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Discussion and forecast based on an industrial study

Current trends in factory planning

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ABSTRACT Factory planning is currently experiencing a major shift, marked by increasing uncertainty. In this context, four trend topics are widely discussed yet lack a clear industrial baseline: systematic risk management, a continuously updated factory planning basis, targeted adoption of new technologies in indirect processes, and management of uncertainties at the product-factory interface. To address this gap, an industrial study was conducted, combining a structured literature review with a self-administered questionnaire. Additionally, further research needs are outlined.

KEYWORDS

Factory Planning, Digitization, Collaboration

Aktuelle Trends in der Fabrikplanung – Einordnung und Prognose auf Basis einer Industrie-Studie

ZUSAMMENFASSUNG Die Fabrikplanung ist aktuell von großer Unsicherheit geprägt. Es werden verschiedene Trend-Themen diskutiert, zu denen jedoch die konkrete Absprungbasis der Industrie unklar ist. Vier davon werden in diesem Beitrag untersucht: systematisches Risikomanagement, eine kontinuierlich aktuelle Fabrikplanungsgrundlage, die gezielte Einführung neuer Technologien in indirekten Prozessen und das Management von Unsicherheiten an der Schnittstelle zur Produktentwicklung. Zur Einordnung wurde eine Industriestudie durchgeführt und es werden weitere Forschungsbedarfe aufgezeigt.

1 Introduction

In 2023 alone, Germany recorded 4,408 factory building completions [1]. At the same time, factory planning faces dual pressures. Volatile markets, geopolitical tensions, and changing regulatory requirements collide with rapid innovation and decision-making cycles. This increases the complexity of factory planning projects, which must be completed at a higher frequency [2, 3]. As a result, success in factory planning will increasingly rely on the ability to make informed decisions under uncertainty. The challenges outlined suggest that factory planning projects are increasingly exposed to risks. Furthermore, research indicates potential gaps between goals and actual results [4, 5].

The study of *Neuhäuser et al.* identified deficiencies in coordination and communication as the most significant challenges in contemporary factory planning processes [6]. *Bermpohl et al.* also identified several significant practical challenges in a recent study. These challenges include data availability, the need for frequent adaptation, and incompatible technical solutions [7]. Building on these findings, the authors identified four key topics to address these challenges. To ensure project success and make informed decisions despite the complexity of factory planning projects, a structured risk management approach is essential. Such an approach involves "coordinated activities to guide and control an organization with regard to risks" [4]. Despite numerous challenges in factory planning, there is no specific process for managing risks during planning [8].

Additionally, this study will explore a solution for the need for replanning due to shorter product life cycles, focusing on a continuously updated factory planning basis [2]. Establishing this foundation depends on identifying relevant target values, information, and technologies. In addition to the aforementioned aspects, incompatible technical solutions also remain a major challenge in modern factory planning [7]. This issue partly stems from promising innovations and new solutions seldom making their way into the industry. To address this, the study will explore the factors that contribute to success and the barriers that hinder the adoption of innovation. The final objective of the study is to examine the challenge of insufficient data availability in factory planning [7]. This often results from planning a factory while the product to be manufactured is still under development, creating uncertainty in relevant information that can change during planning as the product evolves [9]. To develop a solution to these information uncertainties, this study will identify relevant data and approaches for managing these uncertainties as a third topic.

This study will analyze the four topics that, together, influence the ability to plan factories robustly, quickly, and sustainably: Systematic risk management, an updated planning basis, targeted use of new technologies in indirect processes, and managing planning uncertainties at the interface with product development. Chapter 2 provides an overview of the current state of research and technology in the four subject areas, followed by the formulation of hypotheses and the presentation of the methodological approach in chapter 3. Chapter 4 is devoted to the presentation of the study's findings, which are subsequently compared to the extant literature. In chapter 5, the previously formulated hypotheses are either accepted or rejected. In conclusion, the key findings are summarized once more in the final chapter.

2 State of research and technology

To reliably identify the ongoing research requirements in the domain of factory planning with regard to the four trend topics, a systematic analysis of the current state of the art in each subject area is necessary. Consequently, the inquiries addressed in the study can be refined, and a suitable data collection and evaluation methodology can be derived.

