the formation of systems within the framework of an organization that fosters an effective mode of distribution and acquisition of information to boost the workforce's skills and the organization's capacity. Its availability enhances the formation of an organization's mission and vision. The dissemination, reproduction, acquisition, and reapplication of explicit knowledge across this framework is vital for teaching or implementing training and development programs for the employees of each organization (Dalkir, 2013). On the other hand, tacit knowledge is understood as practical skills, technical knowledge, dynamic abilities, and experience acquired directly through work (Dalkir, 2013). This knowledge is based on the experiences of employees and is not accessible to other people. It is not an easy task to pass tacit knowledge on to others who have not gained this understanding through individual work experience. However, the above does not mean that organizations should not create favorable conditions for the transfer of such technical knowledge. This can be achieved through on-the-job management development programs and practices, such as coaching or mentoring transferring it from a more experienced employee to a less experienced one. It enables continued replacement, as well as planning for staff changes.

Since this thesis delves into the tailoring of documents produced by consultants to the specific needs and tasks of the different stakeholders, the focus will be on explicit knowledge contextualization. This focus on explicit knowledge contextualization is particularly relevant for circularity because it ensures that the knowledge shared can be easily codified, documented, and reused across different stakeholders, fostering transparency and consistency in decision-making. Explicit knowledge is crucial for enhancing stakeholders' comprehension on supporting circularity strategies, allowing for continuous improvement and efficient resource management. This emphasis does not limit the study but rather highlights the importance of structured knowledge sharing in achieving long-term sustainability goals.

3.2.2 Knowledge Management Cycle (KMC)

The Knowledge Management Cycle is a collection of resources organizations use to locate, obtain, strengthen, share, maintain, take advantage of, maintain, and eliminate information (Kayani & Zia, 2012). It is a critical activity that aids in the efficient development of organizations and the promotion of new concepts. Many knowledge management cycle models have been introduced over the years including those produced by Wiig (1994), Meyer and Zack (1996), Heisig (2009), and Dalkir (2011b), each one with different variations, but the model that will be employed and analyzed in this thesis will be the one proposed by Evans et al. (2014), which includes seven phases as illustrated in Figure 5.

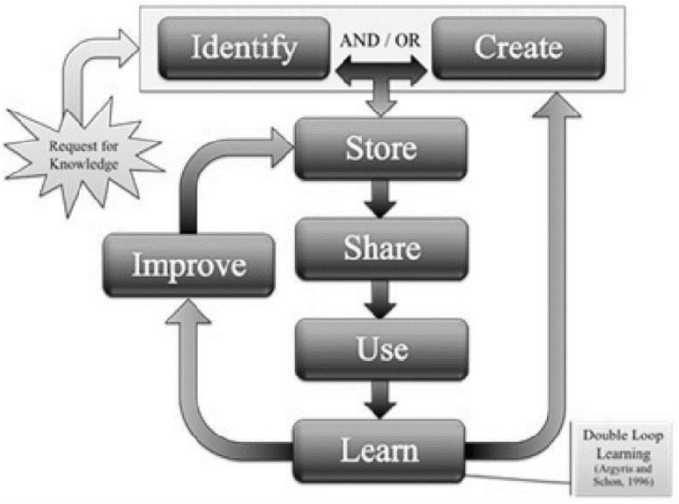

Figure 5: The KMC Model, Source: Evans et al. (2014)

The Knowledge Management Cycle (KMC) is a structured process that ensures organizations effectively manage their knowledge assets through seven interconnected stages. It begins with Identify and Create, where the organization must assess whether existing knowledge is sufficient or if new knowledge needs to be created to address strategic, operational, or innovative challenges. This involves identifying both codified knowledge (such as documents) and tacit knowledge (like expertise) through methods like network analysis and brainstorming (Dalkir, 2011b). If current knowledge is inadequate, new knowledge is developed using approaches like expert interviews or prototyping, highlighting the integration of the identification and creation processes (Meyer and Zack, 1996; Evans et al., 2014). Next is Storage, where validated knowledge is organized into the organizational memory. This involves storing codified knowledge in corporate portals or capturing tacit knowledge through methods like knowledge maps, ensuring the knowledge is structured for easy retrieval and sharing (Meyer and Zack, 1996). The Share phase follows, where knowledge is disseminated within and outside the organization. This can be done proactively (push strategy) or on-demand (pull strategy), with the choice of communication channels and collaborative methods being critical for effective knowledge transfer, particularly for explicit knowledge (Bukowitz and Williams, 1999; Peroune, 2007; Dalkir, 2011b). In the Use stage, the organization applies this knowledge to practical scenarios, such as decision-making

and problem-solving. While codified knowledge is essential, the context often requires drawing on explicit knowledge, emphasizing the importance of translating knowledge into actionable insights (Dalkir, 2011b; Huang et al., 2016). Learning is the next phase, where the application of knowledge helps employees refine their skills and understanding, engaging in processes like double-loop learning to continually evaluate and improve knowledge assets (Evans et al., 2014; Matthies & Coners, 2018). Finally, the Improve phase uses the insights gained from learning to enhance and update knowledge assets, ensuring they remain relevant and valuable. This may involve repackaging knowledge for future use or deciding whether to retire, archive, or transfer it outside the organization. Tools like after-action reviews facilitate this ongoing improvement (Bukowitz & Williams, 1999). The KMC thus ensures that knowledge is continuously managed and utilized, driving the organization's success and adaptability.

The KMC is a crucial framework that forms the basis of an organization's ability to acquire, develop, and use knowledge in achieving continuous improvement and innovation. A vital component of the sharing step is knowledge contextualization, which serves as a bridge between the dissemination and the application of knowledge. It involves the process of converting abstract knowledge and theoretical concepts into actionable, practical applications that align with an organization's operational goals and strategies. This translation is crucial for ensuring that knowledge does not remain theoretical but becomes integrated into everyday processes and decision-making.

Contextualization tailors knowledge to specific situations, making it more relevant and accessible to users. By embedding information within a particular context—such as the business environment, cultural factors, or specific operational conditions—knowledge becomes more understandable and easier to apply (Serafini & Homola, 2012). This tailored approach ensures that employees can quickly grasp the importance of information and how it relates to their roles, tasks, or projects, thereby improving the overall usability of knowledge.

Knowledge is easier to transfer across stakeholders with different expertise when it is contextualized to the specific experience level of each stakeholder. By tailoring information to correspond to the specific expertise of each stakeholder, it can be more easily understood and absorbed by them, leading to more effective dissemination and knowledge application (Serafini & Homola, 2012).

Furthermore, organizations are inundated with vast amounts of data and information. Without contextualization, this amount of data can lead to information overload, where the sheer volume of knowledge becomes overwhelming and counterproductive. Contextualization helps filter and prioritize information, highlighting what is most pertinent to specific users or scenarios, thereby reducing the cognitive load and focusing attention on what matters most (Simperl et al., 2010).

Contextualization also plays a role in maintaining knowledge continuity, especially in organizations with high employee turnover or those undergoing significant change. By embedding knowledge within a context, it is easier to document and transfer critical information, ensuring that institutional knowledge is preserved and accessible to future employees (Brézillon et al., 1998). This continuity is vital for maintaining organizational memory and long-term strategic capabilities.

It is evident that through making learning relevant, organizations can adequately bridge the

gap between knowledge acquisition and application. In the following section of the thesis, the importance of knowledge contextualization for possibly tackling the existing gap between the knowledge produced by the consultants and the comprehension difficulties that other stakeholders encounter with the knowledge that they acquire from them.

3.2.3 Correlation of contextualization of knowledge with circularity

The extent to which the construction industry achieves circularity is dependent not only on the integration of circular practices but also on how the available knowledge is translated and contextualized as part of the themes to the different stakeholders. This section of the thesis outlines the links between knowledge contextualization and circularity, discussing the more complex themes of circularity identified in the literature review and how knowledge barriers can be removed in a multi-stakeholder setting.

The sustainable development theme can hide many knowledge and awareness gaps for various stakeholders for reasons such as the development of a circular project (Dokter et al., 2021), the design for disassembly (Passarelli, 2023), the awareness of long-term sustainability and economic returns (Kumar et al., 2019), insufficient knowledge about regulations and policies (Dąbrowski et al., 2019), the selection of the appropriate materials (Whalen & Peck, 2014), and even limited comprehension of the circularity principles. These barriers can be tackled by contextualizing the necessary explicit knowledge in the context of each stakeholder. Due to its simplicity in simplifying and generating actionable insight from complex concepts, explicit knowledge contextualization makes circularity concepts such as design for disassembly and material reusability more accessible and comprehensive to more stakeholders. Furthermore, knowledge contextualization could benefit consultants, making regulations and policies more comprehensible, ensuring that they know not only their obligations but also the incentives that can aid their decision-making. Explicit knowledge contextualization is also critical in ensuring that stakeholders have clear information on design and material requirements that support circular building and therefore support widespread adoption and innovation.

Explicit knowledge contextualization customized to the unique needs and context of each stakeholder can significantly improve circularity, creating a circular knowledge loop where manufacturers and suppliers, as well as consumers, understand and know how to follow the reusability principle. For manufacturers, explicit contextualized knowledge ensures that they will have clear knowledge of how to modify their products and processes to minimize waste and environmental harm. Suppliers will have a better understanding of what materials and methods contribute to or detract from circularity and will make informed and sustainable sourcing choices. Consumers have access to more transparent, easy-to-understand information and are more likely to make informed purchase decisions, preferring products with low environmental footprints and high potential reuse.

However, while knowledge contextualization plays a pivotal role in the circular transition in the construction industry, the review on knowledge management literature reveals that challenges remain in effectively integrating this essential step of the process to the complex circular construction industry practices (Jensen et al., 2022). In the following section, Generative AI as a solution to this persistent challenge has been researched, and more specifically ChatGPT and its possible applications, offering insights into how this new technology can improve this complex process.

3.3 Generative AI

The continuous development of technology has also affected the construction industry, leading to the integration of smart digital technologies into industrial operations and manufacturing. This digital transformation of the industry is most commonly known as Industry 4.0. This transition has been presented as a promising solution to tackle management deficiencies and boost the construction processes (Jahanger et al., 2021). It covers a range of technologies including industrial IoT networks, big data, artificial intelligence, and robotics. Adopting these digital technologies has been proven to increase revenue and deliver greater value to every stakeholder in the supply chain (Liu et al., 2022). Focusing on the circularity of the construction industry, Industry 4.0 has presented helpful resources for the enhancement of the process (material passports, 3D digital twins, materials marketplace, performance dashboard, etc.) (Jemal et al., 2023b). Despite the potential benefits that these technologies have to offer, the degree of material circularity remains limited, because none of them has a considerable impact on the optimization of the stakeholders' engagement in the process.

AI is the field of study involved in the creation of intelligent machines that have the capability of displaying behaviors like learning, reasoning, understanding, perception, communication, planning, as well as the ability to manipulate and interact with physical objects (Darko et al., 2020). It can enable computers to process and understand data from multiple sources at a faster pace than humans to tackle complex and poorly defined issues and perform intelligent and adaptable decisions based on the insights gained from this data (Brandt & Purdy, 2016). One of the most rapidly growing research domains of AI is Natural Language Processing (NLP). NLP encompasses a set of computational strategies based on theoretical frameworks aimed at analyzing naturally occurring texts and representing them at numerous levels of linguistic analysis to enable processing that simulates human abilities across various applications and tasks (Chowdhary, 2020).

The rapid development of artificial intelligence and natural language processing has led to the emergence of more sophisticated and versatile language models (Mathew, 2023). Generative AI refers to a type of AI model that can generate new training data by identifying patterns and relationships in existing data. Depending on the design, such models could generate content in text, images, music, and other domains. They apply deep learning and specific neural network architectures to analyze, understand, and generate content in a manner that appears humanly crafted (King, 2023).

Among these models, ChatGPT, developed by OpenAI, stands out as a powerful tool with a wide range of applications across different fields. NLP served as the foundation for ChatGPT. These models (GPT-3.5, GPT-4, GPT-4o) are pre-trained on extensive text data and have shown remarkable performance across a variety of NLP tasks, such as language translation, text summarization, and question-answering. The Transformer design pattern is crucial to ChatGPT, as it was created to overcome the many restrictions of sequence-to-sequence models in natural language processing. Transformers are a neural network architecture that converts an input sequence into an output sequence by learning the context and tracking the relationships between the elements of the sequence. In this context, the Generative Pre-Trained Transformer (GPT) is a machine-learning model that employs unsupervised and supervised learning methods to comprehend and produce human-like language. ChatGPT has the potential to significantly enhance the translation of explicit knowledge to the context

of each stakeholder, leading to a deeper and more elaborate understanding of the circularity process and closing the knowledge gaps created through the process. The next chapter will review the ChatGPT key features, workflow process, current application in the construction industry, and opportunities for its utilization for tackling the knowledge translation toward an enhanced circularity process.

3.3.1 Workflow process of ChatGPT

Understanding the inner mechanisms of the latest models behind human-like text generation and its processing is essential for utilizing it for complex circular goals. This section considers the workings and dynamics of ChatGPT. This section is intended to explain the ChatGPT model's procedures in technical terms. The understanding of the processes on which the model runs is fundamental to the comprehension of how the machine converts input into relevant and coherent text replies, thereby forming the basis of understanding and answering advanced questions. making it a powerful tool for a wide range of applications. The steps can be seen in Figure 6.

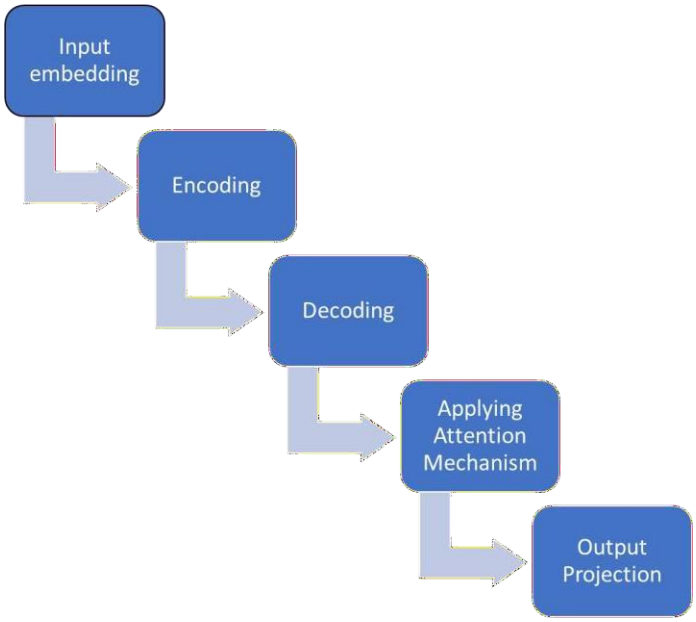

Figure 6: Implementation phases of ChatGPT

When the user inputs a query, ChatGPT would first represent each word in the sentence as a numerical vector in a high-dimensional space. This is achieved by a process known as tokenization, which breaks a sentence into identifying components. To efficiently learn similar words, word embeddings generally set similar words to be nearby points in the vector space. The input sequence of vectors is then passed into a recurrent neural network (RNN) via a process known as recurrence loops, which are utilized to consider relationships between the words in the input sequence. This technique enables the model to encode the context and meaning of such words by capturing the associations between them. The resultant encoded representation is consequently transmitted to a decoder. The decoder's function is to utilize the encoded representation to create a sequence of output vectors, each representing a potential solution. The input combines with the output as the decoder generates these output vectors. As the decoder produces each output vector, it focuses selectively based on the attention mechanism to the section of the input sequence that is most relevant to the output

vector. Thus, it is enabled to generate outputs separately, precisely adjusted to the context and meaning of the input. The output vectors are then passed through a linear layer followed by a softmax activation function to generate a probability distribution over the potential solutions (Briganti, 2023). This process combined with the features of ChatGPT leads to accurate and precise outputs. The following section aims to delve into the features of this tool so that its possible applications in a circularity context can be comprehended.

3.3.2 Key features of ChatGPT

ChatGPT encompasses various features that position it as a powerful tool in the realm of natural language processing, offering significant potential for innovation and application across numerous industries. This section analyzes these features in-depth, creating a clear picture of how these features combined contribute to the model's overall performance and utility, contributing to the thorough understanding of the model's distinctive capabilities. This analysis provides a comprehensive overview of the elements that make ChatGPT a versatile and effective tool in the field of artificial intelligence, through which the possible affordances of this tool for a circular transition can be derived. A clarification should be made at this point, that the more advanced the model of ChatGPT is, the more advanced these features are.

One significant feature of ChatGPT is it has significantly enhanced contextual understanding ability in conversations based on the input text, meaning that with a careful interpretation of what has been written, it is capable of generating appropriate and relevant textual content. In practice, this provides ChatGPT the ability to respond in a much more natural and engaging way, making conversations feel more fluid. This feature makes ChatGPT much better at handling entire conversations, thus making its ability to respond to what a person requests from it much more competent and thoughtful. Overall, this significantly enhances the user experience making interactions with this tool more productive (Du et al., 2023).

Moreover, ChatGPT stands out due to its strong capability to generate text that is coherent, contextually relevant, and grammatically accurate. Given this ability to generate fluent text, ChatGPT can be helpful in various workloads, including generating or creating content, summarization, and rewriting. Thus, ChatGPT can generate high-quality text that meets different user needs and may range from generating full content to creating reports or writing summaries. It can also rewrite with a high level of clarity and coherency, helping improve and elevate content and written work. Overall, as a result of this capability to generate text, ChatGPT can ensure versatility and effectiveness across various domains (Sallam, 2023).

Furthermore, ChatGPT illustrates the remarkable adaptability for multiple tasks which can be utilized across many sectors and domains. The model can be tailored for specific tasks through fine-tuning, such as supporting services, content writing, tutoring, and translation. This feature offers developers the ability to adjust the capabilities of ChatGPT to their needs in specific situations, ensuring optimal performance. Custom solutions for personalized assistance, content creation as well as translation, can be employed using the model. It shows the potential to improve the efficiency and effectiveness of many professionals (Ollivier et al., 2023).

In addition, ChatGPT's versatility in different languages significantly boosts its effectiveness in global applications catering to various user diversity levels. Multilingualism is essential in translation activities, sentiment detection, and content generation on different lingual platforms. These ensure that users with different native languages benefit from ChatGPT

usage, enhancing inclusiveness and making the tool more productive for communication (Lee, 2023).

Additionally, ChatGPT features zero-shot (Wei et al., 2023) and few-shot learning (U. Lee et al., 2023). The former implies that a model can produce responses to tasks even if it has never met them before. The latter allows ChatGPT to comprehend and execute new tasks after receiving just a few examples. This learning approach eliminates the burden of employing vast labeled datasets and long fine-tuning processes, which saves time and effort during the design cycle. In turn, it becomes easy for developers to address new needs and meet tight deadlines, which boosts efficiency. Therefore, ChatGPT is a versatile instrument that can be customized for different applications rapidly and with little preparation (Ateia & Kruschwitz, 2023).

Finally, one of the critical functionalities of ChatGPT is fine-tuning, which enables developers to train the model for precise tasks or domains. This is achieved by training the model on a smaller and more focused set of data, which will enable the model to produce more precise and relevant responses in any application. This is very valuable for developers, who can thus rapidly build well-aligned solutions using chat GPT as a flexible foundation. Fine-tuning improves the model's capabilities by aligning it with the various needs of diverse projects. Whether it's high-level customer service, creating highly focused material, or specialized duties. Its modifiable nature makes chat GPT a valuable source for creating specific, effective applications (Latif & Zhai, 2024).

