Possible Futures for Lean Construction: A Scenario Analysis for Germany

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Abstract
Lean construction is increasingly adopted due to low productivity, industry fragmentation, and adversarial relationships, enhancing stability and transparency. This paper outlines future scenarios for Germany, aiding construction companies in proactive preparation. Using the scenario technique, three Lean construction scenarios were developed and compared with AI-generated results. A literature review examined Lean construction's current state, followed by identifying crucial influencing factors through megatrend analysis and a PESTEL analysis. Sustainability, digitization, and collaboration emerged as key factors. Future projections for each were developed and linked to form scenarios: A sustainability scenario which is shaped by environmental regulations and green technology for sustainability, advancements in Building Information Modeling (BIM) are shaping the digitization scenario and integrated project delivery methods form the third scenario “collaboration”. The scenarios developed in this paper support those initially suggested by an AI tool. This analysis enables construction companies to adapt oneself to future scenarios and derive actions.

Keywords: Lean construction, scenario technique, sustainability, digitization, human collaboration

1 Introduction

In response to the urgent need to address the challenges such as low productivity (Hauptverband der Deutschen Bauindustrie e.V. 2022), structural fragmentation within the Architecture, Engineering, and Construction (AEC) industry (Hauptverband der Deutschen Bauindustrie e.V. 2024), and adversarial relationships that have emerged as a result, Lean Construction (LC) has surfaced as a promising paradigm aimed at enhancing stability and transparency in projects in Germany (Dlouhy et al. 2017). The concept of LC represents the adaptation of the principles of Lean Management to the construction industry. The conceptual roots of LC can be traced back to the automotive sector (Bertagnolli 2020). In essence, the objective of Lean is to eliminate processes that do not contribute directly to customer value (Erne 2019).During the 1990s, the construction industry adopted the Lean approach (Gehbauer 2011).Furthermore, Koskela (1992) extended these principles to the construction context in his study. His findings indicated that implementing Lean practices would enhance competitiveness, leading him to recommend the widespread adoption of this philosophy within the construction sector. The theoretical groundwork for Lean Construction was laid by Koskela's TFV (Transformation, Flow, and Value) model in 1992. The adoption of Lean principles has gained momentum globally, with countries like Germany implementing these principles and practices on a national scale.

Although there is a considerable body of literature examining individual aspects of LC such as the support of Artificial Intelligence (AI) in LC (Lauble 2023), comparisons between Lean and sustainability (Vieira and Cachadinha 2011), and the human factor (Bouranta et al. 2022) - there is a dearth of comprehensive studies that provide an overview of these diverse findings. This paper aims to fill this gap by offering insights into the potential evolution of LC in the year 2040.

Methods applied to identify the evolution were a literature review and a PESTEL analysis defining factors for the evolution of construction industry. Development trends and alternative scenarios are presented using various future models. In a first step, we created future scenarios using AI with the help of the "Board of Innovation" platform (www.ai.boardofinnovation.com) and compared them later with the results of the identified future scenarios The prompt for generating the future scenarios is shown in Figure 1.

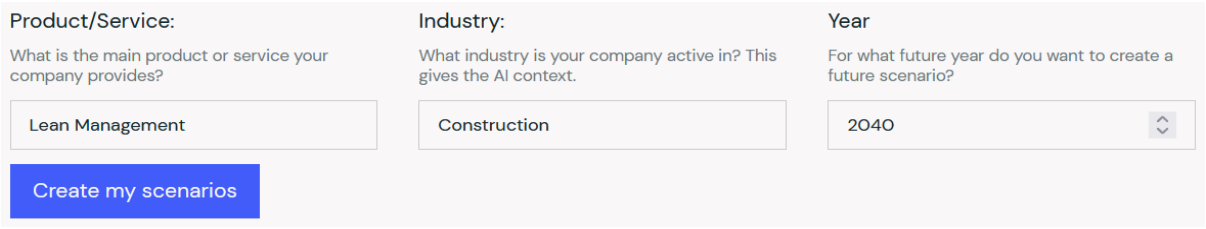

Figure 1: Prompt for creating Future Scenario

The scenarios were generated by varying terms in the "product" field while keeping “Lean” constant, resulting in three focus areas: Technology-driven, sustainable and human-focused LC.