2.1 Risk management for factory planning

In a survey by *Burggräf et al.* conducted in 2022 [10], 68 % of respondents concurred with the hypothesis that the factory planning process can be regarded as particularly risky due to numerous internal and external parties involved in planning, mutual dependencies, and the many uncertainties surrounding information. Despite the necessity for suitable methods to address the risks in factory planning projects, this area has received little research attention to date. This finding emerged from a comprehensive literature analysis on risk management in factory planning, conducted in 2021. The analysis revealed a lack of publications addressing factory planning [8, 11].

Nevertheless, preliminary methodologies for automating risk identification in the construction industry have been identified. One such example is a system for identifying risks within construction project contracts. The contracts are then subjected to a rigorous analysis using text mining techniques, whereby predefined keywords are systematically searched for. These keywords function as indicators of potential risks [12]. Nevertheless, the database for this approach consists exclusively of the contracts concluded between the project participants and does not take into account the specific requirements that arise in factory planning projects from the cooperation between industrial construction and production system planning [3, 12]. A comparable approach to risk identification was developed by *Alsubaey et al.*, in which meeting minutes serve as the primary data source. These are analyzed using Bayesian networks to provide early warning of possible project failure [13]. *Zou et al.* have developed a system that uses natural language processing to evaluate accident and risk reports in order to find similar cases from past projects [14].

In addition to the examples enumerated here, further research has been conducted on the use of text mining for risk identification in construction projects. However, a commonality among these research projects is their exclusive focus on risks inherent in construction planning [12]. Consequently, the characteristic risks of factory planning, which are particularly characterized by the interaction between building and production system design, were not part of the research. In addition to the research work previously referenced, a research project on risk management in the construction industry was also completed in 2022 as part of the "Zukunft Bau" funding program. The objective of this project was to integrate a systematic risk management process into the Building Information Management (BIM) method. In the context of this initiative, risk catalogues were developed from the vantage point of building owners and contractors with regard to risk identification [15]. However, the prevailing focus within these studies was on the domain of construction planning, which precludes the consideration of the distinctive attributes that characterize factory planning projects. Consequently, the extant research findings do not address the specific characteristics of factory planning projects [15]. As a result, there is a general absence of risk management methodologies in research developed for the specific requirements of factory planning.

2.2 Continuous up-to-date factory planning basis

Recent advancements in factory planning have been characterized by a shift towards collaborative efforts in the development of holistic digital factory models (HDFMs) [7]. This evolution is exemplified by the integration of BIM [16], a working methodology that facilitates cooperation among various stakeholders involved in the factory planning. Projects are concluded with the creation of an HDFM that serves as the planning basis and consolidates all planning results [17]. There is a recognized need for digital information continuity at the interface between planning and operations [7]. However, these HDFMs are not transferred and employed in factory operations (e.g., to construct a digital factory twin (DFT)). These HDFMs are therefore not subject to maintenance during operation, and are, consequently, outdated at the start of the subsequent planning project [18]. Accordingly, the process of data preparation, which accounts for approximately 60% of the total effort [19], needs to be conducted at the initiation of a replanning project.

Existing update approaches prioritize faster reaction and higher planning efficiency [20]. However, these approaches do not consider other important objectives in factory planning, such as planning quality [21], flexibility [21], changeability [22], or employee acceptance [23]. The majority of work updates alphanumeric (e.g. [20, 24]) or geometric (e.g. [25–28]) static resource parameters. However, additional relevant parameters related to both the process and the worker [29], such as processing times or ergonomics, have not been addressed. Researchers employ a range of methodologies, including laser scanning (e.g. [25]), localization systems (e.g. [28]), photogrammetry (e.g. [27]), Asset Administration Shell for DFTs (e.g. [20, 24]), and BIM with IFC (Industry Foundation Classes, e.g. [20, 24, 25, 27, 28]). Nevertheless, the justification of technological choices is rarely demonstrated.

The field remains characterized by the absence of a comprehensive, continuously updated definition of requirements for HDFMs. This should specify objectives for short-cycled factory replanning, the information that must be updated in operation, and the technologies to be applied.