To sum up, the identified features of ChatGPT serve as evidence of its versatility and efficiency when used in natural language processing. The analysis of ChatGPT's contextual comprehension, language generation, broad adaptation of tasks, multilingualism, zero-shot learning, few-shot learning, and fine-tuning can be employed to provide help to numerous tasks. Moreover, these features do not just increase its efficacy but also allow developers to adjust it to their specific circularity-related needs. Therefore, ChatGPT is a groundbreaking tool that can foster innovation and advance the efficiency of processes in the construction industry, promoting sustainable and circular practices. This analysis indicates the extreme importance of ChatGPT in aiding intelligent development and use and its application in practical issues related to circularity. However, in order to have a holistic view of this tool, its' affordances in the context of knowledge management are also explored in the next section.

3.3.3 Affordances of ChatGPT

The integration of ChatGPT into various domains, including engineering design, has highlighted its strong affordances in knowledge retrieval, sharing, creation, organization, and discovery. These affordances collectively enhance the efficiency and effectiveness of information management processes, making ChatGPT a valuable tool in circular development efforts. This section will focus on how the key features of ChatGPT provide the construction industry with many affordances in the realm of knowledge management.

The affordance of ChatGPT in **knowledge retrieval** is strong and offers multiple advantages in the regime of information access and summarization, including in the context of engineering design. By simply posing questions to ChatGPT, users can obtain information spanning many different topics and gain quick access to the specific knowledge stored in the model (Hu et al., 2023). This ability allows the users to easily get the needed information without searching for information from different sources which in turn improves the workflow efficiency and enhances on-point comprehension. In addition, ChatGPT does great at summarization by

analyzing long documents, articles, and reports, breaking them down into more comprehensible information. It provides the ability to quickly absorb huge amounts of details making it easy and tidier to acquire the necessary knowledge. By forming an interactive and iterative process, ChatGPT knowledge retrieval could help engineers enhance their understanding of complex problems on an ongoing basis. Through real-time engagement, engineers can probe different angles of the problem, ask questions, and get more background information when necessary. This model is especially helpful in situations where problems are ill-defined and a better solution may result from a more explicit consideration of the constraints and more variables underlying an organization.

Another significant affordance of ChatGPT is **knowledge sharing.** By allowing the creation and dissemination of knowledge artifacts, ChatGPT greatly improves internal knowledge sharing (Fahad et al., 2024c). It excels in content generation such as reports, articles, and documentation. This content is very important to convey information throughout several departments and teams. ChatGPT also helps write concise and efficient communications such as emails, memos, and presentations. Enabling ChatGPT to help with such communication, not only makes sure knowledge is distributed quickly but also that it is properly grounded, improving the overall communication and collaboration within the organization.

Moreover, the affordance of ChatGPT to assist in context creation makes it a very attractive tool for **knowledge creation**. It can allow the generation of ideas and ways of solving problems to aid in the development of new concepts and strategies for the teams, offering a wide array of suggestions and innovations. It helps in sessions where you need to brainstorm lots of ideas for creative and strategic planning. It can also function as a brainstorming and idea-generating collaborator in meetings and discussions, providing instant prompts and contributions that encourage debate and the generation of fresh intellectual capital (Spennemann, 2023). In other words, by incorporating ChatGPT into a group effort, teams can strengthen their brainstorming capabilities and strengthen their learning and development skills along the way. These kinds of dynamic exchanges lend themselves very well to wide-ranging learning, where you can continue to refine your understanding and come up with new insights that further contribute to the collective knowledge of a field.

Additionally, ChatGPT affordance in **knowledge organization** makes it a valuable tool for every company. ChatGPT allows significant organization, categorization, tagging, and data structuring. This helps to catalog documents and information and is great for handling large amounts of data and making data more searchable and organized. Apart from that, ChatGPT is also quite good at arranging data from unstructured to structured data, like digesting raw data into proper tables or similar kinds of structured documents (Tinnes & Ristin, 2023). This makes information more comprehensible and to the point which in turn helps with improved data analysis and quicker decision making.

With the strong affordance of **knowledge discovery**, ChatGPT has been designed to perform trend analysis and contextual understanding very well. ChatGPT can draw trends, patterns, and insights that enable a data-driven decision-making analysis through text data analysis. This power of recognizing hidden patterns in the data enables firms to foresee market dynamics, figure out what influences customer purchasing behavior, and guide their strategic decision-making by taking data-powered recommendations. Plus, ChatGPT can help with additional context and background on the same themes, which supports connecting the dots between different chunks of information (Adesso, 2023). It allows users to understand the

bigger picture of the information, which results in better insight and interrelation between irrelevant pieces of information.

Finally, one significant affordance of ChatGPT is **knowledge tailoring**. ChatGPT's affordance for knowledge tailoring lies in its ability to provide information matching users' specific needs, contexts, and backgrounds. Unlike traditional static resources, ChatGPT can dynamically adapt its responses based on the conversation's flow, the user's prior knowledge, and the relevance of the information to the current inquiry. This allows for a more personalized and relevant learning experience, where complex concepts can be explained in ways that are most accessible and meaningful to the individual (Lim et al., 2023). Furthermore, ChatGPT can integrate diverse sources and perspectives, offering a holistic view that enhances the depth and breadth of understanding, making it an invaluable tool for contextualizing knowledge in real-time interactions.

In conclusion, the affordances of ChatGPT in knowledge retrieval, sharing, creation, organization, discovery, and especially contextualization, are pivotal for advancing knowledge contextualization across circular construction. These capabilities not only streamline the process of accessing and synthesizing information but also ensure that knowledge is tailored to the specific needs and contexts of users. By adapting to the flow of conversations and integrating diverse perspectives, ChatGPT enhances the relevance and depth of understanding, making it an indispensable tool for informed decision-making and innovative problem-solving. The ability to contextualize knowledge in real-time interactions fosters a more personalized and meaningful learning experience, ultimately driving greater efficiency, collaboration, and strategic insight within organizations.

3.3.4 Current research on ChatGPT applications in the construction industry

Artificial intelligence is rapidly changing the construction industry, which has generally been considered quite labor-intensive and slow to adapt to new technologies (Rivera et al., 2020). ChatGPT is increasingly used to improve the construction workflow. Researchers are investigating the role of ChatGPT in optimizing almost every aspect of construction, from project management and design to safety and consumer interactions. Thanks to its ability to process complex data, ChatGPT has the possibility to tackle common industry-specific problems related to comprehension difficulties. This chapter will delve into the latest research regarding ChatGPT's deployment in the construction sector, drawing important conclusions from other researched areas about the usefulness of this tool in the construction sector.

1. **Scheduling and planning**

   The construction industry is inherently complex, with numerous tasks that need to be planned and scheduled with extreme precision, to guarantee that the project is completed in a timely and cost-efficient manner. This section explores the current research on the application of ChatGPT to scheduling and planning in the construction industry, exploring its potential, advantages, and shortcomings. Numerous recent articles have examined this application, offering a thorough analysis of how ChatGPT may aid in the process of scheduling and, more generally, in project management.

   Prieto et al. (2023) conducted a study investigating the use of ChatGPT for generating construction schedules, intending to understand its potential to automate the time-consuming scheduling process in project management. To do that, a case study was

conducted, that implemented the schedule of a simple construction project. The produced timeline developed by ChatGPT was reviewed by the participants for appropriateness, accuracy, and usefulness. The result was a well-organized and sequence-based schedule that met the project's requirements, and participants had a positive experience interacting with the model. However, the author suggested that a few inefficiencies in the schedule were produced and more research should be done before it can be safely used in construction. Overall, the research concluded that ChatGPT is a viable tool that could accommodate complex project scheduling, so far that it will be further explored and develop its capabilities.

Nyqvist et al. (2024) advocated that ChatGPT has the potential to assist with scheduling tasks, especially in the case of using it in construction project management. ChatGPT's capability to process large amounts of data and create nuanced, complex scheduling plans has a great capacity to improve the efficiency of project management. At the same time, ChatGPT's strategies were not always as practical and detailed as those of humans. The conclusion of the research makes a point for the synergistic use of ChatGPT and human expertise, supporting the use of this tool as an augmentative concept regarding the human operator. This means that uniting AI and human efforts can boost the ability of humans to produce more accurate and effective scheduling.

Rane et al. (2023) also researched the use of ChatGPT in creating schedules, combining it with machine learning and natural language processing, resulting in the fast creation of detailed schedules, identification of possible delays, and real-time dynamics in adjusting such schedules. This ultimately saved time in making decisions, enhanced team collaboration, and completion of the project on time. He concluded that using ChatGPT in the construction industry with similar tools has both disadvantages, such as data privacy and training of such innovations, and advantages, including optimized resource distribution, enhanced communication, and overall project achievement.

The reviewed studies collectively indicate a promising future of ChatGPT in streamlining and optimizing the scheduling processes of construction project management. Although Prieto et al. (2023) suggested that they noted inefficiencies that require further investigation before widespread adoption. Nyqvist et al. (2024) argue that ChatGPT will be most efficient when coupled with human capabilities for the creation of actual scheduling plans. Similarly, Rane et al. (2023) advocated that the combination of ChatGPT and other up-to-date technologies, including machine learning, and natural language processing, can allow for better decision-making, team efforts, and project completion rates. Therefore, despite the current challenges concerning ChatGPT's application such as data protection and human applicational capabilities, the future development of this tool can become an instrument for optimal resource allocation and efficiently improved communication, leading to formulating and reaching project goals. Thus, it is highly likely that ChatGPT's further improvement will see an even broader incorporation into the construction industry towards enhanced project scheduling.

2. Cost estimation

The construction industry is known for its complexity, involving multiple stakeholders, massive documentation, and multi-faceted execution processes in each project. Accurate cost estimation is pivotal to efficient project management, affecting the process of budgeting, allocation of multiple resources, and other financial metrics. Current methods

of developing cost estimates are efficient but are time-consuming and often involve human errors. This section examines the existing literature on the utilization of ChatGPT in the field of cost estimation on projections, budgetary accuracy, and resource management.

Rane et al. (2023b) found out in their research that ChatGPT enhances the cost estimation process through its sophisticated data analytics and text analysis functionalities. Through the analysis of historical data and market conditions, ChatGPT can generate highly accurate cost estimations that significantly increase the accuracy of budget approximation. Additionally, the vast quantities of data regarding costs of past projects processed by ChatGPT are used to identify patterns and outliers and make accurate predictions and adjustments based on data from the real world. This data- driven method guarantees that cost analysis is based on considerations of cost from the past. ChatGPT could also help with identifying resources as it discerns and groups project resources, such as materials, labor, equipment, and subcontractors. The semantic analysis feature is beneficial due to its capacity for finding synonyms or variations of phrases. This way, ChatGPT minimizes the likeliness of missing a critically important resource. Thus, construction professionals are sure to consider each item necessary for the cost estimation. Labor costs can also be performed using ChatGPT. In this case, ChatGPT can analyze job descriptions and labor contracts and weigh their requirements and specifications. Thus, market situations, local labor prices, and industry predictors are considered. This detailed analysis helps construction professionals make informed decisions regarding resource allocation and budget planning. They conclude that ChatGPT's integration in the cost-estimating process improves resource allocation, finds alternatives for cost savings, and streamlines financial planning, all of which contribute to more precise and effective project budgeting.

3. Risk management

Risk management is an essential foundation of construction project management that involves identifying, assessing, and controlling a range of risks that can affect the project's timelines, costs, and qualitative outcomes. Construction projects are typically characterized by various risks since they are dynamic and unpredictable and focus on many factors ranging from site selection to personnel management. While conventional approaches to risk management are essential, they may lack the flexibility needed to manage risk emergencies. This section explores the research conducted on the use of ChatGPT in construction risk management examining its potential in handling multiple data, identifying possible risks, and providing relevant information for management.

Aladağ (2023) recognized that ChatGPT can contribute to the improvement of risk identification, assessment, and mitigation due to the analysis of large data sets, real-time insights generation, and the establishment of an effective communication routine among the stakeholders. Since it can process textual information, it can rapidly scan large texts for potential risk factors. Therefore, it is a valuable risk management tool that focuses on dynamic and responsive risk management. The article also advances that even though ChatGPT has the potential to be used as a useful tool to improve the risk management of construction projects, it cannot be utilized alone. Being based on general knowledge of the industry and using publicly available data, ChatGPT does not take into account the variety of factors and peculiarities that each project might have. It has not been trained

to use personal baselines of proprietary databases, industry reports, or regulatory frameworks. Thus, as a tool, it may be inconsistent or incomprehensive in proper risk assessment and prioritization. It can be combined with professional personnel experts and specially gathered data regarding the project under consideration to provide accurate and reliable information. This article further suggests that future research can focus on using ChatGPT with more specialized data and case studies to improve its performance.

Nyqvist et al. (2024c) also research this specific angle. Their article offers a perspective on ChatGPT's utilization in risk management for construction projects. He emphasizes the overall capability of the AI model to develop detailed risk management plans that outperform the common performance of the human expert in terms of the information provided. Due to the quick processing and interpretation of data, the AI model easily identifies and analyzes a large number of potential risks involved. This finding implies a more extensive risk assessment compared to the traditional approach, which is often constrained in terms of time and cognitive biases present in any human. Conversely, the article also highlights several limitations. Among the most pertinent limitations is the feasibility and level of detail in the AI-generated risk management strategies. While ChaGPT can identify more risk factors more comprehensively, the solutions proposed lack the context-specific details and the understanding human experts would. This gap suggests that this tool is still dependent on general knowledge rather than having fully integrated access to the project-specific proprietary or highly-specific data. It should be perceived as an additional instrument, and it cannot substitute human knowledge and experience. Only close cooperation between AI systems and qualified professionals will improve the efficiency of managing risks. While AI should be used to process big data, people should supply knowledge, backgrounds, and practical solutions.

Hofert (2023) researched assessing the capabilities of ChatGPT in quantitative risk management. The article affirms that a summary of large masses of qualitative data with ChatGPT is a suitable approach. It is pertinent to tasks like reviewing history or modeling methods in the fields, which in turn diminishes the likelihood of biases and saves effort compared to manual research. However, the article identifies many limitations of ChatGPT in technical and mathematical terms of quantitative risk management. Querying ChatGPT on more challenging quantitative concepts, such as risk measures and their math foundation, would often result in errors or incomplete responses. This deficiency is rooted in the lack of a built-in sufficiently strong reasoning logical structure. Thus, the answers are misleading at best and wrong at worst if not analyzed by an expert. In conclusion, the article suggests that ChatGPT may serve as a useful tool in summarizing qualitative information and assisting in the early stages of research or risk identification. However, it is unreliable for quantitative analysis in detail or learning new difficult concepts, dependent on prior knowledge. The responses under the ChatGPT- powered tool must always be double-checked by experts, and such platforms cannot be implicitly trusted for use in making an important decision in risk management. Ultimately, the technology potential remains substantial, but advancements have to be made to transform it into a reliable tool in quantitative risk management.

In conclusion, though the utilization of ChatGPT in the field of construction risk management can be instrumental in the identification, evaluation, and control of risks by quickly processing and analyzing extensive data, the current limitations of this tool suggest being cautious. ChatGPT is a tool that can successfully read and summarize reams of text,

which is particularly helpful when it comes to making real-time decisions or facilitating communications among the various stakeholders. However, the major drawback of this AI is that it uses general knowledge and publicly available information only, meaning that project-specific knowledge, proprietary data, or regulatory conditions are likely to be omitted. As a result, ChatGPT should not be seen as a standalone tool but rather as a complementary assistant, which should be utilized in conjunction with professional employees whose knowledge of context and practical experience will enrich and balance the outlined risk management approach. Future studies should be conducted to improve and customize ChatGPT's algorithms by offering a more specialized range of information and incorporating case studies, thus making this AI tool more applicable and efficient in the construction domain.

4. Procurement Management

A field in which the potential utilization of ChatGPT has only been limited researched is procurement management. Procurement is one of the critical aspects of the construction industry with a considerable influence on the success or failure of a project based on the efficiency of procuring materials, services, and equipment. Due to the complexity of construction projects, which have long and complicated supply chains, tight schedules, and low tolerance levels for defects, among other complexities, the procurement system is often faced with numerous challenges. These include poor relations with suppliers, non-compliance with the relevant laws and regulations, the danger of delays in the completion of projects and excessive costs, and the need to simultaneously deliver various materials within the required time. The chapter explores the research of ChatGPT on enhancing construction procurement.

George et al. (2023) delved into the topic of procurement. The article advocates that although ChatGPT is mostly used to teach simple tasks like drafting emails or translating texts, it can impact procurement implementation. By automating and optimizing numerous procurement procedures ranging from just supplier onboarding and contract management to vast inventory control and dispute resolution, ChatGPT can significantly increase productivity, lower overall costs and improve risk management. Therefore, the article calls on procurement professionals to check available options to innovate using AI technologies. However, the article also identified some crucial limitations of ChatGPT implementation in procurement. These include the necessity for intensive industry-specific training to provide accurate outputs, and big dependability on the supplied data scope and quality. Moreover, some critical risks include job loss due to automation, existing systems integration challenges, implausible supplier migration to automated systems, and possible hacking and data stealing risks. Nevertheless, the article concludes that precise adoption and mitigation will positively impact the procurement procedure.

Waseem et al. (2024) further studied this subject. Their article views ChatGPT for procurement management from a positive side, emphasizing the benefits that come with the tool, such as improved efficiency, reduced costs, and risk handling. It can carry out multiple procurement functions such as purchase order drafting, supplier onboarding analysis, contract analysis, and dispute mitigation, achieving that the procurement team will save time which is usually spent on routinized manual tasks, maintaining consistency and accuracy. It would rapidly generate purchase order documents of high detail and level of compliance, which include commercial terms, specifications, and numerous legal

clauses. They support that ChatGPT can change a purchase order in real-time and send notifications to all relevant stakeholders about the changes, track their confirmations, and receive automatic alerts about purchase orders at threat of being delayed. However, the article also does not ignore several limitations. There is extensive training required to work with unique industry-related data to guarantee the specificity of outcomes, the quality of data fed to the algorithm, and the “black box” technique due to which AI can sometimes generate inexplicable answers. However, it argues that, provided with strategic deployment and precaution measures, the implementation of ChatGPT in procurement management is justifiable due to the aforementioned benefits.

In conclusion, the potential use of ChatGPT in procurement management, and the construction industry in particular, is only limited. Procurement is a critical aspect of construction projects, as the efficiency of material, service, and equipment procurement largely determines the success of the project. The general view of the literature is that ChatGPT can greatly enhance procurement processes with careful implementation and risk management. By streamlining routine operations and enhancing decision-making through real-time analysis, ChatGPT can help procurement teams deal with the complexity of construction projects more effectively and enhance their success.

In conclusion, a deep and meaningful analysis of the current applications in the construction industry helps to comprehend this tool's current integration level in construction practices, verifies its beneficial impact and lays the foundation for enabling it for more applications in the construction industry, like contextualizing knowledge. The exploration of ChatGPT's potential in these four key domains of the construction industry allows to draw some key conclusions. The research underscores ChatGPT's ability to enhance decision-making processes, improve efficiency, and handle complex data, making it a valuable tool for construction professionals. However, despite its advanced capabilities, the studies emphasize the importance of human oversight and expertise in conjunction with AI, ensuring that ChatGPT serves as a complementary tool rather than a replacement. This careful balance between technology and human insight will be crucial in fully realizing the transformative impact of ChatGPT on the construction industry's evolving landscape. As research progresses, ChatGPT will likely become increasingly integral to construction practices, driving innovation and improving project outcomes across the sector.