The first scenario envisions a 2040 where LC has transcended into a fully automated system. Here, efficiency and productivity reign supreme, facilitated by AI algorithms that handle operations with unparalleled speed and accuracy. Virtual reality (VR) technologies foster seamless global collaboration, while robots communicate with each other and perform tasks autonomously. In contrast, the second scenario focuses on a sustainable future in LC envisages a future where Lean principles converge with environmental stewardship. In 2040, companies prioritize sustainability, leveraging advanced technology to minimize waste and reduce carbon footprints. From tracking and optimizing resource usage using analytics tools to deploying drones for ethical supply chain monitoring, every decision is guided by a commitment to environmental responsibility. Finally, the human focused scenario presents a vision of 2040 where the focus of LC shifts towards empowering people and fostering a culture of creativity. Here, employee well-being takes center stage, supported by flexible workspaces and personalized development opportunities driven by AI algorithms. Innovative technologies such as mood-sensing tools and mindfulness apps promote stress management and work-life balance, while diverse teams collaborate in vibrant, creative environments to tackle complex challenges.

To conclude, the scenarios predicted by the AI will be compared with the results obtained by the authors. The article is structured as follows: Section 2 outlines the scenario field, followed by a description of the scenario analysis procedure in the Section 3. Here, Section 3.1 gives a literature review as part of the initial step of the scenario analysis. Section 4 presents three selected possible scenarios, each internally consistent but showcasing contrasting development possibilities. The discussion is in Section 5, and the conclusion is in Section 6.

2 Scenario technique procedure

There are several foresight methods that can be used to assess the future. Based on the findings of Gräßler et al. (2020) analyzing different foresight methods, the scenario technique was chosen as it focuses on future orientation and is also widely accepted. The output of the scenario technique, in contrast to other representative foresight methods, is a scenario and not a strategy, narrative, etc.

2.1 Definition

The scenario technique is a visioning process that aims to create a picture of the future and support decision-making in the present (Becker 2002). Future scenarios generally follow three principles:

1. The future is complex and variable, requiring a departure from describing it in terms of a few independent factors. A future scenario is a complex system that requires networked thinking.
2. There are many possibilities for the future, which means that it cannot be accurately predicted. (Gausemeier et al. 2019)

3. The future itself is influenced by several factors (Berger et al. 2008).

According to Ute von Reibnitz (1992), a scenario is a description of a future situation and the path from the present to the future. Scenario technique is a planning technique that typically develops at least two distinctly different and consistent scenarios, extrapolating their implications for a company, region, or individual. It is important to note that scenario technique does not provide an exact prediction of the future but rather presents a possibility. (Reibnitz 1992) In the literature, various scenario techniques have been identified and compared. Based on the meta-analysis of 14 different scenario technique approaches by Ködding and Dmitrescu (2022), scenario technique can be divided into three overarching phases: scenario preparation, scenario development, and scenario transfer. These three overarching phases, in turn, can be subdivided into nine steps, with the fifth step being optional (see Table 1).

Table 1: Nine steps in scenario technique (Ködding and Dmitrescu 2022)

Phase	Step	
Scenario-preparation	1.	Defining and Analyzing the Subject of Investigation
Scenario development	2.	Identifying Influence Factors
	3.	Development of Projections
	4.	Clustering Alternatives
	5.	Sensitivity Analysis (optional)
	6.	Scenario Development
Scenario-transfer	7.	Consequence Analysis
	8.	Scenario Transfer
	9.	Scenario Controlling

2.2 Phase description

This paper deals solely with the first two phases with the goal of developing different scenarios and comparing them with the results of the initial mentioned board of innovation. Therefore, the following five steps were conducted: preparation (Section 3.1), identifying influence factors (Section 3.2), development of projections (Section 3.3), clustering alternatives (Section 3.4), scenario development (Section 4).