2.3 Implementation of new technologies for indirect organizational processes

The implementation of new technologies such digital twins for factory planning, as an example of an indirect organizational process, necessitates cross-functional coordination, complex data integration, and governance [30]. The benefits of such an approach are diffuse and difficult to quantify before deployment [31]. The existing literature suggests the potential for substantial gains [32]. Yet, the empirical evidence supporting these claims remains limited. A significant proportion of the extant studies are based on case examples and pilot programs [33]. However, significant barriers, including interoperability challenges [34], missing standardization [35], cyber security concerns [36], and the need for specialized employee skills [35], block the transition from initial proof of concept to subsequent industrial implementation. DFTs are a manifestation of this paradigm within the manufacturing industry. According to scholars in the field, the application of ex ante economic evaluation to support investment decisions is imperative [37]. Nevertheless, robust benchmarks from real deployments are rare [31]. There is also a lack of sufficient evidence regarding when and why firms choose to stop or avoid further development of these technologies [38].

Consequently, a research gap persists due to the absence of empirical evidence that quantifies the perceived gap between theoretical and realized benefits of factory planning technologies, such as DFTs, and clarifies how ex ante economic evaluation influences investment and discontinuation decisions.

2.4 Uncertainties at the interface between product development and factory planning

The interface between product development and factory planning has been a subject of research for a long time. On the technological side, Product Lifecycle Management (PLM) systems are commonly deployed and continuously improved to manage product-related information throughout the entire lifecycle [39]. In the context of the digital factory, these PLM systems serve as a basis for an integration approach that provides all users with the specific information they need. Therefore, PLM systems offer the opportunity to exchange information along the interface between product development and factory planning [40]. Considering the time-related aspect as well as the condition of the exchanged information between both domains, different approaches can be identified in the literature.

Nyhuis et al. define time-discrete synchronization points in the planning process as points at which information is transferred. The status of each piece of information is implemented via traffic light logic in three increasing degrees of maturity. The information can therefore either be available and sufficient, available but not yet sufficient, or, in the worst case, not yet checked [41]. Thus, the uncertainty of information is described in a qualitative manner. To quantify this uncertainty, probability distributions can be employed. *Unzeitig et al.* derive a corresponding method in the context of factory dimensioning. Each dimensioning size is described by a probability distribution, and a Montecarlo simulation is utilized to aggregate the individual distributions [9]. Apart from probability distributions, which are classified as a stochastic approach, uncertainties can also be described using different approaches. In the context of process time uncertainty, fuzzy and interval representations are valid modeling types. Fuzzy approaches require a given membership function to adjust the level of information to a limited extent.

It is essential to note that these three approaches to modelling uncertainties have different levels of information need and, consequently, different levels of detail [42]. A holistic approach that combines these uncertainty models to describe the information exchanged along the interface between factory planning and product development does not currently exist. Additionally, the potential implementation of uncertainty models in PLM systems has not been thoroughly studied.

3 Scientific approach

3.1 Research objectives

The objective of the present study is to examine the relevance of the four identified topics for factory planning and to provide empirical evidence. In the domain of risk management, the study analyzes the frequency with which initial project goals are being achieved and the significant factors influencing this achievement.

In the domain of short-cycle factory planning, the study ascertains the target values and information that are particularly relevant for replanning, as these have a significant impact on the design of solutions. To facilitate the incorporation of emerging technologies into indirect business processes in the future, an analysis is conducted to identify existing obstacles and investment-related decision-making factors. This analysis establishes the foundation for the development of effective implementation strategies. In a similar manner, to address the information uncertainties inherent in the interaction between product development and factory planning, specific information requirements and relevant target values are systematically documented to facilitate the development of innovative solutions. The findings of this study address the existing gap between research and practice and support the development of application-oriented, effective solutions.

3.2 Research hypotheses

Based on these research objectives, the authors collaboratively developed several hypotheses. In addition to the literature review results, the authors' expertise and experience were utilized. The hypotheses are each presented with a null hypothesis and an alternative hypothesis. A series of related hypotheses can be derived for each research objective. Initially, hypotheses regarding the risk management in factory planning are formulated:

1. The initial hypothesis posits that, in the context of factory planning projects, the majority of quality targets are successfully met, while cost and schedule targets are frequently not met. This hypothesis is founded on the findings of [43], which will be adapted to the present circumstances within the framework of this study.
   - H_0: In factory planning projects, quality targets are not achieved in more than 60 % of projects, and cost and schedule targets are not missed in more than 60 % of projects.
   - H_1: In factory planning projects, quality targets are achieved in more than 60% of projects, while cost and schedule targets are missed in more than 60 % of projects.
2. Given the prevalence of unmet objectives in factory planning projects, it is imperative to assess which risks have the most significant impact on objective achievement. The second hypothesis posits that organizational risks exert a substantial influence on the execution of factory planning projects. This hypothesis can be derived from the work of [6, 7], who identified organizational factors such as communication and coordination as significant challenges in factory planning.
   - H_0: Organizational risks do not significantly influence factory planning projects.
   - H_1: Organizational risks have a significant impact on factory planning projects

Subsequently, hypotheses concerning the continuous up-to-date factory planning basis are presented:

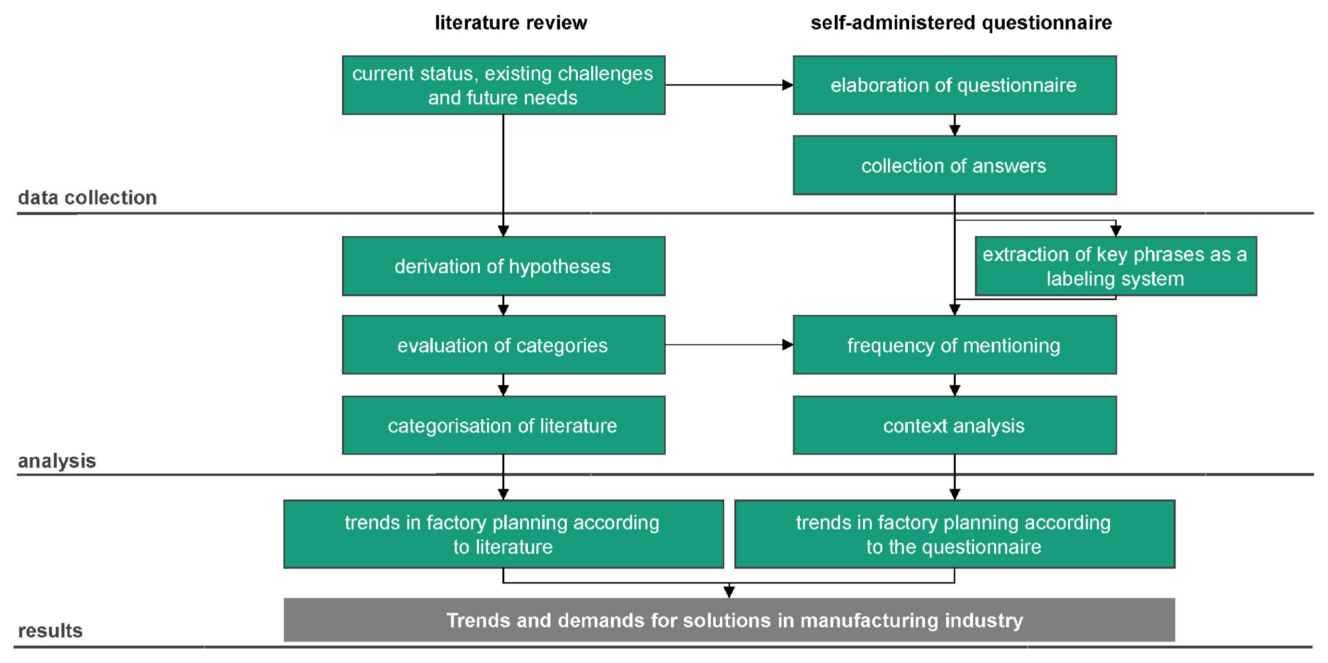


Fig. 1 Methodological approach, including self-administered questionnaire and literature review. *Source: Fraunhofer IGCV*