3.3.5 Leveraging ChatGPT for knowledge contextualization for circularity

Circular construction projects usually involve several stakeholders including architects, engineers, project managers, contractors, dismantlers, and regulatory bodies. Due to the differing levels of expertise in the construction field and the different informational needs of the interest groups, knowledge transfer can be complex, leading to errors, project delays, objectives misalignment, and sometimes even failure. ChatGPT’s contextualization capabilities can improve this communication by providing position and context-specific information, making the task of the consultants much more time- and money-efficient. Furthermore, by employing its’ fine-tuning ability, ChatGPT can be trained on a smaller and more focused set of data relevant to the circularity concept, leading to more specific and relevant information about the provided problem. Additionally, employing its advanced text generation capability allows for accurate and comprehensive information extraction (Alshami et al., 2023). This way, the information generated will be precisely aligned with not the job but the actual job responsibilities. Contextualized information can level up the understanding of the key features of circularity.

From the perspective of consultants, ChatGPT holds the potential to serve as a valuable tool in contextualizing technical data and offering innovative solutions during the early stages of project planning. By leveraging its exceptional ability to understand and interpret complex information, ChatGPT can interpret circular design possibilities, material options, and reuse best practices, all tailored to the specific needs of the stakeholders and projects. This allows consultants to establish a strong foundation for incorporating the reuse strategy of circularity right from the project's inception. Additionally, ChatGPT can assist in tailoring complex documents into easy-to-understand guidelines for contractors and site managers, facilitating smoother project execution. For consultants dealing with regulatory bodies and government officials, ChatGPT can simplify and contextualize compliance and regulatory information, making it easier to navigate the intricacies of regional regulations. It can decode legal documents and policies, providing clear and relevant explanations that ensure projects remain fully compliant without the need for costly legal consultations.

ChatGPT’s capability to adapt the context of information when serving stakeholders ensures that all players know what their role is, and what is expected (Ekin, 2023), leading to a better understanding of how their roles connect to broader goals of circularity in the process. Such a critical and targeted approach minimizes possible miscommunication while fostering enhanced cooperation among all stakeholders, easing project performance and meeting circularity targets. Providing context that meets the definitions of stakeholders involved in construction, ChatGPT can facilitate reduced gaps in knowledge and awareness about the actionable steps and tasks of each stakeholder, leading to advanced and improved comprehension levels of all the stakeholders and ultimately to the enhancement of circularity in the construction industry.

4. Findings

The analysis of the interviews reveals the extensive use of various R-strategies in different projects, with a particular emphasis on the Reuse strategy. The respondents frequently mentioned the application of reuse in their projects, such as dismantling old buildings and reusing materials like steel beams, bricks, and timber in new constructions. This approach not only reduces waste but also significantly cuts down the carbon footprint associated with producing new materials. Participant 2 stated, "*We primarily focus on the reuse strategy in our projects. For example, we've worked on several projects where we've dismantled old buildings and reused the materials in new constructions. We often salvage components like steel beams, bricks, and even timber which can be cleaned, tested, and reintegrated into new structures*." Another notable example is the substitution of concrete with wood-based structures to reduce carbon emissions, despite some limitations like fire hazards, mentioned by Participant 3: "*The most obvious strategy is the Reuse concept where we try to reduce carbon emissions by reusing materials as much as possible*."

Repair and refurbishment strategies are also widely used to adapt buildings for reuse. For instance, evaluating the deconstructability of materials ensures that components can be reused effectively (Participant 3): "*We also use repair, refurbish, and recycle strategies to adapt buildings for reuse*." Recycling strategies were initially focused on but have evolved into more comprehensive circular economy approaches, including refurbishing and remanufacturing, especially in infrastructure projects (Participant 5): "*Initially, it was about developing concepts and understanding how to implement circular thinking in the built environment. Then it evolved into setting up circular economy strategies".*

The responses to the question about which R-strategies are being used and how they are applied in projects validate the relevance of the interviewees to this research. The detailed examples and practical applications of the reuse strategy demonstrate their necessary knowledge and experience in the field of circularity. The respondents' ability to provide specific instances of how this strategy is integrated into the projects they consult highlights their direct involvement and expertise in implementing circular economy principles. This alignment with the core focus of my research confirms the appropriateness and value of their insights for my study.

4.1 Validation of limited understanding

The responses to the question about the challenges when implementing circularity practices reveal a significant barrier related to the limited understanding, awareness, or knowledge of circularity principles among stakeholders. One of the biggest challenges highlighted is "the lack of understanding and experience with circular practices among the stakeholders. Many contractors and subcontractors are used to traditional linear construction methods and find it difficult to adapt to the requirements of reusing materials," as Participant 2 noted. This limited understanding often leads to delays and inefficiencies, as stakeholders struggle to grasp and implement circular solutions effectively.

Participant 7 emphasized that the lack of knowledge about circular innovation can create dependency on subsidies or the willingness of the supply chain to absorb extra costs. Logistical issues also arise during projects involving the reuse of materials, as there can be a mismatch between supply and demand due to knowledge gaps. This barrier was further underscored by Participant 1, who discussed a specific project where misunderstandings

around circular solutions caused delays despite the stakeholders' intention to adopt circular practices.

Another challenge mentioned was the misconception that the circular economy is equivalent to recycling. Participant 5 noted that this persists partly due to the scarcity of case studies or pilot projects demonstrating the broader circularity scope. Many stakeholders jump into the topic because it is trendy, but misconceptions make it difficult to ensure everyone is on the same page.

These insights highlight the significant issue of limited knowledge and understanding among stakeholders, with eight out of ten interviewees recognizing this as the most influential barrier to the adoption of circularity practices. Without a comprehensive understanding of circular principles, businesses and individuals struggle to implement these practices effectively, missing opportunities for innovation, efficiency, and environmental preservation. Addressing this knowledge gap is crucial for advancing circular economy initiatives and ensuring successful project outcomes.

4.2 Difficulties of Consultants

Understanding and processing technical documents and policies are fundamental to various roles within the construction and sustainability sectors, and more specifically for the consultants. These documents are critical for ensuring compliance, guiding project execution, and fostering effective collaboration among stakeholders. However, these documents' inherent complexity and volume often pose significant challenges. This section explores the difficulties consultants encounter in understanding technical documents and policies, based on insights drawn from the interviews. It also discusses the strategies employed to overcome these challenges, offering a comprehensive overview of the current landscape and utilized solutions to enhance comprehension and application of technical information in circular construction projects. The quotes from the problems that consultants face can be seen in Table 4.

One of the most frequently mentioned issues is the complexity and technicality of the documents. Many individuals highlighted that these documents are often written in very technical language, assuming a high level of prior knowledge. Participant 7 remarked, "*First off, complexity and technicality. These documents are packed with jargon and complex terms that can feel like trying to decipher another language.*" This complexity is currently addressed by breaking down information into more manageable sections. To mitigate this issue, organizations create easy-to-follow guides and checklists, simplifying the information to make it more accessible.

Information overload is another significant challenge, with four respondents mentioning it. This term refers to a situation in which the overwhelming amount and speed of incoming information surpass an individual's ability to handle it effectively, resulting in stress, mistakes, and poor decision-making. The volume of information and the dense nature of these documents can be overwhelming. Participant 2 described it as "*the sheer volume of information and the complexity of technical standards*.". To cope with this, professionals emphasize the importance of summarizing and prioritizing critical points. Tools like mind maps or outlines help organize the information. One strategy involves holding standalone discussions within associations to ensure a unified understanding among all members.

Misalignment with expertise was identified by two respondents as a significant barrier. This issue arises when there is a mismatch between the knowledge required to understand the documents and the expertise of the professionals handling them. Addressing this requires continuous communication between different parties to align understanding. For example, providing clear explanations and using visual aids like drawings can bridge the knowledge gap.

Two respondents mentioned a lack of contextualization. This problem involves understanding and applying vast amounts of information, particularly regarding new or changing regulations. To tackle this, continuous updates and detailed discussions within task forces are essential. This ensures everyone has a unified understanding of the regulations and their applications.

Table 4: Quotes on consultants' difficulties

Consultants' difficulties	Quotes (Participant ID)
Complexity and technicality	**Part 2:** *These documents are often written in very technical language and assume a high level of prior knowledge. It's not just about understanding the policies but also about interpreting how they apply to specific materials and reuse scenarios*
	Part 6: *Sometimes the regulation itself is not very clearly written. Even the regulators might lack expertise or clarity which means we need to do our own interpretation.*
	Part 7: *There are a few main issues we bump into: First off complexity and technicality. These documents are packed with jargon and complex terms that can feel like trying to decipher another language*
	Part 9: *The technical documents can be a real headache sometimes... You'll get these massive reports full of technical jargon and it takes ages to sift through and figure out what's relevant to your project*
	Part 10: *The technical documents can be pretty dense sometimes. They're often filled with complex terms and a lot of regulations that are tough to unpack. You'll find yourself reading the same section over and over trying to make sense of it.*
Information overload	**Part 2:** *Well, the main difficulty is the sheer volume of information…*
	Part 3: *I think the most difficult thing for me is receiving the knowledge overload from either a tender provider or our client as a builder.*
	Part 7: *Then there's information overload. These documents are dense and can feel overwhelming.*
	Part 9: *I think one of the biggest issues is information overload—there's just so much to digest.*
Misalignment with expertise	**Part 3:** *The main issue is the mismatch between their knowledge and mine.*
	Part 4: *Yeah, there is a mismatch between the knowledge I have and the knowledge other experts doing a different profession have on circularity. So, I think the mismatch comes from either their goals being different from ours or their scope differing from what we consider necessary*
	Part 8: *We all got our lanes, our expertise to claim, but when we meet at the table, the rules aren't the same*
Lack of contextualization	**Part 5:** *But then, the difficulty lies in moving from theory to implementation. There's very little in terms of case studies or projects that people can learn from*

	because there are still very few pilot or scale projects that explain and demonstrate that it's possible... That's where it gets difficult because we aren't speaking the same language when discussing it
	Part 6: *We need to understand and contextualize a vast amount of information, especially regarding upcoming and already-established regulations*

4.3 Difficulties Collaborating Stakeholders' Encounter

Collaborating stakeholders frequently encounter various comprehension difficulties with the technical documents produced by consultants in projects. These challenges can be broadly categorized into four main areas: the complexity and technicality of documents, information overload, misalignment with expertise, and lack of contextualization. Below is an analysis of these issues, supported by quotations from the transcripts, along with the solutions employed to address them. The quotes from the problems that collaborating stakeholders usually can be seen in Table 5.

One of the primary issues is the complexity and technicality of the documents. Several respondents highlighted this problem. For instance, participant 1 noted, "*A lot of partners in the projects that we work together don't understand the technical documents, the policies, the assessment schemes.".* To mitigate these challenges, several strategies have been implemented. Simplifying the documents is a common approach. Additionally, creating executive summaries and conducting follow-up meetings have proven effective. Training and workshops are also utilized to help stakeholders understand the documents better.

Information overload is another significant challenge, mentioned by several respondents. This issue arises when stakeholders receive too much information, making it difficult for them to extract relevant insights. To address information overload, executive summaries, and additional contextual information are provided to help stakeholders focus on the most critical aspects.

Misalignment with expertise is also an important theme. This problem occurs when the technical level of the documents does not match the expertise of the stakeholders. Bridging this gap often involves providing training and workshops to bring stakeholders up to the necessary level of understanding. Workshops are also essential for setting up the basics and ensuring everyone is on the same page.

Lastly, the lack of contextualization in documents can hinder stakeholders' understanding. This issue was noted by several respondents. Participant 5 explained, "*Part of the work I did as a consultant was to raise awareness even if it wasn't directly part of the project. It was definitely a necessary step to help the client understand what we were talking about.*" Adding contextual information and conducting workshops are key strategies to address this problem. Workshops help set the groundwork for understanding, ensuring that stakeholders are not overwhelmed by the documents.

Table 5: Quotes on collaborating stakeholders' difficulties

Collaborating stakeholders' difficulties	Quotes (Participant ID)
Complexity and technicality	**Part 1:** *A lot of partners in the projects that we work together don't understand the technical documents, the policies, the assessment schemes*
	Part 2: *Stakeholders often struggle with the detailed reports we generate, particularly when it comes to the technical jargon and the extensive data we include*
	Part 9: *A lot of the stakeholders, especially the ones who don't have a technical background, struggle with the complexity of the reports we provide.*
	Part 10: *Some of our stakeholders, especially those not used to working with technical regulations, struggle with the complexity. We've had instances where they've misinterpreted the documents we provided, which led to delays in the project*
	Part 3: *When we do some calculations, we'll produce a report for our organization. This report is very detailed with many different parameters that we monitor from circularity to CO2 emissions... but when we show it to the stakeholders, it's often not comprehensible by them*
Information overload	**Part 2:** *Stakeholders often struggle with the detailed reports we generate, particularly when it comes to… the extensive data we include…. They might be looking for a straightforward answer, but our reports include comprehensive analysis and multiple metrics*
	Part 5: *This often meant adding extra pages of contextualization about the circular economy in reports, which maybe we didn't need to do but it was definitely important. So maybe there was some information overload for other stakeholder*
	Part 9: *They're looking for straightforward answers—'Can we use this material or not?'—and instead they get an extensive document full of charts and numbers. That can lead to confusion or worse, delays when they don't understand what's required of them*
Misalignment with expertise	**Part 6:** *OK, first of all, we have the known issue with customers because it happens many times that they are not very well educated on these topics*
	Part 7: *Most organizations don't have a dedicated team working just on the standards and regulations, so when they need some assistance, they don't really understand the documents produced by us. They think that they are very complicated*
	Part 4: *For example, when you're working with people on the construction side or even product design, they're more focused on the practical application*
	Part 8: *One of the main things we struggle with is that not everyone who reads these documents comes from the same technical background. In the circularity sector, especially when we're focusing on reuse strategies, you've got a mix of experts*
Lack of contextualization	**Part 5:** *Part of the work I did as a consultant was to raise awareness even if it wasn't directly part of the project. It was definitely a necessary step to help the client understand what we were talking about.*
	Part 4: *I might assume that everyone knows the broader framework of circularity or understands why we're focusing on reuse instead of recycling. But that's not always the case. Without that context, the technical details can feel disconnected.*

	Part 8: *Sometimes we get so caught up in the technicalities that we forget to put things into a broader, real-world context*

4.4 Resources for rectification

Based on the interviews conducted, several resources have been identified as critical for addressing and rectifying the above-mentioned deficiencies. Below is a detailed analysis supported by Table 6 including the resources and the frequency that they were mentioned.

Time was the most frequently mentioned resource, highlighted by five different participants. The need for substantial time investments was a recurring theme. Participant 2 mentioned: "*The most important resource we utilize is time for holding follow-up meetings. We organize the sessions to ensure that all stakeholders are on the same page*".

Stakeholder guidance, which is a sub-category of time resource was also highlighted as a vital resource, though it was mentioned by two participants. Participant 9 emphasized the importance of scheduling time to walk through details with stakeholders, answering questions, and clearing up any confusion immediately. Expert consultation emerged as another crucial resource, with Participant 2 pointing out the necessity of specialized knowledge.

Financial costs were a significant concern for four participants, highlighting the economic burden of addressing deficiencies. Participant 6 remarked that money can also be an issue but to a lesser extent.

Education and training, which is a sub-category of both money and time resource were emphasized by three participants as necessary for improving the value chain. Participant 10 stated, " *We invest a lot of time in training sessions and workshops to get everyone on the same page* ".

Table 6: Quotes on rectifying resources

Rectifying resources	Quotes (Participant ID)
Time	**Part 1:** *It's mainly about time investments to get the right data on the table or to get to know a methodology you have to invest upfront time to learn it.*
	Part 2: *The most important resource we utilize is time for holding follow-up meetings. We organize the sessions to ensure that all stakeholders are on the same page*
	Part 3: *It's mostly time again. So yeah, time and money. We're a consultancy firm so we're very hourly driven*
	Part 5: *Time is a problem and delays often happen despite our ongoing discussions. It takes a lot of time for corrections and clarifications*
	Part 6: *It's mostly about time because we have very limited resources—just one full-time employee for these matters*
	Part 7: *Time is crucial because some of these issues require a lot of hours to analyze, break down, and address properly.*
	Part 9: *When it comes to addressing the issues in understanding technical documents, it all boils down to time.*
Stakeholder guidance	**Part 2:** *We use visual aids like diagrams and flowcharts to make complex information more digestible… We also invest in hiring or consulting with experts*

	who can provide specialized knowledge and guidance
	Part 9: *We make sure to schedule time to walk through the details with the stakeholders, answer questions, and clear up any confusion right away.*
Stakeholder training	**Part 10:** *We invest a lot of time in training sessions and workshops to get everyone on the same page*
Financial cost	**Part 2:** *So it is also a matter of extra costs too.*
	Part 3: *We're very hourly driven. They pay for every hour that we act and so on*
	Part 6: *Money can also be an issue but to a lesser extent. For instance, the end customer may have requirements that a small subcontractor doesn't want to pay for.*
	Part 7: *To tackle and fix deficiencies the main resources we use are really just time and money… Money comes into play when we need to invest in new tools, training, or even bringing in outside expertise.*

4.5 Effects on Circular Projects

Circular construction projects are increasingly being recognized for their potential to enhance sustainability in the construction industry. However, several deficiencies impact the overall efficiency and success of these projects. Through the insights gathered from industry professionals, this thesis identifies key areas where these deficiencies manifest and their repercussions. Quotes on these effects can be seen in Table 7.

One significant impact mentioned by multiple respondents is the increased project timeline and costs. As Participant 2 highlighted, "*These deficiencies can significantly slow down the project timeline and increase costs. When stakeholders don't fully understand the circularity principles or how to implement correct reuse strategies, it leads to delays as we spend additional time on clarifications.*" This indicates that a lack of understanding among stakeholders necessitates additional time and resources to clarify circular principles, thereby increasing both the duration and budget of projects.

Another significant theme is the sub-optimal reuse of materials. The same respondent (2) noted that "*In some cases, it can also result in suboptimal reuse of materials where the potential benefits of circularity are not fully realized. For example, if the reclaimed materials are not properly assessed or integrated, it can compromise the quality and sustainability of the project.*" This highlights how gaps in data understanding can cause companies to misallocate their focus, thereby reducing the overall impact of their circular construction efforts. These points suggest that improper assessment and integration of reclaimed materials can hinder the project's overall sustainability goals, resulting in missed opportunities to fully capitalize on the benefits of circular construction.

The lack of proper implementation of projects is also a concern. This points to a broader issue within the industry where many circular construction projects remain theoretical and fail to transition into full-scale implementations.

Additionally, the loss of circular ambitions during planning was mentioned. Participant 8 pointed out that incorrect planning or delays in the review process can cause circular goals to be abandoned, especially due to time constraints and rising costs. This reflects the challenges faced in maintaining the integrity of circular ambitions through the planning and

review phases, often leading to their abandonment due to time constraints and escalating costs.