2.2.1 Scenario preparation

Before embarking on a scenario project, it is crucial to define and analyze the subject of investigation. This involves not only establishing project objectives and organization but also defining and analyzing the actual subject of investigation or field of design, as well as determining the scenario field in which the subject of investigation is embedded. (Gausemeier et al. 2019; Reibnitz 1992) For this matter, we identified megatrends in the construction industry and compared the proceedings of the International Group of Lean Construction (IGLC) from the last 14 years (see Section 3.1).

2.2.2 Scenario development

Scenario development begins with the identification of influence factors. In this process, the previously defined scenario field is structured into areas of influence and described using influencing factors. The influence factors can be identified by analyzing relevant literature; expert interviews; questionnaires or workshops with the target group (Kelly et al. 2004). A common approach (e.g. Erdogan et al. 2009; Lavikka et al. 2018) is to categorize them by techniques like PESTE – political, economic, social, technological, ecological. In this paper, the PESTE technique was expanded by the legal environment (PESTEL) as the legal aspect plays a crucial role in the German construction industry. Influencing factors within the environments were identified through a comparative literature review analyzing different scenarios for the construction industry (Section 3.2). The identified factors were then summarized in a catalogue of influencing factors. The most crucial influencing factors, termed descriptors, are then selected based on their interconnection and relevance. In the context of projection development for each descriptor, alternative development possibilities, known as future projections, are elaborated (Section 3.3). These future projections are linked to coherent projection bundles and scenarios. This was accomplished through an intuitive assessment (Section 3.4) but can also be accomplished through

a cross-impact analysis, or a pairwise consistency assessment of the future projections followed by a cluster analysis. The scenario development concludes in this case with the preparation of three different scenarios (Section 4). (Ködding and Dumitrescu 2022)

2.2.3 Scenario-transfer

The last step involves transferring the developed scenarios into practical applications or relevant contexts to assess their viability and potential impact. The consequence analysis entails the potential consequences and outcomes of each scenario to understand the implications and effects on the AEC industry and related stakeholders. The last step is left out as it involves monitoring and controlling the scenarios to track progress, measure effectiveness, and make necessary adjustments to align with evolving conditions and objectives.

3 Scenario analysis for Lean Construction

As described in Section 2, in this paper the scenario analysis was applied as it focuses on future orientation and scenarios are created instead of narratives or strategies. Scenario analysis is divided into the steps of (1) current state, (2) identification of influencing factors, (3) development of projections, and (4) clustering of alternatives. These steps are described below.

3.1 Current State

The construction industry is undergoing significant changes driven by three key megatrends: digitalization, sustainability, and labor challenges in Germany. The advent of digital technologies is modernizing the industry, improving efficiency, and professionalizing processes using methods such as Building Information Modeling (BIM) and automation. The focus on sustainability has become a central concern, with efforts to reduce environmental impact and support global climate goals. The industry faces a major shortage of skilled workers, worsened by high investment costs and challenges in attracting and retaining talent. (Handelsblatt Research Institute 2022) To provide a comprehensive overview of the current state of research on the three defined focus areas regarding LC, a systematic analysis was conducted on the digitally published papers of the International Group of Lean Construction (IGLC) from the last 14 years (2010-2023). This collection comprises 1,502 publications. The publications were exported as a Bibtex file and transferred to Excel for further analysis. Different keywords were defined for each cluster.

- Technology-driven LC: technology, autom*, digital, software, innovate*, artificial, NFC, IoT, BIM
- Sustainable LC: green, waste, environment, energy, sustain*, lifecycle
- Human-focused LC: worker, education, safety, knowledge, training, collab*, human, social

The number of keywords was counted in the abstracts. The publication was then assigned to a cluster. A total of 899 publications could be assigned (equals 60% of all publications), including 129 in the field of technology-driven LC, 353 in the field of sustainable LC, and 417 in the field of human-focused LC. No publication was assigned to more than one cluster. For further analysis, the percentage share per cluster and per publication year was calculated. The results are shown in Figure 2. A discernible upward trajectory can be observed in the technology and human clusters, which reinforces the significance of these two clusters in prospective scenarios.