3. The third hypothesis is that there are additional target criteria to be considered in the context of short-cycled factory replanning than the improvement in reaction times and cost-efficiency (derived from [7]).
   - H_0: No significant proportion of the participants believe that additional target criteria should be considered in the context of short-cycled factory replanning than the improvement in reaction times and cost-efficiency.
   - H_1: A significant proportion of the participants believe that additional target criteria should be considered in the context of short-cycled factory replanning than the improvement in reaction times and cost-efficiency.
4. Existing works often focus on geometric or alphanumeric resource-related information in HDFMs (e.g. [16]). The fourth hypothesis states that process-related information is also relevant data to be updated throughout the operational interphases between two replanning cycles.
   - H_0: No significant proportion of the participants believe that process-related information is relevant data to be updated throughout the operational interphases between two replanning cycles.
   - H_1: A significant proportion of the participants believe that process-related information is relevant data to be updated throughout the operational interphases between two replanning cycles.
5. Furthermore, the fifth hypothesis states that worker-related information is also relevant data to be updated throughout the operational interphases between two replanning cycles.
   - H_0: No significant proportion of the participants believe that worker-related information is relevant data to be updated throughout the operational interphases between two replanning cycles.
   - H_1: A significant proportion of the participants believe that worker-related information is relevant data to be updated throughout the operational interphases between two replanning cycles.

In relation to the challenges in the implementation of new technologies for indirect organizational processes such as factory planning, two hypotheses are drawn:

6. The sixth hypothesis states that there is a perceivable gap between the theoretical potential and the practically utilized potential of innovations such as DFTs.
   - H_0: No significant proportion of participants rate the gap as high or very high.
   - H_1: A significant proportion of participants rate the gap as high or very high.
7. The seventh hypothesis states that the ability to assess the economic value of an innovation prior to investment is relevant for decision-making.
   - H_0: No significant proportion of participants rate the ex-ante economic assessment as relevant.
   - H_1: A significant proportion of participants rate the ex-ante economic assessment as relevant.

Considering the uncertainties at the interface between product development and factory planning, one hypothesis is derived:

8. The eighth hypothesis states that currently, PLM systems are not used comprehensively to describe and assess uncertainties of product development in factory planning.
   - H_0: A significant proportion of the participants use PLM systems to describe and assess planning uncertainties
   - H_1: No significant proportion of the participants use PLM systems to describe and assess planning uncertainties

3.3 Methodological approach

A mixed-methods approach, which combines qualitative and quantitative data, is employed. Hypothesis testing, which utilizes significance tests as a quantitative research method, requires the collection of quantitative data. The qualitative data, on the other hand, helps gain a better understanding of the research topics and improves the overall quality of the study's results by supporting the collected quantitative data. As the mixed-methods approach

Table Questions and answer choices associated with the hypotheses.

No.	Associated hypotheses	Question	Answer choices
1	H1	In what percentage of factory planning projects can the goals set at the start of the project be achieved? The following types of objectives were assessed by the participants: – Cost – Date – Quality	– 0-20 % (very low) – 21-40 % (low) – 41-60 % (moderate) – 61-80 % (high) – 81-100 % (very high)
2	H2	Which risks have the greatest impact on the achievement of project goals in practice? The following categories of risks were assessed by the participants: – **Organizational:** Influences on the project due to insufficient coordination between project participants, poor communication or coordination, or inadequate knowledge management. – **Legal:** The causes of these risks lie, for example, in regulations and laws, but also in contracts [15]. – **Scheduling:** This type of risk distinguishes between risks arising from changes in the general conditions and risks resulting from incorrect scheduling [15]. – **Market risks:** Market risks in factory planning projects are uncertainties and potential negative effects resulting from fluctuations in demand or prices. These can affect the planned capacities, schedules, and profitability of the factory [15]. – **Environmental risks:** influences on the project at the political level, from the environment and nature, or from the public [15].	– Not at all – Slightly – Moderately – Strongly – Very strongly
3		What methods and tools do you use to identify and assess risks in your projects?	Open question
4	H3	Which target criteria are particularly relevant in the context of short-cycled factory replanning?	– Improvement in reaction time – Improvement in replanning costs – Improvement in planning quality – Improvement in worker acceptance – Improvement in flexibility – Improvement in changeability
5	H4, H5	What information is particularly relevant for factory replanning?	– Alphanumeric resource- related information (e.g., availability, capacity, energy consumption) – Geometric resource-related information (e.g., position, orientation, dimensions) – Process-related information (e.g., processing times, idle times, transportation times) – Worker-related information (e.g., ergonomics)

represents a valid research strategy, self-administered questionnaires with both open and closed questions, along with a literature review, are employed [44, 45].