Table 7: Quotes on the effects on circular projects

Effects	Quotes (Participant ID)
Increased project timeline and costs	**Part 2:** *These deficiencies can significantly slow down the project timeline and increase costs. When stakeholders don't fully understand the circularity principles or how to implement correct reuse strategies it leads to delays as we spend additional time on clarifications.*
	Part 3: *I doubt it will lead to failures, but in the worst case, it might cause delays.*
	Part 7: *When there's a lack of knowledge or resources, it slows everything down. For example, if people don't fully understand circularity principles, we end up spending more time educating or fixing mistakes, which delays the project.*
	Part 10: *These issues definitely slow things down. When stakeholders don't fully understand the requirements or how to implement circularity practices, we see delays in execution*
Sub-optimal solutions	**Part 1:** *The limited comprehension of data can result in a sub-optimization so it can mean that a company is focusing on a certain aspect that is in the end not the most impactful.*
	Part 2: *In some cases it can also result in suboptimal reuse of materials where the potential benefits of circularity are not fully realized*
Lack of proper implementation of projects	**Part 5:** *Well most of them don't really happen. Most of them are just nice projects that never get fully implemented.*
Loss of circular ambitions during planning	**Part 8:** *The plans are not always correct and some circular ambitions get lost. Maybe because they're not good in planning but it's also possible that during the whole review process too much time is lost.*
	Part 9: *As I already mentioned this limited awareness creates an environment that few people understand the ultimate goal of the circularity practices and yeah it leads to many delays and often to results that do not fully correspond to the original plan.*

4.6 Current use of ChatGPT

In the rapidly evolving sector of artificial intelligence, ChatGPT has emerged as a useful tool across various professional domains. To gain insights into how this technology is being utilized, a question was posed to interviewees: "Are you currently using ChatGPT? If yes, for what reasons?". The responses provided a look at the diverse applications of ChatGPT in their daily work routines. This section delves into these applications, illustrating the specific tasks and functions for which ChatGPT is employed, enriched with direct quotations from the participants. This question aims to unveil the knowledge of the respondents with the various capabilities of this Generative AI tool. However, it also reveals the limited knowledge and understanding some professionals have about the full scope of ChatGPT's capabilities, emphasizing the need for greater awareness and education on how to effectively utilize this AI tool in the circular construction sector. Table 8 reveals the current applications of ChatGPT in the circularity sector by the consultants interviewed.

Table 8: Current ChatGPT applications

Reason for using ChatGPT
Supporting writing and structuring work
Generating presentations and images
Creating summaries
Data analysis and extrapolation
Brainstorming and generating ideas
Streamlining project management tasks (emails, calendar)
Comparing documents

Several participants use ChatGPT to support writing and structuring their work. Participant 5 noted, "*Yes, I do use it and I use it more and more. I don't use it for knowledge generation. I use it more mainly for supporting writing and supporting structure of my work.*" This indicates a growing reliance on ChatGPT for tasks that require organizing and drafting documents. Participant 6 mentioned using ChatGPT to create drafts and summaries of large documents, especially when detailed reading is unnecessary, saving time and effort. This highlights the tool's utility in summarizing extensive documents, saving time and effort.

ChatGPT is also employed for generating presentations and images. Participant 1 described using it for tasks like drafting text, generating images, and creating abstract information bulletins from large texts. This showcases ChatGPT's versatility in handling various creative and informational tasks. Creating summaries of large texts is another prominent use case. Participants find ChatGPT helpful for condensing lengthy regulations or documents. This use case is particularly beneficial for professionals dealing with extensive and detailed documents, as it allows them to quickly grasp the key points.

In the realm of data analysis and extrapolation, Participant 3 highlighted the potential of ChatGPT for assisting in material estimation: "*We're trying to use AI for a lot of data analysis. For example, a client might provide us with a bid or the financial details of their building and we need to extrapolate and get exact material amounts from that.*" This application underscores ChatGPT's ability to handle specific and technical tasks within a professional setting.

Generating abstract information bulletins was mentioned alongside creating presentations and images. The same participant elaborated on using ChatGPT for producing abstract information bulletins based on large texts, illustrating the tool's capability in distilling and disseminating complex information. Streamlining project management tasks is another valuable application of ChatGPT. This reflects how ChatGPT can enhance efficiency by managing routine but essential tasks. Finally, brainstorming and generating ideas is a use case mentioned by several participants. This comment illustrates how ChatGPT can serve as a catalyst for creativity and ideation.

In conclusion, the analysis of ChatGPT usage from the transcripts reveals its wide-ranging applications in professional settings. From supporting writing and summarizing large texts to data analysis and project management, ChatGPT proves to be a valuable tool. The insights and direct quotations from participants underscore both the benefits and limitations of using ChatGPT in their workflows, offering a detailed understanding of its role in their professional lives, but also revealing the limited knowledge of the construction industry consultants about

the full range of this tool's capabilities.

4.7 Concerns about ChatGPT

This section delves into the most important worries expressed by the participants, highlighting the key issues they foresee in integrating ChatGPT into their workflows. By examining these concerns, we gain a comprehensive understanding of the challenges that need to be navigated to ensure a smooth and effective adoption of this AI technology. The following section categorizes and elaborates on these concerns, using direct quotations to provide a detailed perspective on the obstacles faced. The main concerns of the interviewees and the quotes mentioned can be seen in Table 9.

A significant concern mentioned is related to security issues and data safety. Six participants highlighted this as a major worry. Participant 8 emphasized, "*I think two things. First, the security of the documents we use is important. We work for a lot of clients and we don't want all the information on the Internet. So that's one concern".* This apprehension is rooted in the fear of sensitive information being compromised, reflecting a significant hesitation toward fully integrating ChatGPT into processes where confidentiality is paramount.

Even more important is the concern about the reliability and accuracy of the information provided by ChatGPT. Six participants noted the issue of needing to verify outputs to ensure they meet professional standards. Participant 2 stated, "*One of our biggest concerns is the reliability and accuracy of the information provided by ChatGPT. We always have to verify the outputs to ensure they meet our standards."* The potential for misinformation and the necessity for continuous validation of AI outputs are critical barriers to its adoption.

Three participants expressed concerns about over-reliance on AI, which could lead to a reduction in critical thinking skills. This reflects a broader societal worry about the implications of excessive dependence on AI tools, emphasizing the need for maintaining human cognitive engagement. Two participants mentioned the challenge of adapting AI to be user-friendly for all colleagues, especially those less familiar with technology This highlights the need for comprehensive training and support to ensure seamless integration of AI tools across diverse user groups.

Ethical concerns, particularly regarding transparency and the potential misuse of AI, were also noted by two participants. These concerns underline the importance of ethical AI deployment practices. Lastly, a unique concern raised was the environmental impact of AI, with computing power requirements becoming an increasing issue. This reflects a growing awareness and responsibility towards the environmental footprint of advanced technologies.

In summary, while the adoption of ChatGPT presents opportunities for efficiency and innovation, several significant concerns must be addressed. Security and data safety, reliability, over-reliance on AI, adaptability, ethical considerations, and environmental impact, are issues that organizations need to address before leveraging the full potential of AI tools effectively.

Table 9: Quotes on concerns about ChatGPT

Concerns about ChatGPT	Quotes (Participant ID)
Security issues and data safety	**Part 1:** *The biggest concern is security issues and data safety issues.*
	Part 2: *Security is another major issue especially when handling sensitive project data.*
	Part 3: *Security issues are another big concern. We're trying to figure out which AI to use and what the terms of agreement are. We need to know what information they use from us because many AI models train on the inputs and information you give them.*
	Part 8: *Yeah I think two things. First, the security of the documents we use is important. We work for a lot of clients and we don't want all the information on the Internet. So that's one concern.*
	Part 9: *There's also the security issue—especially when you're dealing with sensitive project data*
	Part 10: *There's also a bit of a gray area when it comes to data privacy. You don't want to inadvertently share sensitive information so we're cautious about what we input.*
Reliability and accuracy of information	**Part 2:** *One of our biggest concerns is the reliability and accuracy of the information provided by ChatGPT. We always have to verify the outputs to ensure they meet our standards.*
	Part 3: *Another point mentioned is reliability. We're trying to figure this out because while you can get answers to questions we need to know how reliable those answers are. We're still in the process of evaluating this but I'm optimistic about its reliability.*
	Part 6: *My biggest concern and I actually read an article about this a couple of days ago is the ability of generative AI and language models to provide information that looks very accurate and right but is actually wrong.*
	Part 7: *When it comes to the biggest concerns associated with adopting ChatGPT, reliability of the outputs stands out.*
	Part 9: *I think the biggest concern is accuracy. It's one thing to use it for generating ideas or writing a draft but when it comes to the technical stuff you really need to be careful.*
	Part 10: *Sometimes it gives you something that sounds correct but isn't quite right so you have to be careful not to rely on it too much.*
Over-reliance on AI and reduction in critical thinking	**Part 1:** *If used all the time you are not training your own brain to think and you're depending too much on AI or other devices. Your brain gets lazy.*
	Part 2: *We are also mindful of the ethical considerations particularly regarding data privacy and the potential for over-reliance on AI which could lead to a reduction in critical thinking skills among our team.*
	Part 8: *We might end up copying mistakes from the past into the future because we're not thinking for ourselves anymore.*
Unfamiliarity with using AI prompts	**Part 3:** *Well we have a very young company but we also have some older colleagues and some who aren't very interested in technology. They're not familiar with using prompts because it's different from how they're used to using their computers.*

	Part 5: *Probably it's a lack of awareness on how to use it because I never really thought I should upload anything.*
Ethical considerations	**Part 2:** *We are also mindful of the ethical considerations…*
Environmental impact	**Part 3:** *Another concern is environmental impact. We know that the computing power required for these AIs is getting out of hand. The system is evolving rapidly almost in a brute-force manner where more computing power leads to more powerful AI.*

4.8 Difficulties for integration of ChatGPT

The participants were also asked about possible concerns about integrating new technologies in their organizations to explore possible issues that may arise from adopting ChatGPT. Several key themes emerged from the transcripts, which can be seen in Table 10.

One of the most frequently mentioned challenges is the need for training and skill development. Several respondents highlighted the difficulty of ensuring all stakeholders are sufficiently knowledgeable about this new technology. For instance, Participant 2 stated, "*The most significant challenge is getting all employees of the company to adopt and effectively use the new technology... There's often a knowledge gap, especially with more experienced colleagues who might be less comfortable with AI tools.*" High-quality training is essential for the effective implementation of AI technologies. This disparity in technological proficiency can hinder the overall integration process, making it crucial to address through comprehensive training programs.

Resistance from experienced staff is another significant barrier. Long-standing employees often find it challenging to adapt to new technologies, s Participant 1 mentioned that there is a disparity in the level of knowledge among stakeholders, particularly with older employees. Management approval and support are critical for the successful adoption of new technologies. Without the backing of senior leadership, initiatives often stall. As Participant 3 put it, "We're pitching it to our management team. Our management team needs to give us the go-ahead but they are hesitant."

Integration with existing systems also poses a considerable challenge. Ensuring that new technologies work seamlessly with current workflows and systems can be complex and time-consuming, underscoring the need for thorough planning and coordination to minimize disruptions.

The fast-paced evolution of technology can be also challenging. It requires continuous learning and adaptability, as it evolves rapidly, making it difficult to predict future capabilities. Keeping up with rapid advancements requires continuous learning and adaptability. Lastly, resource constraints, including time and money, are significant considerations. The learning curve associated with new systems can be a deterrent, particularly when tight deadlines are involved.

In summary, the integration of new technologies faces multiple challenges, including knowledge gaps, resistance from experienced staff, management approval, system integration, the fast-paced nature of technological advancements, and resource constraints.

Addressing these issues requires a well-designed approach involving training, cultural shifts, and strategic planning to ensure successful technology adoption.

Table 10: Quotes on difficulties of integration

Difficulties of integration	Quotes (Participant ID)
Training and skill development	**Part 2:** *The most significant challenge is getting all employees of the company to adopt and effectively use the new technology... There's often a knowledge gap especially with more experienced colleagues who might be less comfortable with AI tools.*
	Part 6: *There are certainly things this can be applied to and things it cannot... extensive and high-quality training is required.*
Resistance from experienced staff	**Part 1:** *I think the most significant challenge is that there's a disbalance in the level of knowledge of all your stakeholders, so you will have stakeholders that are not really up and running with all these technological, especially the elderly ones*
	Part 5: *it's about a culture change in the sector… but it might take time, especially for older people who might have trouble familiarizing themselves with this technology*
	Part 8: *Maybe for new engineers it will take less time than for experienced engineers because they're already fixed in a certain way of thinking.*
	Part 9: *One of the biggest challenges is getting everyone on board... You've got people who have been doing things a certain way for years maybe decades and the idea of bringing in something new—whether it's AI or just a new type of software—can be pretty intimidating.*
Management approval and support	**Part 3:** *Well as we're trying to integrate this right now we're pitching it to our management team…they're curious but also very skeptical.*
Integration with existing systems	**Part 2:** *Additionally ensuring the technology integrates smoothly with our existing systems and workflows can be complex*
	Part 9: *A lot of the systems we work with aren't exactly built to integrate with the latest technologies so you end up needing to spend time and money on customization or figuring out workarounds.*
Fast-paced of the evolution of this tool	**Part 3:** *Even though we've spent quite some time researching what AI can do and when it will be able to do it it's evolving very quickly. You don't know what it will be able to do next week or two weeks from now. It's very fast-changing and that's one of the biggest challenges we have right now*
Resource constraints (time)	**Part 7:** *A lot of time spent on getting everything aligned. So that's in general, that's a challenge*
	Part 9: *Another issue is the learning curve—no one wants to spend a lot of time learning a new system especially when deadlines are tight***.**
	Part 10: *And of course there's always the cost both in time and resources to fully implement and train everyone.*

4.9 Willingness to adopt ChatGPT for knowledge contextualization

Finally, the participants were asked about their willingness to use ChatGPT for knowledge contextualization. Below is an analysis of their feedback along with quotations to illustrate their views.

The consultants generally express openness to using ChatGPT for knowledge contextualization, recognizing its potential to simplify complex information and bridge knowledge gaps with stakeholders who may not be familiar with technical details. Several view it as a useful tool for tailoring information to different expertise levels and providing clearer explanations, helping streamline communication and understanding. However, some consultants express concerns about its reliability, preferring to rely on their own expertise or using ChatGPT primarily for generating summaries or drafts. While most are positive about its potential, a few remain hesitant or fixed in their current ways of working, emphasizing the need for more understanding of the tool's capabilities.

Table 11: Quotes on willingness to utilize ChatGPT

Quotes (Participant ID)
Part 1: *At this moment? Not really because I am happy with the way we are working.*
Part 2: *Yes definitely. We see a lot of potential in using ChatGPT to tailor information to different stakeholders' knowledge levels. It could help us provide clearer explanations and more context-specific insights making our communications more effective and ensuring that everyone is on the same page*
Part 3: *Yeah, I would like to. I would love to at the moment... Having the opportunity to use GPT to handle the explanations our project leaders provide during presentations and calls with clients, I think that's very valuable*
Part 4: *Honestly I wouldn't rely on ChatGPT for that. In situations where accuracy and context are critical I'd rather stick to my own expertise or collaborate directly with other professionals.*
Part 5: *Yes I would. That's the short answer. I've already told you that in many situations I really need to use it because it saves so much time.*
Part 6: *Personally I have a paid subscription now as an employee of the company. The most frequent reason for using it is to make a very high-level summary of a regulation or something that isn't worth my time to read through in detail.*
Part 7: *Yes, I am open to the possibility of having an assistant with these capabilities.*
Part 8: *Yeah I think I've tried it a little but I'm also maybe a bit fixed in my way of working. And with the lack of time I haven't had the chance to understand ChatGPT better. So yeah I think I need to learn more about its possibilities.*
Part 9: *Yes I would. I think it could be really useful in helping to break down complex information and make it more understandable to different stakeholders.*
Part 10: *Definitely. It's a great tool for simplifying complex information. I think it has a lot of potential especially for bridging the knowledge gap with stakeholders who aren't as familiar with the technical side of things.*

In conclusion, the feedback indicates a strong inclination toward using ChatGPT for understanding and clarifying information among the participants. The general consensus is

positive, with acknowledgments of both the potential benefits and the need for careful application to ensure accuracy and context-appropriateness.

Table 12: Summary of findings

No.	Findings	Category
1	Information overload	Problem
2	Complexity and technicality	Problem
3	Misalignment with expertise	Problem
4	Lack of contextualization	Problem
5	Time	Rectifying resources
6	Money	Rectifying resources
7	Stakeholder guidance	Rectifying resources
8	Stakeholder training	Rectifying resources
9	Increased project timeline and costs	Effects on projects
10	Sub-optimal solutions	Effects on projects
11	Lack of proper implementation of projects	Effects on projects
12	Loss of circular ambitions during planning	Effects on projects
13	Security issues and data safety	Concerns for ChatGPT
14	Reliability and accuracy of information	Concerns for ChatGPT
15	Over-reliance on AI and reduction in critical thinking	Concerns for ChatGPT
16	Unfamiliarity with using AI prompts	Concerns for ChatGPT
17	Ethical considerations	Concerns for ChatGPT
18	Environmental impact	Concerns for ChatGPT
19	Training and skill development	Difficulties for integration
20	Resistance from experienced staff	Difficulties for integration
21	Management approval and support	Difficulties for integration
22	Integration with existing systems	Difficulties for integration
23	Fast-paced of the evolution of this tool	Difficulties for integration
24	Resource constraints (time)	Difficulties for integration

5. Discussions

In the following section, the analysis of the findings will be discussed, which will be the basis for the creation of guidelines for the smooth integration of Generative AI in the circular construction industry. Examining the data will allow for the identification of key steps that need to be considered that contribute to successful Generative AI implementation and highlight potential challenges. The analysis is structured to provide actionable insights and best practices that will support industry stakeholders in leveraging Generative AI to enhance circular construction principles.

5.1 Reasons for poor knowledge contextualization in circularity

The analysis of the difficulties consultants and their collaborating stakeholders face in understanding technical documents and policies reveals a consistent set of challenges: complexity and technicality, information overload, misalignment with expertise, and lack of contextualization. These difficulties are prevalent among both consultants and stakeholders, though their frequency and nature differ slightly between the two groups. Identifying them is the first step in recognizing the need to utilize Generative AI for knowledge contextualization and the key concepts where employees should receive training on this Generative AI technology.

The complexity and technicality of the documents and policies associated with implementing circular principles in construction projects is the challenge that is the most frequently mentioned issue for consultants and stakeholders. Technical documents often assume a high level of prior knowledge and are packed with jargon and complex terms, which could lead to many adverse setbacks to circular projects like disputes, communication barriers, and interpretation errors (Rameezdeen & Rodrigo, 2013). This complexity can make the documents feel like "*trying to decipher another language*" as one consultant 7 noted. Stakeholders similarly struggle with detailed reports, technical jargon, and extensive data, finding it demanding to comprehend all the information.

Information overload refers to the overwhelming volume and speed of incoming information, which surpasses an individual's ability to handle it effectively (Edmunds & Morris, 2000). Tang et al. (2008) advocate that the sheer volume of technical standards and detailed reports can lead to many setbacks to circular projects. Excessive volumes of information complicate the retrieval of useful data, leading to delays and inefficiencies as project teams spend significant time searching for relevant information, which reduces productivity and increases the time spent on administrative tasks rather than actual project work. Information overload also leads to stress and information fatigue among workers, decreasing their ability to process and utilize information effectively, which results in lower job satisfaction, higher error rates, and reduced decision-making quality (Tang et al., 2008). Consultants emphasized the need for summarizing and prioritizing critical points, using tools like mind maps and outlines to organize the information effectively.