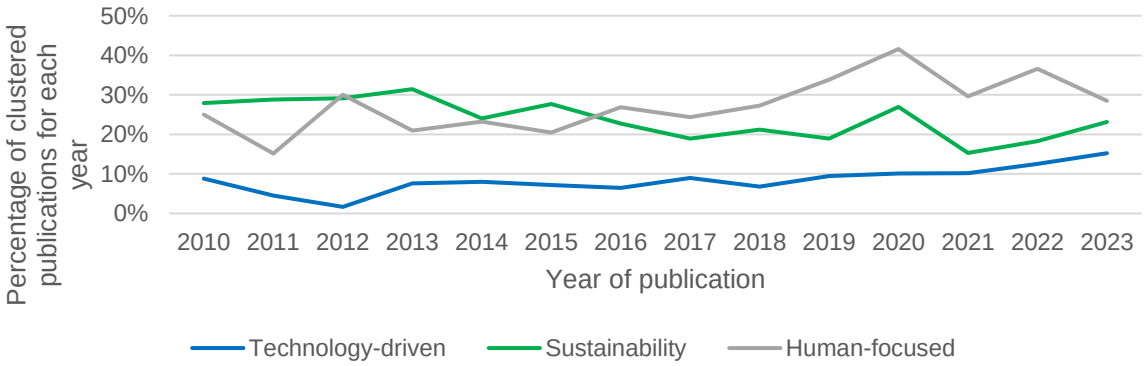

Figure 2: The proportion of papers from the IGLC that fall within the focus areas, broken down by publication year.

3.2 Identifying Influence Factors

When analyzing the influence factors in the literature research, solely the main influence factors stated by the authors were considered as they represent the main findings. The 83 identified different influence factors (Erdogan et al. 2009; Garcia and Murguia 2021; Kamers 2018; Kavuri et al. n.d.; Lavikka et al. 2018; Schwimmer et al. 2022) were grouped and added in one of the six influence areas. The clustered influence factors are shown in Figure 3.

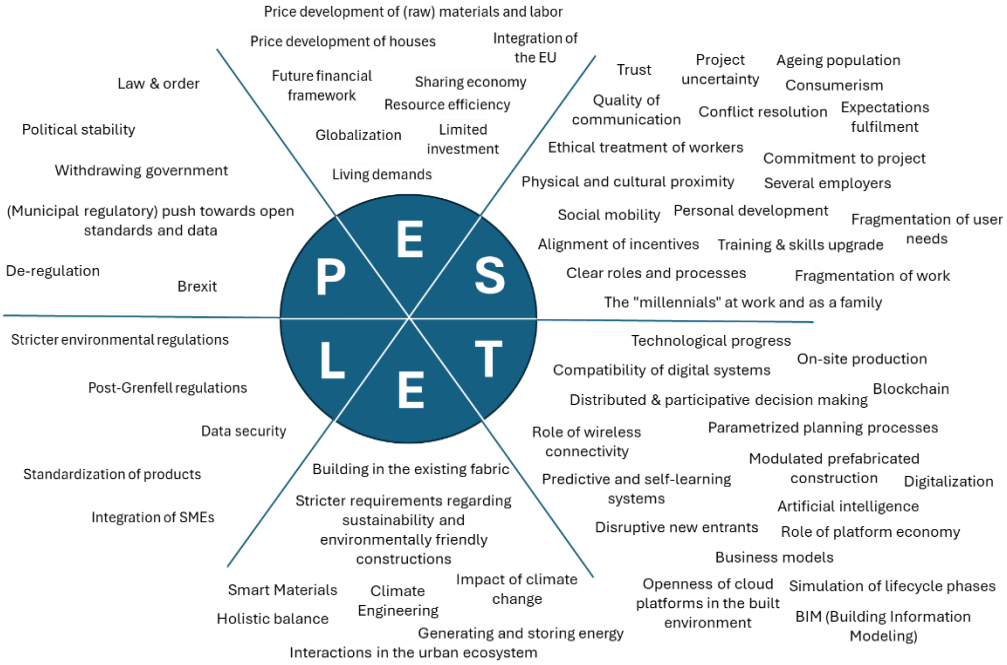

Figure 3: Overview of influence factors gathered in literature research

It can be observed that the construction industry is shaped by a complex interplay of political, economic, social, technological, environmental, and legal factors. The most influential factors were found to be in the technological field, which in turn affect the other fields. Politically, regulatory frameworks and government policies such as deregulation introduce uncertainties, affecting costs and project timelines. To illustrate, a considerable number of financial resources are currently available in Germany for the advancement of sustainable construction (KfW 2023). Economically, fluctuations in material and labor prices, global market dynamics, and EU economic policies impact budgeting and project feasibility in the construction industry. In terms of social factors, the demographic shift in Germany (Destatis 2019), evolving work patterns, and effective communication are of critical importance for labor management and client satisfaction. Technological advancements such as digital modelling, AI, and BIM drive efficiency and innovation, enabling methods such as modular prefabrication. Although construction is still one of the least digitalized sectors in Germany, there is an upward trend in the digitalization of the construction industry. (Hofstadler and Motzko 2023) In terms of environmental factors, sustainability efforts, climate engineering, and smart materials help reduce the industry's ecological footprint, while legal compliance with safety standards and data management regulations ensures operational legitimacy and protects against liabilities.

3.3 Development of Projections

Out of 83 influence factors, 18 descriptors and projections for each of them were developed. These projections were closely modelled on the literature to create a coherent and realistic future space. Table 2 provides an illustrative example of the descriptors of the political influence area and their projections.

Table 2: Example of descriptors and projections of the political influence area

Descriptor	Projections
1.1 Regulatory Environment	- Strict regulations and standards for green practices - Funded task forces to establish guidelines and regulation - Adaption of regulations and guidelines to promote collaboration in construction projects
1.2 Government involvement	- Government promotes integrated and collaborative project delivery models - Funding of initiatives for research and development of new technologies - Subsidies for green and sustainable building procedures

3.4 Clustering Alternatives

In accordance with the findings of Ute von Reibnitz (1992), the scenarios were grouped in a manner that was intuitive and uniform. When the projections were compiled into scenarios, three main differences emerged: sustainability-, digitalization and human-oriented LC.

4 Description of the developed scenarios

Based on the found descriptors and clustered alternatives, three distinct scenarios were developed. To provide a comprehensive overview of the various scenarios, a future-oriented scenario PESTEL analysis was conducted.

4.1 Scenario 1: A sustainable LC site

The goals of LC, such as process optimization and increased efficiency, are aimed at economic improvements for the stakeholder. In addition, the avoidance of waste and optimized use of resources addresses environmental aspects. Aslam et al. (2021 p. 183), Bae and Kim (2008, p. 165), Francis and Thomas (2019), and Wu and Wang (2016 p. 35) provide evidence that Lean methods contribute to sustainable development, particularly through the common goal of reducing waste.

In the Lean philosophy, the term waste ("MUDA") is considered when analyzing and optimizing processes, as well as when producing more than the customer wants or producing defects. LC as a basis for sustainable construction results in emission-reduced construction processes and waste-free products. This is contingent on the customer's agreement with the understanding of sustainable targets. A scenario in which sustainability is an integral element of each Lean methodology, assumes a (politically, legally, and economically supported) understanding of sustainable needs by the customers of construction projects. (Table 3)