Misalignment with expertise occurs when there is a mismatch between the knowledge required by the documents and the expertise of the professionals handling them. This issue is more frequently found when stakeholders have to analyze circularity documents, who often do not have the same level of technical understanding as the consultants producing the documents. Varying levels of expertise among project team members can lead to significant

setbacks, particularly in communication. These differences often create barriers, causing misunderstandings and inefficiencies that impede project progress. Delays in responses further exacerbate these issues, requiring additional time and adjustments. Moreover, managing stakeholder expectations becomes complicated as different expertise levels lead to diverse approaches and potential conflicts (Senaratne & Ruwanpura, 2015). These setbacks highlight the critical need for effective communication strategies and a unified approach to project management, ensuring all team members can collaborate efficiently and effectively, regardless of their expertise. Bridging this gap requires continuous communication, clear explanations, and the use of visual aids to align understanding.

The lack of contextualization involves difficulties in understanding and applying vast amounts of information, especially regarding new or changing regulations. This problem hinders the move from theory to practical implementation. Continuous updates and detailed discussions within task forces are essential to ensure everyone has a unified understanding of the regulations and their applications.

An important distinction must be made between more and less experienced consultants in the field of circular construction. Consultants with over 10 years of experience highlighted misalignment with expertise as the most significant barrier they face. Experienced consultants often receive documents from clients who lack sufficient knowledge of circularity and subsequently have requests that are unrealistic and not feasible. Furthermore, the documents produced by these consultants are not fully comprehensible to the collaborating stakeholders, also due to the limited circular understanding of the collaborating stakeholders. This issue is more frequently reported by stakeholders who often do not possess the same level of technical understanding as the consultants. Experienced professionals tackle this barrier by navigating these complexities and ensuring that all parties involved have a mutual understanding of the project's requirements and goals, facilitating better alignment and collaboration.

In contrast, professionals with less than 10 years of experience focus more on immediate tasks. Their primary challenges revolve around understanding the volume and technical nature of documents, which can be complex without extensive prior knowledge. The complexity and technicality of these documents, coupled with the sheer volume of information, pose significant hurdles that are more immediate and tangible compared to the systemic issues their more experienced consultants face. With limited exposure to fewer projects and stakeholders, their focus tends to be on mastering technical content and navigating the immediate demands of their roles. Less experienced professionals are generally more adaptable and open to new technologies and methods, as they are still in the early stages of their careers. However, they require more support in understanding and applying technical details of new documents and practices. Their challenges lie in acquiring and processing new information rather than reconciling it with long-held practices. By understanding these differing challenges, the integration of ChatGPT can be tailored to meet the specific needs of both seasoned and less experienced professionals, enhancing their ability to grasp and apply technical information effectively.

Another distinction is the problems faced by consultants and their collaborating stakeholders. Consultants and collaborating stakeholders both face significant challenges in understanding and processing technical documents and policies, but the frequency and nature of these problems differ slightly between the two groups. Consultants most frequently mentioned

issues with complexity and technicality, followed by information overload, misalignment with expertise, and lack of contextualization. For collaborating stakeholders, the primary issue was also complexity and technicality but they more frequently reported misalignment with expertise and lack of contextualization than consultants did. While both groups struggle with the dense and technical nature of documents, stakeholders particularly face difficulties due to their varying levels of expertise and the need for more contextual information to fully understand the content.

ChatGPT is capable of addressing all the issues of poor knowledge contextualization, providing valuable solutions to employees and organizations. ChatGPT addresses the problem of poor knowledge contextualization due to **information overload** through its strong knowledge retrieval and organization affordances and its' contextual understanding and text generation features. The affordance of knowledge retrieval allows users to quickly access and retrieve information across diverse topics without the need to search through multiple sources, thus streamlining the information acquisition process. This capability is particularly beneficial in environments such as engineering design, where quick access to relevant knowledge can significantly improve workflow efficiency. Additionally, ChatGPT excels at knowledge organization, where it can categorize and structure vast amounts of data, making unstructured information more searchable and easier to analyze. Furthermore, ChatGPT's enhanced contextual understanding allows it to interpret user input more effectively and generate appropriate, contextually relevant responses that align with the user's needs. This feature ensures that interactions are not only more engaging and natural but also more insightful, helping users gain a clearer understanding of vast amounts of documents. Furthermore, ChatGPT's text generation feature allows it to produce coherent, contextually relevant, and grammatically accurate content, which is vital for summarization, report creation, and content refinement. These affordances and features combined enable ChatGPT to tackle information overload by delivering concise, relevant, and organized information tailored to the specific context, improving overall knowledge contextualization and decision-making.

ChatGPT can also address effectively the issue of poor knowledge contextualization caused by **complexity and technicality** by leveraging several key features and affordances. One of the primary affordances is knowledge discovery, which allows ChatGPT to efficiently search through vast amounts of information to find and present relevant data. This capability ensures that even highly technical or obscure topics can be made accessible to users without overwhelming them with unnecessary details. Another crucial feature is few-shot learning, where ChatGPT can be fine-tuned with just a few examples, allowing it to adapt to sector-specific knowledge quickly. This is particularly beneficial in specialized fields like circular construction, where deep, domain-specific expertise is required. Additionally, ChatGPT's ability for coherent and comprehensive text generation further aids in breaking down and simplifying complex technical jargon into clear, coherent text. This helps users understand intricate concepts and systems more easily. Through these features, ChatGPT can enhance the dissemination and contextualization of knowledge, providing precise, customized information that can reduce the cognitive load for stakeholders and improve understanding in complex environments.

Additionally, ChatGPT can effectively address the issue of poor knowledge contextualization, often resulting from a **misalignment between the knowledge available and the expertise of the users**, by leveraging two key features— its strong contextual understanding and its

adaptability to multiple tasks—and one affordance, knowledge sharing. First, ChatGPT's knowledge-sharing affordance facilitates the rapid dissemination of tailored information across diverse stakeholder groups, ensuring that content is not just transmitted but also adjusted to different levels of expertise. Second, its adaptability to multiple tasks allows ChatGPT to pivot between different knowledge domains and tasks, ensuring that the information remains relevant regardless of the stakeholder's role or function. Finally, its affordance of contextual understanding ensures that the knowledge provided is both meaningful and immediately actionable, as ChatGPT can dynamically adapt its responses based on the specific context and needs of the user. This combination of features and affordances helps bridge the gap between abstract knowledge and practical application, making information more accessible and useful to diverse audiences.

Finally, ChatGPT can effectively address the **lack of contextualization** by leveraging its affordance of knowledge tailoring and its feature of contextual understanding. Through its advanced contextualization feature, ChatGPT adjusts information to fit specific tasks and projects. This allows it to tailor knowledge in real-time, making complex information more understandable and actionable. Its affordance of knowledge tailoring enables it to dynamically adapt to conversations by interpreting prior inputs and the user's needs, providing highly relevant and personalized responses. This combination ensures that abstract or complex data is translated into practical, easily graspable insights, thereby bridging the gap between theoretical knowledge and practical application, as seen in sectors like circularity in construction.

Consultants in circular construction projects should utilize ChatGPT to address their own knowledge contextualization challenges, but they should also extend this process to their collaborating stakeholders. To ensure the documents they provide are appropriately tailored, consultants can take some steps to address the issues of poor knowledge contextualization for stakeholders with varying levels of expertise. First, consultants need to provide ChatGPT with detailed information about each stakeholder's level of expertise, roles, and specific tasks. This helps resolve misalignment with expertise and the complexity of the information by adjusting the content accordingly. For example, for stakeholders with less technical expertise, consultants can instruct ChatGPT to simplify complex information and avoid excessive technical jargon, whereas, for expert stakeholders, more detailed and advanced content can be generated. Second, to minimize information overload and ensure clarity, consultants should input details about the specific tasks and responsibilities of stakeholders. This enables ChatGPT to create task-specific summaries, focusing on the most relevant information, which helps reduce unnecessary content and aligns the communication with each stakeholder's immediate needs. Additionally, addressing the lack of contextualization, consultants can ensure that documents are tailored by giving ChatGPT context about the current project, sector-specific knowledge, and ongoing tasks, allowing it to produce content that is directly applicable to the stakeholder's situation. This dynamic contextualization step is crucial to making the information actionable and understandable, helping stakeholders apply circularity principles effectively in their roles. By following these steps, consultants improve the clarity, relevance, and alignment of information, ultimately enhancing stakeholder comprehension in circular construction projects.

The analysis reveals that the primary challenges in understanding and processing technical documents and policies revolve around complexity, information overload, misalignment with expertise, and lack of contextualization. Addressing this issue in a faster way than it is already

been handled is an important step for the integration of ChatGPT in the circular construction industry and will provide many benefits to the workflow process of the organization. The possibility of ChatGPT in coping with these deficiencies provides a significant opportunity for consultants to enhance the communication between stakeholders and promote more circular ambitions in the construction industry. The results of the analysis also underscore which concepts the training of the stakeholders should be focused on, differentiating between more and less experienced consultants and consultants and their collaborating stakeholders.

5.2 Rectifying Resources and Produced Setbacks

Based on the interviews, four critical resources have been identified for addressing and rectifying deficiencies in circular construction projects. This section is significant for the creation of the guidelines, as the recognition of the adverse conditions of the current way of knowledge contextualization helps convince the stakeholders that a change is necessary.

Time emerged as the most frequently mentioned resource. Participants emphasized the necessity of substantial time investments to hold follow-up meetings and ensure all stakeholders are aligned. One participant noted that they invest considerable time in holding follow-up meetings and organizing sessions to ensure that all stakeholders are on the same page. Additionally, the complexity of the process was highlighted, indicating that it takes a lot of time for corrections and clarifications, which further complicates the process. In the time resource, two more mentioned sub-resources can be incorporated: stakeholder guidance and training. Stakeholder guidance is crucial for project success. Enthusiastic and committed stakeholders positively impact outcomes (Węgrzyn & Wojewnik-Filipkowska, 2022). Stakeholder training is necessary for improving the value chain (Michalski & Cousins, 2000). Training enhances stakeholders' understanding and capability to implement circularity principles effectively. It is essential for raising awareness and understanding of circularity principles among employees, managers, and other stakeholders. Training programs help also develop the necessary skills and competencies required to identify and implement circular opportunities (Klein et al., 2021b). However, the current way this training is provided to the stakeholders is very time-consuming for the consultants and all the participants who mentioned this resource concluded that a more effective method of educating the stakeholders is necessary.

Extra financial costs were identified as a significant resource. A participant pointed out the dual challenge of managing both time and financial constraints, mentioning that they have very limited resources and money can also be an issue but to a lesser extent. All of the participants agreed that figuring out a solution to minimize these extra financial costs would improve the efficiency of their companies.

The impact of deficiencies on circular projects was analyzed based on the interview responses, and several key effects were noted. Increased project timelines and costs were the most frequently mentioned effects. These issues arise from a lack of understanding of circularity principles among stakeholders, leading to additional time and resource expenditures. These deficiencies can significantly slow down the project timeline and increase costs (Durdyev & Hosseini, 2019). When stakeholders do not fully understand the circularity principles or how to implement correct reuse strategies, it leads to delays as they spend additional time on clarifications.

Sub-optimal solutions were another significant theme. Sub-optimal reuse of materials often

results from the improper assessment and integration of reclaimed materials, compromising the quality and sustainability of the project (Parigi, 2021). Participant 2 noted that in some cases, it can also result in suboptimal reuse of materials where the potential benefits of circularity are not fully realized. For example, if the reclaimed materials are not properly assessed or integrated, it can compromise the quality and sustainability of the project.

The lack of proper implementation of projects was also highlighted as a concern. Many circular projects remain theoretical and are not fully implemented, which is a significant barrier to achieving the full benefits of circularity (Klein et al., 2021). Participant 5 stated that most of the projects do not really happen and are just nice projects that never get fully implemented as circular projects.

Loss of circular ambitions during planning was also noted. Circular ambitions are often lost during the planning and review phases due to time constraints and escalating costs (Hoogenstrijd, 2019). Participant 8 pointed out that the plans are not always correct and some circular ambitions get lost. That happens because they are not good at planning, but it is also possible that during the whole review process, too much time is lost.

In conclusion, the analysis highlights many adverse setbacks to implementing circularity principles due to poor knowledge contextualization and recognizes the additional resources for rectifying these difficulties. Consultants and their collaborating stakeholders face substantial challenges, including the complexity and technicality of documents, information overload, misalignment with expertise, and lack of contextualization. These issues lead to increased project timelines, higher costs, sub-optimal solutions, and the loss of circular ambitions during planning. To address these setbacks, organizations must invest considerable time in follow-up meetings, stakeholder guidance, and training sessions to ensure all parties are aligned and informed. Financial resources are also crucial, as managing both time and monetary constraints can strain project execution and sustainability efforts. The current consultation methods in circular construction projects need significant improvement to enhance communication and understanding among stakeholders. ChatGPT presents a promising solution to these challenges. By leveraging its advanced features for knowledge contextualization, ChatGPT can streamline the dissemination of information, provide tailored insights, and facilitate a better understanding of complex technical documents. This technology can bridge the knowledge gaps, offering precise and accessible information to all stakeholders, ultimately leading to more efficient and successful circular construction projects. Recognizing the need for the utilization of this tool for this specific purpose and the benefits it can provide in minimizing the utilized resources and in tackling the setbacks of poor knowledge contextualization is a significant step toward the smooth integration of it into the circular construction sector.

5.3 Familiarity with ChatGPT and willingness to utilization

This section will delve into the interviewees' familiarity with ChatGPT and assess their knowledge of the diverse capabilities of this tool. While ChatGPT is increasingly integrated into various professional workflows, the current usage applications suggest that users have a narrow understanding of its full potential, particularly in the area of knowledge contextualization. The interview findings reveal that while professionals in the circular construction sector employ ChatGPT for tasks such as writing support, summarization, and idea generation, they don’t grasp the full scope of its capabilities.

The responses indicate that most users leverage ChatGPT for relatively straightforward tasks—organizing documents, generating presentations, or managing project-related communications. For instance, several respondents highlighted their reliance on ChatGPT for drafting and structuring work or summarizing large volumes of text. However, the more advanced capabilities of ChatGPT, such as deep knowledge synthesis, contextual analysis, and advanced data generation, remain underutilized.

This limited scope of application suggests that many users are not fully aware of ChatGPT's potential to contextualize and integrate diverse pieces of knowledge to inform decision-making or enhance strategic thinking. The answers of the participants encapsulate this trend, reflecting a broader hesitation or lack of understanding regarding the tool's ability to move beyond basic content production to more context-driven applications.

The willingness of the interviewees to adopt ChatGPT for knowledge contextualization reveals a strong interest in exploring its broader applications, particularly in enhancing communication and understanding within their professional contexts. While the current usage of ChatGPT has been confined to tasks like writing support and summarization, the feedback from participants indicates a growing recognition of its potential to contribute to more complex processes, such as tailoring information to diverse audiences and explaining complex concepts. Despite some skepticism, mainly from more experienced and older respondents, the overall view among interviewees is positive, with many expressing a desire to learn more about ChatGPT's capabilities and integrate it more deeply into their work

The underuse of ChatGPT for knowledge contextualization points to a critical need for increased education and awareness about the tool's full range of affordances. As AI continues to evolve and integrate into professional environments, helping users expand their understanding and utilization of this tool will be essential in maximizing their potential. In particular, sectors that rely heavily on complex, interconnected information—like circular construction—stand to benefit significantly from a more comprehensive adoption of AI capabilities, including those that go beyond surface-level tasks.

5.4 Concerns about ChatGPT

This section explores the most significant concerns raised by participants regarding the integration of ChatGPT into company workflows. These concerns highlight the challenges that must be addressed to ensure a smooth and effective adoption of AI technology, which is also the aim of the guidelines development. The key concerns are categorized and discussed below.

Security and data safety emerged as critical concerns, particularly when integrating ChatGPT into workflows involving sensitive information. Participants expressed worry about the potential for compromised sensitive data, leading to confidentiality breaches, improper user data use, and sharing user information with third parties without sufficient safeguards (Leboukh et al., 2023). To address these concerns, companies could implement differential privacy techniques to add noise to data, reducing the risk of reverse-engineered sensitive information, restricting AI access to sensitive information, and conducting regular audits of AI data handling practices to ensure compliance with security standards (Derner & Batistič, 2023). Furthermore, essential to tackle this risk is to train the employees utilizing this tool to have the necessary knowledge of the prohibited documents that cannot be uploaded in ChatGPT. This approach would help mitigate the risks associated with data breaches and

enhance trust in AI systems.

The reliability and accuracy of the information provided by ChatGPT were among the most frequently mentioned concerns. Participants noted the need for continuous verification of AI-generated outputs to ensure they meet company standards. The potential for ChatGPT to produce inaccurate or misleading information poses a significant barrier to its adoption depending on the domain (Tanaka et al., 2023). On the domain of circularity, ChatGPT may struggle as it is a continuously developing concept that has started to find support in the construction sector over the past few years. To mitigate this risk, organizations might establish a verification process where human experts review AI outputs before they are used in critical decisions. Additionally, investing in ongoing AI training and updates could improve the accuracy of the system, reducing the need for constant oversight (Shen et al., 2023).

Concerns about over-reliance on AI, potentially leading to a reduction in critical thinking skills, were also prominent. The convenience and speed of obtaining information from ChatGPT may make users overly dependent on the tool. This dependence could result in users gradually losing their critical thinking skills, as they might stop evaluating the accuracy, logic, and sources of the information provided by the ChatGPT (Haleem et al., 2022b). To counteract this, companies should encourage a balanced approach, using AI to complement rather than replace human decision-making. The users must maintain their critical thinking skills when evaluating information, as the convenience offered by ChatGPT should not replace the need to assess the validity and reliability of the content they receive. Incorporating human oversight in the review and validation of AI-generated content is a supporting measure to this concern, ensuring accuracy and preventing blind trust in the outputs. Additionally, educating users about the limitations of ChatGPT and encouraging them to cross-check information with other reliable sources can help reduce overreliance (X. Wu et al., 2023). Finally, implementing context-aware filtering mechanisms further aids in guiding users to utilize ChatGPT as a supplement rather than their primary source of information.

The challenge of adapting AI tools to be user-friendly for all employees, particularly those less familiar with technology, was another key concern. Some participants highlighted the need for comprehensive training and support to ensure complete integration of AI tools across diverse user groups. To address this, companies could offer tailored training programs, develop user-friendly guides, and provide ongoing technical support. These efforts would help build confidence and competence among all employees, facilitating a smoother transition to AI-assisted workflows.

Ethical concerns, especially regarding the potential misuse of AI, were also noted. Participants expressed caution about the transparency of AI training data and the implications for data privacy. These concerns emphasize the importance of developing clear ethical guidelines for AI use. Companies should ensure transparency and accountability in how AI systems are trained and conduct regular ethical reviews to assess the impact of AI on many sensitive areas (Stahl & Eke, 2024). Another measure that should be taken into consideration is implementing impact assessment to ensure that ChatGPT is utilized appropriately within the companies (Guleria et al., 2023). By adopting ethical AI deployment practices, organizations can address these concerns and foster trust in their AI initiatives.

The environmental impact of AI was a unique concern raised by one participant, reflecting a growing awareness of the sustainability challenges associated with advanced technologies. The significant computing power required for AI operations was highlighted as a potential

issue. However, this is an issue that cannot be tackled within the organizations that aim to utilize ChatGPT as a tool for enhancing knowledge contextualization and would not be taken into consideration during the creation of the guidelines.

In conclusion, while the integration of ChatGPT presents various opportunities for enhancing efficiency and innovation, several significant concerns must be addressed to ensure its successful adoption. Security and data safety, reliability, over-reliance on AI, adaptability, ethical considerations, and environmental impact are key issues that organizations need to address. By addressing these concerns through strategic planning, training, and ethical practices, companies can effectively leverage ChatGPT while minimizing risks and ensuring integration into their workflow processes.