Table 3: Characteristics of scenario 1

Influence areas	Characteristics
Political	• Subsidies and support programs by the government • Strict regulations and standards for green practices • International climate change agreements and urban development guidelines
Economic	• Tax incentives and financial support to invest in sustainable practices • Growing market demand for green buildings and sustainable construction processes • Transparency of long-term cost savings by resource minimization in building operation • Competitive advantage for construction companies that adopt sustainable practices
Social	• Increasing public awareness and interest in sustainability • Education trainings for architects and engineers
Technological	• Rise of green technology and methodology such as IoT or BIM • Automation of CO2-tracking for all process • Material innovation grows
Environmental	• Emission reduction to target a Carbon-free construction site • Waste management strategies
Legal	• Contract conditions with criteria sustainability • Laws and regulations requiring sustainable building practices • Reporting regulation with sustainability indicators and progress

Government policies offer subsidies, e.g. KfW and support programs to encourage green building practices, setting strict regulations and standards aligned with international climate agreements

and eco-friendly urban development guidelines. These political measures combine with economic incentives like tax breaks and financial support to facilitate investments in sustainable practices. The market demand for green buildings and long-term cost savings provides competitive advantages. Social awareness and interest in sustainability increase, supported by educational programs for architects and engineers. Technological advancements, including IoT and BIM, enhance resource management and reduce environmental impact, with automation enabling continuous CO2 tracking and material innovations like recycled concrete contributing to sustainability. Environmental efforts focus on emission reductions, waste management, and biodiversity preservation. Legal frameworks mandate sustainable practices, requiring sustainability criteria in contracts and progress reporting. To facilitate the implementation of sustainable practices, it is essential to demonstrate the long-term financial savings that can be achieved through such measures. Furthermore, integrating sustainability key performance indicators (KPIs), such as emission measurements, into Lean methodologies, such as the Last Planner System, can prove invaluable. The development of automated progress reporting systems that incorporate sustainable criteria and the enhancement of educational programs to emphasize sustainability will also prove beneficial.

The current construction industry in Germany, which is characterized by traditional practices with limited integration of sustainability, is expected to undergo a significant transformation under Scenario 1. This scenario is shaped by a combination of political, economic, and social incentives, encompassing waste-free processes, emission-reduced methods, and the utilization of sustainable KPIs and technologies to enhance resource management and minimize environmental impact.

4.2 Scenario 2: A digitized LC site

The first significant methods in the field of LC originated in the 1990s and have since spread worldwide (Gehbauer 2011). A major advantage of LC is its simplicity and clarity, which promotes acceptance in its use. At the time when the fundamental methods were developed, simple analog tools were used, such as flipcharts or Post-it's. However, these analog processes also have disadvantages, such as time-consuming and error-prone manual adjustments.

In addition, new technologies are spreading exponentially, and innovative tools are being established. As an example, there are already many digital solutions to implement LC use cases digitally. Software like LCM Digital (2024) support Lean methods digitally to replace manual work steps and increase productivity. The development of new methods, such as BIM, for example, and new technologies such as Reality Capturing, Robotics, or AI provide new opportunities. The use of AI in the optimization of schedules or the usage of Robotics and computer vision can increase productivity and more easily capture actual states of current construction progress. Based on collected data, decision-making bases for site management can be improved.

Table 4: Characteristics of scenario 2

Influence areas	Characteristics
Political	• Strict regulations and standards for digital technologies • Government and public institutes as role models • Task forces to establish guidelines and regulation for innovations • Initiatives for research and development of new technologies
Economic	• Increased investments in digital technologies for construction • Partnerships between competitors to explore new technologies such as robotics • Higher Market competition leading into the need to increase productivity by new procedures
Social	• The influence and mindset of the younger generation as a main criterion to increase the usage of digital tools • Digital communication platforms promote work culture • Success Stories of innovative companies showing how to succeed in digital transformation • Education trainings for architects and engineers • Innovation culture in construction industry

Technological	• Continuous improvement of technologies such as Reality Capturing, IoT, AI and methods such as BIM • Automation of processes with robotic and AI systems • Decreased costs of new technologies • Support in decision making using big data
Environmental	• Digital technologies and systems to observe the efficient use of resources
Legal	• Standardized data protection laws for construction projects • Clarification of legal responsibilities and liability issues • International and national regulations for the use of digital technologies and data management

To unleash the enormous potential, several prerequisites are necessary. Political initiatives and well-established regulations are needed to drive the use of digitization potentials. Companies must show the courage to create new innovative processes and invest more in research and development. The construction industry needs to establish a culture of pioneers and innovation spirit. The development of new technologies and improvement of innovations is necessary to be able to use technologies economically. Therefore, research in technologies such as Robotics, AI, and data analysis is needed. Another prerequisite is the establishment of legal regulations as a prerequisite for the implementation of new innovations.

In accordance with Scenario 2, the existing construction industry in Germany, which is predominantly based on traditional, analogue LC techniques, is anticipated to transform into a highly digitized sector, adopting tools like BIM, AI, robotics, and reality capturing. This shift will streamline processes, reduce errors, and enhance productivity, supported by political initiatives, regulatory frameworks, and increased investment in research and development.

4.3 Scenario 3: A human-oriented project delivery based on Lean philosophy

Taiichi Ohno emphasized the human factor in Lean philosophy, recognizing its value in the Toyota Production System (Liker 2022; Ohno et al. 2013). However, many companies overlook this aspect when implementing Lean, driven by economic interests. They often apply Lean methods without considering the fundamental human-centric mindset (i.e., employees, partners, customers, as well as the current and future society)., resulting in unchanged attitudes towards humans despite following Lean principles to some extent.

Nevertheless, it is evident that human beings play a crucial role in the success of construction projects. Projects are created by and for humans. A multitude of studies that have examined the success and failure of construction projects have confirmed the critical role that humans play (e.g. (Denicol et al. 2020). Despite this, there have been few changes in the way the construction industry thinks. This raises the question of why, given the importance of people in project success, we continue to focus on measuring only facts-related indicators such as costs and deadlines.

Over the past several years, an increasing number of issues have been identified in relation to this subject. The number of employees absent from work due to illness is on the rise. Furthermore, mental health is also causing an increasing reduction or even loss of performance(Badura et al. 2023). Moreover, the younger generation has a distinct perspective on their working conditions and work-life balance. Increasingly, demands such as four-day weeks, no overtime, sabbaticals, and long vacations of more than three weeks are being made by career starters (Klaffke 2014). Therefore, considering the growing shortage of labor and the increasing demands placed on construction projects by clients, users, and society, companies are no longer able to avoid these problems and demands - otherwise, performance will decline, or the workforce required cannot be covered due to employees leaving and a lack of new employees. The focus on human concerns - both company's own employees and project partners, as well as customers and subsequent users - is likely to play a much greater role in decisions and thus change the way projects are delivered. The Lean philosophy offers several effective strategies for addressing the needs of employees and customers. Furthermore, respect for society plays also a significant role in the initial Lean approach (Gomez et al. 2020; Ohno et al. 2013).

Table 5 presents a PESTEL analysis of the various external influences on this scenario. This demonstrates that a multitude of developments do have a positive impact on the scenario of placing humans at the center of project delivery.

Table 5: Characteristics of scenario 3

Influence areas	Characteristics
Political	• Government promotes integrated and collaborative project delivery models for its projects. • Adaptation of regulations and guidelines to promote collaboration in construction projects. • Encouraging the exchange of experiences among individuals engaged in the human factor and collaboration in projects
Economic	• Collaboration and teamwork as the main criteria in the tendering process for construction projects. • Collaborative conflict resolution is recognized • Labor shortage • Project's incentive systems are designed as win-win or lose-lose
Social	• Flatter hierarchies, collaboration and working culture. • The concepts of diversity, inclusion, and mental health are an integral part of the organizational and thus project cultures. • Local communities are involved in the process, advocating for stakeholder engagement and pursuing collaborative solutions. • Blame culture is a thing of the past.
Technological	• Digital technology promotes communication, collaboration, transparency, and feedback processes. • Process management increases added value and controls collaboration.
Environmental	• Awareness of climate challenges provides a unifying objective • Collaborative approaches represent an effective means of addressing the need to build more resource-efficiently.
Legal	• Development of contracts that promote collaboration, joint problem-solving, and shared risks, and rewards.