5.5 Difficulties for integration of ChatGPT

Integrating new technology, such as ChatGPT, into organizations presents several challenges that need careful consideration. These challenges include the need for comprehensive training, overcoming resistance from experienced staff, securing management approval and support, ensuring smooth integration with existing systems, keeping pace with rapid technological advancements, and managing resource constraints.

One of the primary challenges is ensuring that all stakeholders possess the necessary knowledge and skills to use the new technology effectively. This is particularly important because a disbalance in technological proficiency can create bottlenecks in the integration process (Helpman & Rangel, 1998). Some employees may be highly adept at using the new tools. In contrast, others, especially those with several years of experience in the circular construction sector and who have learned to implement this process in a certain way, may struggle. Addressing this requires the implementation of extensive and ongoing training programs tailored to different levels of expertise and familiarity with this AI tool. These programs may differ based on the age of the employees, as older adults may require specific types of training to address their unique cognitive needs.

Another significant barrier is resistance from experienced staff, who may be hesitant to adopt new technologies. This reluctance often stems from a lack of familiarity and comfort with the new tools, which can be perceived as a threat to established workflows and expertise (Holmes & Schmitz, 1995). Organizations must foster a culture of continuous learning and change management to mitigate this. This involves communicating the benefits of the new technology clearly and involving experienced staff in the decision-making and implementation process. By doing so, their concerns can be addressed, and they can be encouraged to see the new technology as an enhancement to their existing skills rather than a replacement. Another similar and critical issue is securing management approval and support for the successful adoption of new technologies. Without buy-in from senior leadership, even the most promising technological initiatives may not be adopted. To address this, it is essential to present a compelling case that outlines the strategic benefits of the new technology, such as improved efficiency, cost savings, or competitive advantage. Demonstrating how the technology aligns with the organization's goals and objectives and mitigates the inefficiencies that poor knowledge contextualization creates can help gain management's approval and support.

Ensuring that new technology integrates with existing systems is another challenge. This process can be complex and time-consuming, particularly if the new technology operates on

fundamentally different principles from the current systems (Delaney & D'Agostino, 2015). To address this, thorough planning and coordination are necessary. This might involve conducting a detailed assessment of existing workflows, identifying potential friction points, and developing a phased implementation plan that allows for gradual integration and minimizes disruptions.

The rapid pace of technological evolution adds another layer of complexity. As new advancements in AI and related technologies occur frequently, organizations must remain agile and adaptable. This requires a commitment to continuous learning and staying informed about the latest developments. Organizations might need to establish dedicated teams or partnerships focused on monitoring and evaluating emerging technologies to ensure they are not left behind and their employees are continuously updated about the new features of this AI tool. Lastly, resource constraints, such as time and budget limitations, can hinder the integration of new technologies. Addressing this requires informed decision- making. ChatGPT is a tool that is affordable for most organizations to use and can minimize the existing financial resources used to rectify the miscommunications between consultants and stakeholders.

In conclusion, while integrating new technologies like ChatGPT into organizations presents significant challenges, these can be effectively addressed through comprehensive training, cultural shifts, strategic planning, and continuous adaptation. Organizations can overcome these barriers by taking a proactive approach and fully realizing the benefits of new technological innovations.

5.6 Rationale behind the need for the creation of the guidelines

This chapter serves as a crucial transition between the discussions of key findings identified during the interviews and the development of the corresponding guidelines aimed at addressing possible integration issues. Through a thorough analysis of findings related to knowledge management, stakeholder engagement, and the integration of circularity principles, it becomes evident that these challenges require innovative, technology-driven solutions. The chapter outlines the rationale behind each step of the guidelines, illustrating how ChatGPT can be smoothly integrated into the workflow process of organizations to tackle poor knowledge transfer. This chapter sets the foundation for practical solutions that enhance efficiency, sustainability, and collaboration within circular construction projects by bridging the gap between the identified barriers and actionable recommendations.

Initially, the problem discovered in the findings is evident that a more effective method of knowledge transfer is essential. These were frequent barriers to successful knowledge transfer and circular construction implementation. Information overload and complexity were common issues in technical documents, making it difficult for stakeholders to extract relevant insights. Misalignment with expertise further complicated this, as stakeholders with different knowledge levels struggled to engage with the material. This led to the guideline steps focusing on identifying specific challenges and aligning knowledge-sharing strategies with the expertise level of each stakeholder.

Next, the assessment step is directly connected to the rectifying resources identified in the findings, such as time and financial constraints, as well as the need for stakeholder guidance and training. The time-intensive process of aligning stakeholders through multiple meetings and continuous clarifications underscored the importance of creating efficient workflows and minimizing resource usage. Participants expressed the need for a more streamlined and

effective method of transferring the necessary knowledge to stakeholders on circular visions and objectives. A thorough analysis of the existing knowledge transfer is essential to allocating the deficiencies and acknowledging the usefulness of ChatGPT in minimizing them.

Findings around increased project timelines and costs, sub-optimal solutions, lack of proper implementation of projects, and loss of circular ambitions drive the KPI and monitoring steps. These findings highlighted the need for consistent monitoring and evaluation to implement circularity principles properly. By setting clear KPIs, such as accuracy of information, comprehension levels among stakeholders, and resource optimization, organizations can ensure that the integration of ChatGPT is aligned with project goals, improving the current way of knowledge transfer, and addressing these setbacks as a result of enhanced knowledge comprehension.

Moreover, the findings around resistance from experienced staff and management approval necessitate a change management and stakeholder engagement strategy in the guidelines, with a focus on securing management approval and support for scaling up the technology by clearly communicating the benefits of ChatGPT for this process.

The user training and scaling up sections of the guidelines are rooted in concerns about over-reliance on AI, security issues, and the fast-paced evolution of the tool. To mitigate risks associated with reliability, accuracy, reduced critical thinking, or dependence on AI, training is necessary, to ensure that stakeholders can critically evaluate AI outputs and effectively use the tool in their workflows so that ChatGPT can be ingrained and scaled up in more projects.

Testing and validation is also a critical step in ensuring that AI tools perform accurately and ethically within specific industry contexts. These processes verify the reliability of AI outputs and assess the tool's ability to handle domain-specific knowledge, which is particularly important in sectors like circular construction. Furthermore, testing is vital in addressing ethical concerns, such as transparency and accountability, by ensuring that the AI's decision-making processes are clear and traceable. Validation helps ensure that AI-driven knowledge transfer does not introduce biases, misinformation, or obscure reasoning, fostering trust among stakeholders and maintaining ethical standards in AI deployment. Finally, because circularity includes very sector-specific knowledge, terminology, and workflows, an imperative step in the guidelines is the ChatGPT adaption to the circularity context. This customization improves the relevance and accuracy of the AI's outputs,
enabling it to provide more precise guidance and contextualized information tailored to the unique challenges of circular construction projects.

In summary, each phase of the guidelines was a direct response to the findings of the study. The structured approach ensured that identified challenges were systematically addressed, leading to a smoother integration of generative AI in circular construction practices.

Table 13: Guidelines development

No.	Findings	Guideline step
1	Information overload	Problem
2	Complexity and technicality	Problem
3	Misalignment with expertise	Problem
4	Lack of contextualization	Problem
5	Time	Assessment
6	Money	Assessment

7	Stakeholder guidance	Assessment
8	Stakeholder training	Assessment
9	Increased project timeline and costs	KPI/ Monitor-Evaluate
10	Sub-optimal solutions	KPI/ Monitor-Evaluate
11	Lack of proper implementation of projects	KPI/ Monitor-Evaluate
12	Loss of circular ambitions during planning	KPI/ Monitor-Evaluate
13	Security issues and data safety	Assessment/ user training
14	Reliability and accuracy of information	User training/ KPI/ Monitor-Evaluate
15	Over-reliance on AI and reduction in critical thinking	User Training
16	Unfamiliarity with using AI prompts	User Training
17	Ethical considerations	Testing - Validation
18	Environmental impact	(Concern that should be addressed by the developing company, not by users)
19	Training and skill development	User Training
20	Resistance from experienced staff	Change Management
21	Management approval and support	Change Management
22	Integration with existing systems	Scaling up
23	Fast-paced of the evolution of this tool	Scaling up
24	Resource constraints (time)	Assessment

5.7 Comparison of ChatGPT and other Generative AI tools

In the landscape of generative AI, ChatGPT, and other generative tools offer distinct capabilities that play unique roles in knowledge contextualization. While ChatGPT excels in natural language processing and conversational interaction, other generative tools like DALL-E, Midjourney, and Stable Diffusion offer specialized features that enhance contextualization through multimodal and industry-specific outputs.

Other generative AI tools provide added value in contextualization by integrating visual outputs, handling real-time data, and offering precision for specific domains. Tools such as DALL-E and Midjourney specialize in creating images from text prompts, making them invaluable for visually conveying complex concepts (Marcus et al., 2022). For instance, in technical fields like construction or engineering, where stakeholders benefit from visual schematics, these tools can generate detailed images that clarify otherwise abstract or intricate information (Zhou & Nabus, 2023). While ChatGPT can generate images, this functionality is less advanced than the specialized generative tools mentioned (Aydın & Karaarslan, 2023). A concept like circularity, often difficult to grasp through text alone, becomes more accessible when depicted visually, illustrating how visual tools enhance understanding and engagement in knowledge contextualization.

Real-time data processing is another significant advantage offered by generative AI tools such as Stable Diffusion. Known primarily for its text-to-image generation, Stable Diffusion integrates with real-time data sources, making it suitable for knowledge contextualization in environments that demand continuous updates (S. Lee et al., 2023). In sectors like environmental monitoring or construction, where variables such as material usage change frequently, Stable Diffusion can visually represent this data, allowing stakeholders to contextualize knowledge based on the latest project conditions (Cao et al., 2024). This real-time adaptability offers a level of immediacy that makes contextualized knowledge highly relevant and actionable.

In conclusion, while other generative AI tools such as DALL-E, Midjourney, and Stable Diffusion bring valuable enhancements to knowledge contextualization through multimodal integration, real-time adaptability, and domain-specific tuning, ChatGPT stands out for its versatility in language synthesis and its conversational, adaptable interface. This positions ChatGPT as a uniquely flexible tool for cross-disciplinary, real-time knowledge contextualization, where simplicity, accessibility, and responsiveness are crucial. Together, these tools offer a comprehensive suite of generative AI capabilities, each supporting knowledge contextualization through complementary strengths.

6. Guidelines development

The integration of ChatGPT into organizational workflows represents a significant opportunity to enhance efficiency, improve knowledge management, and foster innovation. However, to realize its full potential, it is essential to develop comprehensive guidelines ensuring smooth and effective integration. Based on the discussions outlined in this thesis, this section will provide a framework for creating these guidelines, addressing the challenges and considerations necessary for successful implementation.

The thesis' discussions highlight key areas where ChatGPT may provide solutions but also where organizations may face difficulties, such as aligning ChatGPT's capabilities with existing processes, addressing security and privacy concerns, and ensuring that employees are adequately trained and comfortable with the new technology. Additionally, it underscores the importance of tailoring the use of ChatGPT to the specific needs of the organization and its stakeholders, ensuring that it serves as a tool to enhance, rather than complicate, existing workflows.

This section will explore best practices for integrating ChatGPT into organizational processes, focusing on strategies for overcoming potential barriers, optimizing the technology's use, and creating a supportive environment for its adoption. For the development of the guidelines, the key findings of the thesis played a pivotal role. The literature provided a comprehensive understanding of different technology integration frameworks, focusing more on the construction sector. By examining these frameworks, the research identified successful strategies and steps that have been applied to similar challenges. These literature findings were crucial in addressing the concerns raised by interviewees and ensuring the successful integration of this tool. The guidelines were crafted by incorporating solutions from the literature that aligned with the specific needs and barriers identified during the interviews. This ensured that the final recommendations not only tackled theoretical challenges but also provided practical, evidence-based steps for integrating Generative AI to enhance circularity in the construction industry.

After all the interviews were conducted, a draft of the guidelines was sent to each participant for their review to validate the result. Each participant then provided their feedback, which was considered for developing the final guidelines. This validation process explores whether the research accurately represents the participants' concerns and experiences, helping to bridge the gap between the researchers' theoretical interpretations and their practical insights (Buchbinder, 2010).

The guidelines described in this chapter are primarily designed for intra-organizational use. They focus on integrating ChatGPT into the workflows within individual organizations, particularly those in the circular construction sector. The emphasis is on improving internal knowledge contextualization processes, training consultants, and aligning processes with circularity goals. Although the guidelines consider interactions with various stakeholders, the guidelines are mainly about improving efficiency, knowledge management, and contextualization within the organization, making them a tool for enhancing intra-organizational operations. The guidelines are divided into three sections: preparation, pilot, and development. By following these guidelines, organizations can leverage ChatGPT's capabilities to enhance knowledge contextualization, streamline communication, and achieve more effective and efficient operations. An overview of these guidelines can be seen in Figure 7.

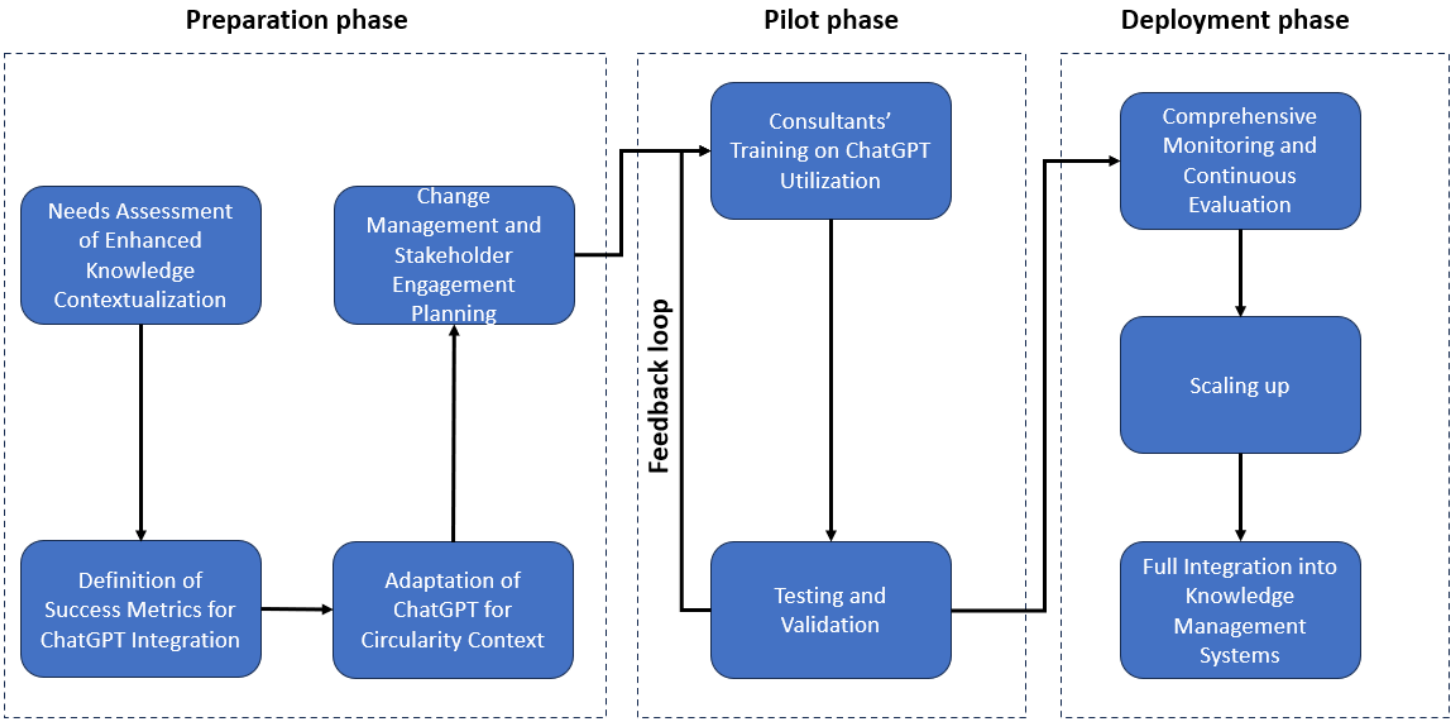

Figure 7: Guidelines for smooth integration of ChatGPT

6.1 Preparation phase

6.1.1 Needs Assessment of Enhanced Knowledge Contextualization

The first step in creating effective guidelines for the utilization of ChatGPT in enhancing knowledge contextualization within circular construction projects is the recognition for the need for an improved knowledge transfer process. This step is foundational, as it sets the stage for the entire process, ensuring that the specific needs of the circular sector are identified and that the objectives align with those needs.

One of the primary needs identified is the necessity for more effective knowledge contextualization tailored to the specific knowledge level of each stakeholder. The interviews revealed that a significant barrier to the successful implementation of circularity principles is the lack of understanding among stakeholders due to four different reasons. This deficiency has led to substantial setbacks, including increased project timelines and costs, sub-optimal solutions, and the loss of circular ambitions during the planning stages.

The complexity of circular construction projects demands a high level of stakeholder alignment, which requires considerable time investments for follow-up meetings, guidance, and training. The current approach to training and information dissemination is time-consuming and often ineffective, as it does not account for the varying levels of expertise among stakeholders. The recognition of the produced setbacks is crucial for convincing consultants that the utilization of ChatGPT in the current approach to knowledge contextualization is necessary. By tailoring the information to the specific needs and roles of each stakeholder, ChatGPT can reduce the time and resources required for stakeholder alignment and training, ensuring that each participant has access to the contextualized knowledge necessary for their role.

While ChatGPT has the potential to revolutionize knowledge management in circular construction, its integration comes with specific challenges, particularly concerning data privacy and security. Given the sensitivity of many construction documents, not all data can be processed by AI tools. A thorough assessment is required to identify which types of documents are suitable for AI processing. Sensitive information, such as proprietary or confidential data, should be excluded to mitigate any potential risks associated with data breaches or misuse. Establishing robust data governance frameworks and security protocols is essential to ensure the safe and ethical integration of AI technologies into organizational workflows.

After identifying the needs and suitable documents, the next step is to establish clear and measurable objectives for integrating ChatGPT into circular construction workflows. These objectives should focus on enhancing the efficiency of knowledge contextualization, reducing the time required for stakeholder training, and improving the overall understanding of circularity principles among all project participants. Specific goals could include:

- Improving Stakeholder Alignment: Use ChatGPT to tailor training materials and project updates to the specific roles and expertise levels of each stakeholder, thereby reducing the need for repeated follow-up meetings and clarifications.
- Reducing Financial Costs and Timelines: By streamlining the knowledge dissemination process, organizations can significantly lower the costs associated with training sessions and project delays.
- Minimizing Sub-Optimal Solutions and Loss of Ambition during Planning: Ensuring that all stakeholders have a clear and comprehensive understanding of the reuse strategies implemented in each project will help formulate solutions that better align with the project's sustainability goals.

This assessment ensures that the technology aligns with the organization's goals and adds value rather than creating unnecessary complexities or inefficiencies (Shaw et al., 2018b). By setting clear, actionable goals, organizations can ensure that the integration of ChatGPT not only addresses the immediate challenges but also contributes to the long-term success of reusing materials in circular construction projects. A possible use case could involve ChatGPT assisting in compliance by providing stakeholders with context-specific guidance on regulatory requirements and best practices for implementing reuse strategies.