Scenario 3 encompasses human-oriented delivery of construction projects in accordance with the principles of Lean philosophy. This includes the standardized use of integrated and collaborative delivery models in all kinds of construction projects. Through the early involvement of all project participants, the establishment of collaborative project structures, the implementation of monetary incentives, and the creation of contractual framework conditions, a foundation will be established for those involved to pursue common goals and recognize that more can be achieved by working together than by working independently. The traditional hierarchies of construction companies are being dismantled, and a new work environment is being created where the health and well-being of employees are regarded as the most valuable assets. Targeted training and professional development facilitate the enhancement of employees' skills in social interaction and collaboration, which in turn engenders a more favorable work environment within the company and its projects. This encompasses, for instance, conflict resolution techniques that seek to view conflicts as a joint task, emphasizing prompt resolution and a value-oriented approach. Moreover, there is a continuous effort in the market to critically assess and improve project delivery models in line with project goals and the needs of project participants. This is done with the aim of aligning with the perfection advocated by the Lean philosophy.

Currently, the construction industry in Germany focuses on economic concerns, often neglecting the human factor despite its critical role in project success. Scenario 3 envisions a shift towards human-oriented project delivery, prioritizing employee well-being, collaboration, and the full integration of Lean principles to create a more supportive and productive work environment.

5 Discussion

The scenarios generated by an AI tool do not differ significantly from those we created using the traditional scenario technique. This indicates that AI-generated results can serve as preliminary indicators for potential directions in which LC might develop. However, it should be noted that the AI-generated results lack the depth and representativeness of those produced by the traditional scenario technique. For instance, while political and economic factors are deeply

considered in the traditional method, the AI-generated scenarios often overlook these critical aspects.

All three scenarios align with some of the five Lean principles, underlining the future importance of defining customer value - the first principle of Lean Construction. Regardless of how the future unfolds, stakeholders will need to clearly identify whether the key value lies in sustainability, digitalization or human collaboration. As the Lean philosophy is about people, it could be said that collaboration and shared understanding are the foundation of any scenario. Furthermore, the presence of regulations and standards is a recurring theme in LC, as standardized processes are essential for identifying the value stream. The principle of perfection will be realized through new methods leading to continuous improvement. Consequently, innovative methods and approaches will drive the development of LC. Advanced technological approaches will contribute to the reduction of MUDA (waste), whether through reduced CO2 emissions or the reduction of analogue processes. Our contribution to the knowledge gap is clear, as we offer insights into the potential evolution of LC through a comprehensive study and systematic procedure. Comparing AI-generated scenarios with traditional methods shows that while AI offers valuable insights, it lacks the depth of human-driven techniques, highlighting both the potential and current limitations of AI in industry foresight. Our results relate to other relevant studies on influence factors for the construction industry and the traditional scenario technique, ensuring that our interpretations are supported by the literature.

6 Conclusion

In our analysis, three scenarios for the German LC in 2040 using an AI tool and compared them with those generated using the traditional scenario technique. The AI-generated results were comparable to the traditional scenarios, producing distinct and consistent scenarios focusing on sustainability, digitalization, or human-oriented project delivery. This scenario analysis identified key characteristics influencing the future development of LC, such as policy regulations and funding. Companies that innovate and adopt new methods will gain a market advantage. It is crucial to identify customer value and align company development with this goal. The political, economic, social, technological, ecological, and legal aspects will significantly change and influence LC's transformation. The study is limited by the fact that the scenarios constructed are based on descriptors found in literature and have not been validated by experts. Furthermore, the clustering included a subjective component.

Future studies could further explore the identified aspects and their impact on LC.

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