In conclusion, the Needs Assessment of Enhanced Knowledge Contextualization is a critical first step in the development of guidelines for using ChatGPT in circular construction projects. It ensures that the specific challenges faced by stakeholders are recognized and addressed through targeted, effective solutions, while also safeguarding sensitive information through careful document selection.

6.1.2 Definition of Success Metrics for ChatGPT Integration

Defining Key Performance Indicators (KPIs) is crucial to effectively measure the impact of changes on productivity and knowledge transfer within circular construction projects. KPIs serve as quantifiable metrics that allow organizations to assess the efficiency and success of implemented strategies. During the integration of a new technology in the workflow process of a company it is imperative to measure continued technology use effectively. KPIs play a critical role in assessing the success of technology integration by tracking the consistent use of new systems and the achievement of desired outcomes (Braglia et al., 2022b). These

metrics allow organizations to assess whether the technology effectively integrates into daily operations, enhances performance, and satisfies user motivations. Without such measurements, organizations risk underutilizing the potential of new technologies or failing to recognize when a technology might need further adaptation to meet the needs of its users (Velimirović et al., 2011). Below are three suggested KPIs and their relevance based on the thesis findings:

1. Error Rate of AI-Generated Content (Measuring the Accuracy of the Produced Output): The error rate is a critical KPI for evaluating the accuracy of outputs generated by ChatGPT in circular construction projects. As the thesis highlights, maintaining the reliability and precision of AI-generated information is paramount to ensuring that stakeholders receive accurate, context-specific data. This is particularly crucial when Generative AI is used for knowledge contextualization in a sector as complex as circular construction, especially in the context of reusing materials, where mistakes might be proven crucial for the enhancement of circularity. A low error rate indicates that ChatGPT's sector-specific adaptations are effective, reducing the risk of misinformation and enhancing trust in AI outputs.
2. Stakeholder Comprehension Level (Measuring the Efficiency of the Utilized Method): This KPI is designed to measure how well stakeholders understand the information and reuse methodologies shared with them. The current methods of disseminating circularity knowledge are often generic and not tailored to the diverse expertise levels of stakeholders. By leveraging the adaptive learning and fine-tuning capabilities of ChatGPT, information can be customized to meet the specific needs of different stakeholders. Improved comprehension levels would reflect the success of AI in enhancing the understanding of circular principles among various project participants, a key factor in the successful implementation of circularity.
3. Resource Optimization Rate (Measuring the Reduction in Rectifying Resource Usage Due to the Implementation of the New Method): Resource optimization is another critical KPI, particularly in circular construction, where extra time, financial resources, and stakeholder training are often needed. The thesis highlights that substantial time investments are currently required for follow-up meetings and training sessions to familiarize stakeholders with the utilized reuse strategy, which is essential but also resource-intensive. By measuring the reduction in resource usage, this KPI would help determine whether the new method of knowledge contextualization and sharing is leading to more efficient use of resources. A higher resource optimization rate would indicate that less time and money are being spent on aligning stakeholders, thus freeing up these resources for other essential tasks within the project.

In summary, these KPIs are directly aligned with the challenges identified in the findings and are designed to measure the impact of new strategies on improving productivity and knowledge contextualization in circular construction projects. By focusing on accuracy, stakeholder comprehension, and resource optimization, organizations can ensure that they are moving toward more efficient and sustainable practices by tracking down if the rectifying resources are minimized. Furthermore, the creation of these KPIs is significant at the later stage of testing and validation.

6.1.3 Adaptation of ChatGPT for Circularity Context

To effectively integrate ChatGPT into the circularity context of the construction industry,

customization, and continuous training are critical. This step involves three key sub- processes: tailoring the model to understand domain-specific terminology, training it with relevant data, and ensuring ongoing updates to keep pace with the evolving field of circularity.

Circularity within the construction industry is a specialized domain with its own set of terminologies and stakeholder expectations, including architects, engineers, contractors, and policymakers. For ChatGPT to provide relevant insights, it must be customized to understand the unique language and priorities of these stakeholders. This can be achieved through few-shot learning techniques, which allow the model to perform well with limited data, a common scenario in niche applications like circularity (Kim & Lu, 2024). By integrating stakeholder perspectives and needs into the customization process, the model can better address the challenges and opportunities identified by different actors in circularity.

The scope of this research focuses on the reuse strategy, a core component of circularity in construction. Training ChatGPT with relevant data—including case studies, best practices, and real-world examples of reusing materials—can significantly enhance its contextual understanding. For instance, use cases involving the reuse of building materials, adaptive reuse of structures, and lifecycle assessments should be included in the training datasets. These practical examples not only help the model understand specific terminologies but also illustrate the application of circularity principles in construction projects, making it more effective in generating actionable insights (Tanaka et al., 2023).

To ensure comprehensive adaption, it is crucial to include datasets comprising industry-specific documents, research papers, and regulatory guidelines related to reuse strategies. Incorporating these elements enables the model to learn not only the specific terminology but also the relationships and principles that govern circularity in construction. This approach ensures that ChatGPT can serve as a reliable resource for industry stakeholders by providing accurate and contextually relevant information.

The dynamic nature of circularity in the construction industry necessitates continuous updates to the AI model to incorporate the latest developments in reuse strategies, innovative reuse techniques, and shifts in regulatory frameworks (Shen et al., 2023). Ongoing training and updates should be guided by feedback from domain experts and stakeholders to ensure that the model remains aligned with current industry standards and practices.

For example, recent advancements in material reuse and new regulatory requirements for circularity must be integrated into the model's knowledge base. This process not only keeps the AI up-to-date but also helps in mitigating the risk of producing outdated or irrelevant information. By continuously adapting to new information and stakeholder feedback, ChatGPT can provide insights that are both accurate and timely, reducing the need for constant human oversight and verification.

In summary, the customization and training of ChatGPT for circularity in the construction industry involve a systematic approach to tailoring the model to domain-specific terminology, training it with relevant and up-to-date data, and ensuring its continuous adaptation to new information. These steps are critical in addressing the concerns of accuracy and reliability, ultimately enhancing the model's effectiveness in supporting reuse strategies in construction.

6.1.4 Change Management and Stakeholder Engagement Planning

The successful integration of Generative AI into an organization, particularly within the

context of a circular economy, requires a comprehensive change management strategy that not only addresses potential concerns and barriers to adoption but also aligns with the organization's reuse strategies and engages key stakeholders. A primary challenge in this process is the resistance from experienced staff members, who may be hesitant to embrace new technologies due to a lack of familiarity and discomfort with altering established workflows. This reluctance can be exacerbated by fears that these technologies might undermine their expertise or render their skills obsolete, posing a significant barrier to successful implementation. (Holmes & Schmitz, 1995).

To effectively correlate circularity, stakeholders, and AI, it is crucial to illustrate how ChatGPT can support the reuse and optimization of existing resources and knowledge within the organization. For instance, by automating routine knowledge contextualization tasks, ChatGPT can help repurpose organizational insights and foster a more circular use of information, aligning with the principles of circularity. This approach not only enhances operational efficiency but also contributes to sustainable practices by reducing the need for redundant processes and enabling the reuse of valuable intellectual assets.

Fostering a culture of continuous learning and active stakeholder engagement is essential to overcoming employee resistance. This can be achieved by clearly communicating the benefits of ChatGPT in specific, relatable terms that align with the employees' current roles and tasks. For example, demonstrating how ChatGPT can automate mundane tasks, such as report generation or customer query responses, allows employees to allocate more time to strategic, creative, or higher-value activities, positioning the technology as an enabler rather than a disruptor. Moreover, involving experienced staff in the decision-making and implementation processes can significantly reduce resistance. By actively participating in the integration of ChatGPT, these employees are more likely to feel a sense of ownership and control over the change, which helps to mitigate apprehension and foster a more positive attitude towards the new technology (Yager, 2005). Incorporating use cases is another effective strategy to demonstrate the practical applications and benefits of ChatGPT. For instance, in a use case where a consultancy firm aims to implement a reuse strategy in a project, ChatGPT could assist in the analysis and repurposing of design data, thus supporting the circularity goals of the organization. By presenting such specific use cases, organizations can provide a clearer picture of how the technology can be tailored to meet their unique needs and contribute to their overall strategy.

Securing management approval and support is also a critical component of this process. Without strong backing from senior leadership, even the most promising technological initiatives can fail. To gain this crucial support, it is essential to present a compelling case that demonstrates how ChatGPT aligns with the organization's strategic goals, such as enhanced operational efficiency, cost savings, and competitive advantage. For example, by illustrating how the technology can lead to improved efficiency, significant cost savings, or a competitive advantage in the market, leadership can be persuaded of its value.

Furthermore, it is important to showcase successful case studies or pilot projects that demonstrate the tangible benefits of ChatGPT. This evidence can help tackle concerns about the risks associated with adoption and provide a clear, practical example of how the technology can be implemented effectively. By addressing both employee resistance and securing management buy-in through these strategies, organizations can create a more friendly environment for the successful adoption of ChatGPT, ensuring that the technology is

embraced as a valuable asset rather than a disruptive threat.

6.2 Pilot phase

6.2.1 Consultants' Training on ChatGPT Utilization

Given the complexities and potential risks associated with integrating ChatGPT into workflows, user training is a critical component for ensuring the accuracy and reliability of AI-generated outputs. This training must be designed not only to familiarize users with the tool itself but also to equip them with the skills needed to critically assess and verify the information it provides, particularly in the context of circularity and stakeholder engagement. Effective training should emphasize continuous verification of AI outputs, as the reliability of the information provided by ChatGPT is a primary concern, especially in specialized domains such as circular construction. This field requires adherence to principles of resource reuse, sustainability, and collaboration among various stakeholders, all of which can be impacted by the integration of AI (Tanaka et al., 2023).

To address these challenges, training programs must be aligned with the research scope of the organization, particularly the reuse strategy in circular construction. These programs should focus on practical use cases that simulate real-world scenarios, demonstrating how AI can support the identification and evaluation of reusable materials, project planning, and stakeholder coordination. By embedding these use cases into the training, users can better understand how to apply AI outputs in a way that aligns with circularity principles and better stakeholder comprehension. Moreover, the training should guide users on how to provide detailed and relevant inputs to improve the quality of AI-generated outputs. For example, in a circular construction project, specifying the type and condition of reusable materials can lead to more accurate and actionable outputs from ChatGPT. This is crucial because generic inputs often result in abstract outputs that may not be directly applicable to specific projects or stakeholder needs (Y. Liu et al., 2023). The training should thus include strategies for crafting precise queries and interpreting the results in the context of the project's reuse strategy.

Organizations should implement robust training programs that extend beyond basic tool usage, incorporating stakeholder perspectives and circularity considerations. These programs should teach users how to critically evaluate AI outputs against the organization's standards and project requirements, ensuring alignment with the specific needs of their projects. For example, users could be trained to cross-check AI-generated recommendations for material reuse with other reliable sources, such as industry databases or expert consultations, to validate the content. This approach can help mitigate the risk of over-reliance on AI, which may otherwise diminish critical thinking skills and reduce the capacity to effectively collaborate with stakeholders (Haleem et al., 2022b).

Moreover, the training should be tailored to the varying levels of experience among users. For more experienced consultants in the circular construction sector, who may struggle with the misalignment between AI outputs and their expertise, the training should focus on enhancing their ability to navigate and correct AI-generated content that may be overly simplistic or misaligned with the complex realities of their field. Conversely, less experienced professionals, who may face challenges with the volume and technical nature of documents, would benefit from training that helps them understand and apply technical details effectively. This could include strategies for breaking down complex information and integrating AI-generated

content into their workflows without overwhelming them (Hickman et al., 2007).

Security and data safety are also crucial components of the training. Users need to be aware of the potential risks of using AI tools, especially when handling sensitive information. Training should cover best practices for maintaining data security, such as which documents are eligible to be uploaded to ChatGPT, how to anonymize data before inputting it into the AI, and the importance of following company protocols to prevent data breaches. Additionally, users should be informed about the organization's policies regarding AI use, including any restrictions on accessing or sharing sensitive information (Leboukh et al., 2023).

Finally, the training should be an ongoing process. As AI technologies and the fields in which they are applied continue to evolve, so too must the training programs. Regular updates and refresher courses can ensure that all users, regardless of their experience level, remain competent and confident in their ability to use ChatGPT effectively. By continuously adapting the training to address emerging challenges and incorporating feedback from users, organizations can foster a culture of continuous learning and improvement, ultimately leading to more reliable and accurate AI-assisted workflows (Shen et al., 2023).

6.2.2 Testing and Validation

To ensure the successful integration of ChatGPT into organizational workflows with a focus on circularity and stakeholder involvement, it is essential to conduct a small-scale pilot in a controlled environment. This pilot will help identify potential issues early in the process and allow for adjustments before full-scale implementation. The pilot phase should specifically focus on key areas such as data privacy, accuracy, and ethical concerns, while also considering how AI can support reuse strategies and circular business models by engaging relevant stakeholders. This is particularly important given the ethical concerns raised in the thesis, which emphasize the need for transparency in AI training data and the protection of data privacy. Conducting a pilot in a controlled setting allows for a thorough assessment of these ethical considerations and the potential of AI to support circularity goals, ensuring that ChatGPT's deployment aligns with the organization's values, stakeholder expectations, and regulatory requirements (Stahl & Eke, 2024).

During the pilot phase, it is crucial to establish a process for regular validation of ChatGPT's outputs, with a specific focus on how AI can enhance reuse strategies comprehension and contribute to circularity. Given the concerns about the potential misuse of AI and the accuracy of AI-generated content, continuous monitoring is necessary to maintain high standards of output quality. The error rate, as outlined in the thesis, serves as a critical Key Performance Indicator (KPI) in this regard. By regularly measuring and analyzing the error rate, organizations can ensure that the information generated by ChatGPT is reliable, supports sustainable reuse strategies, and aligns with company standards. This ongoing validation process will help mitigate the risks associated with inaccurate or misleading information, fostering greater trust in AI outputs and its contribution to a circular economy. The outputs of ChatGPT should be examined through the predefined KPIs, including metrics that measure its impact on resource optimization and stakeholder comprehension throughout the entire pilot program.

In addition to performance metrics, it is imperative to conduct regular ethical impact assessments, specifically evaluating the role of AI in supporting circularity and stakeholder interests. These assessments should evaluate the broader implications of ChatGPT's deployment, including its effects on data privacy, transparency, and how well it aligns with

reuse strategies. Adopting ethical AI deployment practices can address concerns about the misuse of AI and foster trust in AI initiatives (Guleria et al., 2023). By incorporating ethical impact assessments into the validation process, organizations can ensure that their AI systems are not only effective but also aligned with ethical standards, societal expectations, and circular economy principles.

Implementing a robust feedback loop is critical for the continuous improvement of ChatGPT's performance. Consultants should have multiple channels to provide ongoing feedback. This could be through surveys, direct feedback forms, or meetings dedicated to reviewing ChatGPT's contributions to stakeholders' comprehension of the utilized reuse strategies. Such feedback should be systematically analyzed to identify common challenges and opportunities for refinement, such as adjusting training data to better reflect reuse principles or enhancing user interfaces to improve accessibility.

In summary, the testing and validation phase is critical for ensuring that the integration of ChatGPT is both successful and responsible. Through small-scale pilot testing, regular validation of outputs, performance measurement against KPIs, and ethical impact assessments, organizations can address potential challenges and maximize the benefits of ChatGPT within their workflows, ultimately supporting sustainable reuse strategies and circular business model

6.3 Deployment phase

6.3.1 Comprehensive Monitoring and Continuous Evaluation

A structured monitoring and evaluation process must be implemented to ensure the successful integration and ongoing effectiveness of ChatGPT in enhancing stakeholders' comprehension of the reuse strategies. This step is crucial for continuously aligning ChatGPT's performance with project objectives, making necessary adjustments to optimize its contributions, and monitoring the continuously updated models against the KPIs to ensure its efficiency.

Regular performance assessments should be conducted at predefined intervals, such as monthly or quarterly, depending on the project's complexity and needs. Key performance indicators should not only measure ChatGPT's ability to enhance knowledge contextualization but also its impact on promoting reuse and circularity. For example, monitoring this process can give valuable conclusions for user comprehension ratings, the accuracy of information contextualization, the reduction in reuse knowledge gaps, and the speed at which relevant information is retrieved and applied in reuse scenarios, leading to improvements in project timelines or outcomes. By consistently measuring these indicators, organizations can ensure that ChatGPT effectively supports the project's goals.

Additionally, it is critical to account for the continuous evolution of ChatGPT models, as both improvements and potential drawbacks can arise with each new version. While updates generally enhance functionality, there is a risk that newer models may produce less effective outputs, particularly in specialized fields like knowledge contextualization in the circular construction industry. Therefore, it's important to evaluate these outputs through the aforementioned KPIs. These KPIs—such as error rate, stakeholder comprehension levels, and resource optimization rate—will serve as benchmarks for assessing the tool's performance as it evolves. Regular monitoring using these established KPIs will ensure that the evolving models continue to support reuse strategies implementation effectively. For example, if a

newer version of ChatGPT produces outputs that are misaligned with stakeholder needs or less precise in technical areas, this can be quickly detected through a KPI review. In such cases, corrective actions, such as refining prompts or reverting to previous models, can be taken to maintain the AI's effectiveness in supporting reuse strategies. This ensures that despite the ongoing evolution of ChatGPT, the tool continues to enhance knowledge dissemination without compromising quality.

Transparency in the evaluation process is key. Regular reports should be shared with all relevant consultants, detailing the outcomes of the monitoring and feedback processes. These reports should highlight improvements made, issues encountered, and plans for further refinement. By involving stakeholders in this process, organizations can foster a collaborative environment where ChatGPT's role is continuously optimized.

6.3.2 Scaling up

As the use of ChatGPT expands across more projects and teams following the possible success of the pilot phase, it's crucial to ensure that the integration of this technology is smooth and does not disrupt existing workflows. The process of scaling up should be done gradually, with thorough planning and coordination to mitigate potential challenges. To achieve this, a thorough assessment of existing workflows is necessary to identify areas where ChatGPT can facilitate resource optimization. This assessment should focus on how AI can support stakeholders in implementing reuse strategies, such as repurposing data and insights across different projects, thereby enhancing the comprehension of information flows.

A phased implementation plan is recommended, allowing for the gradual introduction of ChatGPT into various teams and projects. This approach not only minimizes disruptions but also enables a targeted deployment aligned with the specific reuse strategies of each team. For instance, in a new project setting, ChatGPT could be used to optimize knowledge reuse, aiding consultants in drawing on prior findings to inform new projects, thereby reducing redundancy and resource expenditure. Moreover, continuous support for users is crucial during this scaling-up phase. Providing ongoing training tailored to the needs of different teams of consultants ensures that they can leverage ChatGPT effectively to achieve their reuse objectives. This support will help users not only adapt to the new system but also utilize AI to its full potential in promoting sustainable practices and enhancing collaboration across the organization.

6.3.3 Full Integration into Knowledge Management Systems

The last step is the full integration of ChatGPT. In fully integrating ChatGPT into the organization's workflows and systems, it is critical to recognize that while this powerful AI tool can significantly enhance efficiency, accuracy, and knowledge contextualization, human oversight remains imperative throughout the process, as recognized through the literature review on current research on applications of this tool in the construction industry. Human oversight ensures that the outputs generated by ChatGPT are relevant accurate and aligned with the organization's ethical standards, values, and strategic goals. AI should serve as a complement to human expertise, not a replacement. Human professionals must remain actively involved in reviewing and validating the AI's contributions, particularly in complex decision-making scenarios where nuanced judgment and ethical considerations are paramount.

7. Conclusions

7.1 Research questions

The insights gathered from the various sub-questions explored throughout the research aim to answer the main research question of the thesis. These sub-questions have systematically addressed the core aspects necessary to understand how Generative AI, particularly ChatGPT, can enhance knowledge contextualization among stakeholders in the construction industry to promote circularity. The findings from the literature review, coupled with data from interviews, provide a comprehensive understanding of the current state of knowledge management, the challenges faced in knowledge contextualization, the potential affordances of Generative AI, and the practical considerations for its integration into existing construction practices. This section will summarize the key points derived from each sub-question, offering a view of the potential of Generative AI to transform knowledge practices in the construction industry and conclude with the answer to the main research question.

- What is Generative AI's state of the art and its current affordances relating to knowledge management for enhancing circularity in construction projects?

Generative AI, particularly models like ChatGPT, represents a significant advancement in Natural Language Processing with a range of capabilities highly relevant to knowledge management in the context of circularity in construction projects. Currently, the state-of-the-art Generative AI includes features like enhanced contextual understanding, text generation, multilingual adaptability, few- and zero-shot learning and fine-tuning for specific tasks, all of which can significantly improve the management and contextualization of knowledge across multiple stakeholders involved in circular construction projects. These features enable the efficient retrieval, organization, and sharing of knowledge, thereby enhancing the understanding and implementation of circularity principles among stakeholders. By facilitating better knowledge contextualization—tailoring information to fit each stakeholder's specific needs and expertise—ChatGPT can help overcome the significant barriers to adopting circularity in construction, such as lack of awareness and knowledge of circularity practices and the complexity of circular processes. This makes ChatGPT a valuable tool in driving the transition toward more sustainable construction practices by ensuring that critical knowledge is accessible, relevant, and actionable for all involved parties. ChatGPT's affordances each play a crucial role in enhancing knowledge contextualization. Its strong knowledge retrieval capabilities allow users to quickly access relevant information, ensuring that they receive content specifically suited to their needs. Knowledge sharing is facilitated through ChatGPT's ability to generate and disseminate clear communications, making sure that critical insights are effectively distributed across teams. The organization affordance helps structure and categorize data, making it easier to find and apply the right information in the right context. Lastly, ChatGPT’s discovery capabilities help users connect disparate pieces of information, providing a comprehensive view that enhances the relevance and application of knowledge. Together, these affordances ensure that knowledge is not just delivered, but contextualized in a way that makes it more accessible, actionable, and meaningful for specific tasks and stakeholders.

- What are the most influential reasons for poor knowledge contextualization and the produced setbacks in implementing circular projects?

Poor knowledge contextualization in circular projects is primarily driven by four key factors: the complexity and technicality of documents, information overload, misalignment with stakeholders' expertise, and lack of contextualization. The complexity and technicality of documents often overwhelm stakeholders, as they struggle to comprehend detailed reports filled with technical jargon and extensive data. This issue is compounded by information overload, where stakeholders receive more information than they can process, leading to difficulty in extracting relevant insights. Misalignment with expertise further exacerbates the problem, as the technical content of the documents does not match the varying levels of knowledge among stakeholders, leaving them unable to fully grasp the information presented. Lastly, the lack of contextualization means that the information provided is not adequately tailored to the specific needs and tasks of different stakeholders, making it challenging for them to apply the knowledge effectively. These factors result in significant setbacks in implementing circular projects, such as increased project timelines and costs, sub-optimal reuse of materials, and, in some cases, the failure to fully implement circular ambitions.

- What are the concerns associated with the utilization of Generative AI to enable knowledge contextualization?

The concerns associated with the utilization of Generative AI, specifically tools like ChatGPT, to enable knowledge contextualization primarily revolve around issues of security, data privacy, and ethical considerations. Users in the construction industry, where knowledge contextualization is crucial, have expressed their concerns about the integration of such AI tools due to the potential risks of sensitive data being exposed or misused. There is also a concern regarding the reliability of the information generated by these models, as they might produce outputs that are not entirely accurate or contextually appropriate, which could lead to misinformed decisions. Furthermore, ethical issues arise from the dependency on AI for decision-making processes that traditionally require human judgment, which could lead to reduced human oversight and potential biases in AI-generated content. These concerns highlight the need for cautious implementation and robust guidelines to ensure that the use of Generative AI in knowledge contextualization is both secure and effective.

- How can Generative AI be integrated into the existing construction industry practices to facilitate knowledge contextualization?

Integrating ChatGPT into the construction industry to enhance knowledge contextualization requires a structured, step-by-step approach. The first step is Needs Assessment, where the specific gaps in knowledge transfer and the varying expertise levels of stakeholders are identified. This sets the foundation for the entire process, ensuring that AI is applied where it's most needed. Next, Success Metrics must be defined, establishing Key Performance Indicators (KPIs) to track the effectiveness of the integration. These metrics focus on measuring the accuracy of AI-generated content, improving stakeholder comprehension, and optimizing resources. Following this, the Adaptation of ChatGPT for the circular construction context is essential. This involves customizing the AI with industry-specific data, ensuring it understands circularity concepts, terminologies, and reuse strategies. Change Management and Stakeholder Engagement planning is the next step, focusing on addressing potential

resistance from stakeholders by demonstrating how ChatGPT can complement their existing workflows and enhance their understanding of circularity principles. Once the groundwork is laid, Consultants' Training becomes a priority. This step ensures that consultants can effectively use ChatGPT and critically assess its outputs. After training, Testing and Validation is conducted through a small-scale pilot, where ChatGPT's performance is closely monitored, focusing on accuracy, privacy, and alignment with project goals. Continuous Monitoring and Feedback Collection follows, where stakeholders provide input to refine and improve the system. With successful pilot results, the process moves to Scaling Up, where ChatGPT is gradually expanded to more projects and teams, ensuring minimal disruption to existing workflows. Finally, Full Integration into the organization's knowledge management systems completes the process, ensuring that ChatGPT is fully embedded in workflows and continuously adapted to remain effective and accurate. This comprehensive approach ensures the successful integration of ChatGPT into circular construction projects, improving knowledge transfer and supporting sustainability goals.

- How can Generative AI enable knowledge contextualization among stakeholders for enhancing the circularity in the construction industry?

Generative AI, and in this case ChatGPT, holds significant potential to enable knowledge contextualization among multi-stakeholders in the construction industry, thereby enhancing the circularity of construction practices. The insights gathered from the literature review and interviews conducted in the research provide a comprehensive understanding of how this technology can address the challenges and inefficiencies currently hindering the effective implementation of circular principles in the industry.

ChatGPT represents a notable advancement in Natural Language Processing, with features such as enhanced contextual understanding, text generation, multilingual adaptability, and fine-tuning for specific tasks. These capabilities are crucial in improving knowledge contextualization, especially in the context of circular construction projects. By also leveraging the tool's affordances in knowledge management, like knowledge retrieval, organization, and sharing of information, ChatGPT can ensure that stakeholders at various levels of expertise have access to tailored and relevant knowledge. This is particularly important in the construction industry, where the complexity of circular processes and the technicality of documents can often overwhelm stakeholders, leading to poor knowledge contextualization and significant setbacks in project implementation.

The research identifies several key reasons for poor knowledge contextualization in circular projects. These include the complexity and technicality of documents, which often result in stakeholders struggling to comprehend detailed reports filled with jargon and extensive data. Information overload further compounds this issue, as stakeholders receive more information than they can process, making it difficult to extract relevant insights. Additionally, there is often a misalignment between the technical content of documents and the varying levels of expertise among stakeholders, leaving many unable to fully grasp the information presented. The lack of contextualization—where information is not adequately tailored to the specific needs and tasks of different stakeholders—also contributes to these challenges, leading to delays, increased costs, and sub-optimal reuse of materials in circular projects. ChatGPT, leveraging its features and affordances, offers a potential solution to tackling these problems and enable a better knowledge contextualization process within each organization.

Despite the potential benefits, the integration of Generative AI into the construction industry is not without concerns. The primary issues revolve around security, data privacy, and the reliability of AI-generated information. Stakeholders have expressed apprehension about the risks of sensitive data being exposed or misused, as well as the possibility of AI producing outputs that are not entirely accurate or contextually appropriate, which could lead to misinformed decisions. Ethical considerations also arise, particularly regarding the dependency on AI for decision-making processes that traditionally require human judgment, potentially reducing human oversight and introducing biases in AI-generated content.

To effectively integrate Generative AI into existing construction practices and facilitate knowledge contextualization, a comprehensive, multi-phase approach is required. This process begins with the preparation phase, where organizations must assess their needs, establish clear objectives, and ensure that the AI integration aligns with specific industry challenges and goals. Customization and ongoing training of ChatGPT are crucial next steps, allowing ChatGPT to understand industry-specific terminology and keep up with the latest developments in circular construction. The pilot phase involves user training, testing, and validating the AI's outputs on a small scale, with continuous monitoring to refine its performance. Finally, the deployment phase focuses on scaling the integration across more projects and teams, providing continuous support and training to ensure users can fully leverage the technology. Throughout this process, it is essential to maintain human oversight to ensure that AI outputs are accurate, relevant, and ethically sound.

In conclusion, ChatGPT has the potential to play a transformative role in enhancing knowledge contextualization among multi-stakeholders in the construction industry. By addressing the challenges associated with understanding in implementing circularity principles, ChatGPT can make critical knowledge more accessible, relevant, and actionable, thereby promoting more sustainable and circular construction practices. However, to fully realize this potential, careful consideration of security, privacy, and ethical issues is necessary, along with a well-planned integration process that ensures the technology complements and enhances human expertise.

7.2 Theoretical and practical contribution

This thesis makes significant theoretical contributions by advancing the understanding of how ChatGPT can facilitate knowledge contextualization within the construction industry to enhance circularity practices. While the concept of circularity has been explored extensively in academic literature, the integration of ChatGPT as a tool for improving knowledge contextualization among stakeholders is a new contribution. The thesis builds on existing theories of knowledge management, circular economy, and artificial intelligence by proposing a new framework that combines these fields. This interdisciplinary approach not only enriches the body of knowledge in each of these domains but also offers a new perspective on addressing the persistent challenges of poor knowledge contextualization in circular construction projects. By placing ChatGPT within the Knowledge Management Cycle (KMC), the thesis provides a theoretical foundation for understanding how AI can bridge the gap between theoretical knowledge and practical application in complex, multi-stakeholder environments.

The thesis specifically extends the existing literature by introducing ChatGPT as a more effective way to enhance knowledge contextualization processes. Several tools are utilized in the construction industry to improve knowledge contextualization among stakeholders. Some

examples include Building Information Modeling (BIM), a collaborative platform that simplifies complex construction data into visual, interactive formats (Al-Saeed et al., 2020), reducing technical complexity and information overload. However, its limitation lies in its inability to automatically adjust information based on individual user needs, which can lead to a misalignment with stakeholders' expertise. Similarly, Knowledge Management Systems (KMS) capture and distribute organizational knowledge, such as lessons learned from previous projects and best practices (Bagheri et al., 2016). KMS is effective in addressing information complexity, as it provides a structured repository of knowledge that stakeholders can access. However, it also fails to address misalignment with expertise and lack of contextualization, as the knowledge stored in KMS is often static and does not dynamically adapt to the specific tasks, roles, or levels of expertise of the users. Another example is Decision Support Systems (DSS), which help break down technical data into actionable insights, addressing the complexity of documents to improve decision-making (Galjanić et al., 2022). However, the outputs generated by DSS are often based on predefined models that are not tailored to the specific knowledge levels of all stakeholders, making it difficult for non-technical participants to comprehend or apply the insights provided fully. While the literature outlines these mechanisms to address factors contributing to poor knowledge contextualization individually or coupled, this thesis proposes ChatGPT as a comprehensive tool with the potential to simultaneously tackle all these issues in a unified manner by leveraging its features and affordances. More specifically, the thesis focuses on the circular construction sector and argues that ChatGPT can tackle the identified reasons for poor knowledge contextualization by adapting knowledge outputs to individual stakeholders' roles and tasks in real-time. Through this AI-driven approach, the thesis provides a more automated, quick, and scalable solution to knowledge contextualization, significantly advancing the field.

Practically, this thesis offers actionable insights and guidelines for integrating ChatGPT into the workflows of construction industry stakeholders to enhance circularity. By addressing the specific needs and challenges of consultants and other key stakeholders, the research provides a clear pathway for the adoption of ChatGPT to improve knowledge contextualization in real-world projects. The practical guidelines developed in this thesis are grounded in empirical research, including interviews with industry consultants, which ensures their relevance and applicability in the field.

One of the key practical contributions is the development of a set of guidelines for using ChatGPT to overcome the barriers to effective knowledge contextualization, such as the complexity of technical documents and the varying levels of expertise among stakeholders. These recommendations are designed to help practitioners tailor information to the specific roles and tasks of different stakeholders, thereby improving the implementation of circular practices. The thesis also identifies potential concerns and challenges associated with the use of AI in the construction industry, such as data security and user adaptation, and provides strategies to address these issues.

In summary, the thesis contributes both theoretically and practically by offering a new framework for understanding the role of AI in circular construction and by providing practical tools and guidelines to enhance knowledge contextualization in the industry. These contributions are expected to facilitate the adoption of circular practices, ultimately leading to more sustainable and efficient construction processes.

7.3 Limitations

Although this research adopts a thorough approach, it is important to recognize the limitations to understand what the study can and cannot conclude accurately. While notable, these limitations do not undermine the overall validity and importance of the findings, they should be taken into account when interpreting the results.

The focus on the circular construction sector in the Netherlands, particularly targeting consultants, allows the research to provide detailed insights into the specific challenges and opportunities within this context. However, this narrow focus limits the extent to which the findings can be applied to other regions or stakeholder groups in the construction industry. The unique characteristics of the Dutch construction sector, including regulatory frameworks, cultural factors, and market dynamics, may not be directly comparable to those in other countries. As a result, while the research offers valuable contributions to understanding circularity in the Netherlands, its applicability to broader contexts remains constrained, necessitating caution when attempting to generalize the conclusions to different geographic locations or industry segments.

Additionally, the use of a purposive sampling approach in the research ensures that participants are highly relevant to the study's objectives, capturing the diverse experiences and perspectives of consultants deeply involved in circular construction. However, this method inherently introduces selection bias, as the participants are deliberately chosen based on specific criteria rather than randomly selected. Consequently, the findings reflect the views and experiences of a particular subset of the population, potentially overlooking the perspectives of other relevant stakeholders. This bias could skew the results, making them less representative of the broader industry and limiting the study's overall validity. While the purposive sampling method provides depth, it also necessitates careful consideration of its implications on the reliability and generalizability of the research outcomes.

Additionally, another limitation of this thesis lies in the narrow focus on one particular Generative AI tool, namely ChatGPT. While the title implies a comprehensive exploration of various generative AI models and their applications in knowledge contextualization, the study predominantly examines the specific features and affordances of ChatGPT. By limiting the study to a single tool, the research does not explore the potential contributions of other AI models that could enhance knowledge contextualization, such as models for image generation, multi-modal applications, or AI systems designed for specific industry needs. This singular focus constrains the applicability of the findings, as it overlooks how other Generative AI tools might address the same challenges or provide additional benefits. As a result, the research may not fully capture the wider possibilities offered by the rapidly evolving field of Generative AI, limiting the generalizability and comprehensiveness of the conclusions drawn.

A further significant limitation of this research is that Generative AI is a relatively new topic in the academic literature, with limited studies available on its applications and implications. As a rapidly evolving technology, the understanding of its capabilities, limitations, and potential impacts is still in its early stages. This scarcity of existing research means that the findings of this study are based on a relatively small body of knowledge, which may limit the depth of analysis and the robustness of the conclusions drawn. Moreover, as Generative AI continues to develop and its applications become more widespread, new insights and data will likely emerge, potentially altering the understanding of its role and effectiveness in various contexts. Therefore, while this research provides valuable preliminary insights, it should be

viewed as an initial exploration subject to refinement and expansion as the technology and the literature surrounding it evolve.

7.4 Future Research

Several areas warrant further exploration to build upon and extend the insights gained from this research.

- Expanding Stakeholder Groups: This study primarily focused on consultants within the circular construction sector. Future research could explore the perspectives and roles of other key stakeholders, such as contractors, clients, and regulatory bodies, to develop a more comprehensive understanding of how Generative AI can be integrated across all phases of construction projects.
- Expand Generative AI tools: Future research should expand beyond the narrow focus on ChatGPT by exploring the potential of other Generative AI tools in knowledge contextualization. Investigating a broader range of models, including those for image generation, multi-modal AI, or domain-specific applications, could provide a more comprehensive understanding of how different AI systems might address diverse challenges in knowledge contextualization. By including various Generative AI tools, future studies could offer deeper insights into their complementary roles and unlock additional opportunities for enhancing knowledge dissemination across industries.
- Cultural and Geographical Contexts: This research was conducted within the context of the Dutch construction industry. Future studies could explore how cultural and geographical differences influence the adoption and effectiveness of Generative AI tools in knowledge management across different countries and regions.
- Ethical and Security Concerns: As the adoption of AI tools grows, so do concerns regarding data security, privacy, and ethical implications. Future research should investigate these aspects in greater detail, particularly focusing on how to mitigate risks while maximizing the benefits of AI in circular construction practices.
- Impact on Workforce Skills and Employment: The integration of AI tools like ChatGPT could have significant implications for the construction workforce. Future research could explore how AI affects skill requirements, job roles, and employment patterns within the construction industry, with a focus on developing strategies to manage these changes effectively.

By addressing these areas, future research can contribute to a more comprehensive understanding of the role of Generative AI in the construction industry, ultimately supporting the broader adoption of circularity practices.

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Appendix A

Interview Questions

Introduction questions

1. What is your role/position in your organization?
2. How many years of experience do you have in this field?
3. Which R-strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) are you using and how are you applying them in your projects? Can you give some examples?
4. What are the challenges when implementing circularity practices?
    a. A limited understanding of the circularity process and its principles among the stakeholders has been recognized as an important barrier to the enhancement of circularity. Have you encountered similar issues during your career? If yes, please describe one instance

Current Challenges in Knowledge Contextualization

Knowledge contextualization in the context of this thesis refers to the process of adjusting information to fit the recipient's expertise and tasks. This process involves translating and tailoring complex technical information into actionable, understandable insights that are relevant to the specific needs, experiences, and roles of the stakeholders involved in circular projects.

5. What are the difficulties you encounter in understanding the technical documents/policies you must process? (Complexity and technicality of documents, Information overload, Misalignment with expertise, Lack of contextualization)
    a. How do you solve these problems? Can you give examples?
6. What are the comprehension difficulties collaborating stakeholders encounter from the technical documents that you produce? (Complexity and technicality of documents, Information overload, Misalignment with expertise, Lack of contextualization)
    a. How do you solve these problems?
7. What resources are utilized to address and rectify these deficiencies?
8. How do these deficiencies impact the overall efficiency and success of your circular construction projects?

Concerns about ChatGPT

9. Are you currently using ChatGPT?
    a. If yes, for what reasons?
10. What are your biggest concerns associated with adopting ChatGPT both in your processes and for the dissemination of knowledge tailored to the specific needs of each stakeholder? (ethical considerations, reliability and accuracy, security issues, limited managerial oversight, reconfigured roles)
11. In your experience, what are the most significant challenges to integrating new technologies in your processes?
12. Would you consider using ChatGPT to understand the meaning and context of information, or clarify the knowledge you produce tailored to the specific knowledge level of collaborating stakeholders?