The self-administered questionnaire consists of six fully standardized questions with predetermined answer options in a multiple-choice format, as well as five open-ended questions that require the insertion of free-text blocks. For each trend, two to three questions are implemented. Additionally, control questions are implemented to ensure only responses from the target group are captured. The questionnaire is distributed to as many potential respondents as possible. Due to the self-administered character, a significant number of participants can be reached efficiently.

Figure 1 illustrates the methodological approach employed in this study, focusing on trends and demands for solutions in the manufacturing industry.

A comprehensive literature review is carried out to capture the state of the art and identify existing challenges and future needs. Based on that the questionnaire is elaborated and hypotheses are derived. These hypotheses are subsequently tested using the evaluated results of the questionnaire. In an intermediate step, the qualitative data from the questionnaire has to be analyzed regarding the key phrases before it is applicable to test the hypotheses. Following the general procedure of hypothesis testing, null and alternative hypotheses are formulated. Subsequently, their statisti-

Table Questions and answer choices associated with the hypotheses.

No.	Associated hypotheses	Question	Answer choices
6	H8	Which technologies are of particular relevance in the context of continuously updating the factory planning basis?	Open question
7	H6	How do you assess the gap between the theoretical potential and the potential actually utilized in practice of innovations such as digital factory twins?	– Very low – Low – Moderate – High – Very high
8		When and why do companies decide not to further develop innovations such as digital factory twins: Before, during, or after the investment decision making or implementation phase?	Open question
9	H7	How important is it for you to be able to assess the economic value of a new innovation (e.g. a digital factory twin) before you invest?	– Not relevant – More not relevant – Neutral – More relevant – Relevant
10		Which information from product development affects the factory planning and especially the planning of the production system?	Open question
11	H8	What kind of approaches currently exist to counteract the planning uncertainties?	Open question

cal significance is determined, and statistical testing methods are applied to test them [44, 46]. As a result of this process, a comprehensive understanding of the current trends and demands for solutions in the manufacturing industry is derived from the results of the literature review and the self-administered questionnaire. This knowledge serves as the foundation for future research proposals.

4 Results

4.1 Study design

The target population of this study comprises individuals with prior experience in factory planning. It is essential to consider this factor by integrating control questions in the self-administered questionnaire. The required sample size for quantitative hypothesis testing can be determined in advance by considering several factors. In the present study, nominal-distributed variables are involved, and the correlation between them can be calculated using the c^2-test. For this study, an expected effect size ω of 0.3, a significance level (α-error) of 5.0 %, and a power (1-β-*error*) of 0.8 are assumed. These values have proven to be effective in practice [47]. The optimal sample size is determined using the number of degrees of freedom with the computer program G-Power. In this case, the maximum number of degrees of freedom is 25 for the relationship between responses and sociodemographic background. In this case, a sample size of 92 participants is required to calculate a significant relationship. Aside from the correlation analyses with sociodemographic background, the study primarily employs simple majority tests. These typically require smaller sample sizes, as statistical significance is established via one-sided one-sample proportion tests (exact binomial) against the majority threshold of $p = 0.50$ rather than c^2-based associations. Moreover, for correlations involving open-ended questions, the necessary sample size cannot be decided beforehand because the categorization and coding of responses, and therefore the degrees of freedom, are determined during analysis.

The survey employs a self-administered questionnaire comprising quantitative closed ordinal five-level Likert-scale questions as well as qualitative open questions. The initial section of the questionnaire addresses the risk management in factory planning. The second section addresses the continuous up-to-date factory planning basis. The third section includes questions about the implementation of new technologies for indirect organizational processes. The fourth section comprises questions about the interface between product development and factory planning. An overview of the questions and answer choices is provided in the **Table**. The authors devised the answer choices based on the hypotheses, and the literature review discussed in a workshop.

4.2 Sociodemographic background of the study participants

A total of 51 participants were recruited to complete the survey. Each participant had to complete five standardized questions at the beginning of the questionnaire to capture their sociodemographic background. The evaluated results of this sociodemographic background are visualized in detail in the **Appendix 1–3**.

4.3 Results in the context of the research objective

4.3.1 Risk management for factory planning

To assess the impact of project-specific risks on the performance of factory planning projects, respondents were asked to indicate the percentage of their projects in which the targets defined at the project's start were actually achieved. A distinction was made between three key target categories: schedule, cost, and quality targets [43]. The results show a clear discrepancy between quality and schedule and cost achievement (**Figure 2**).

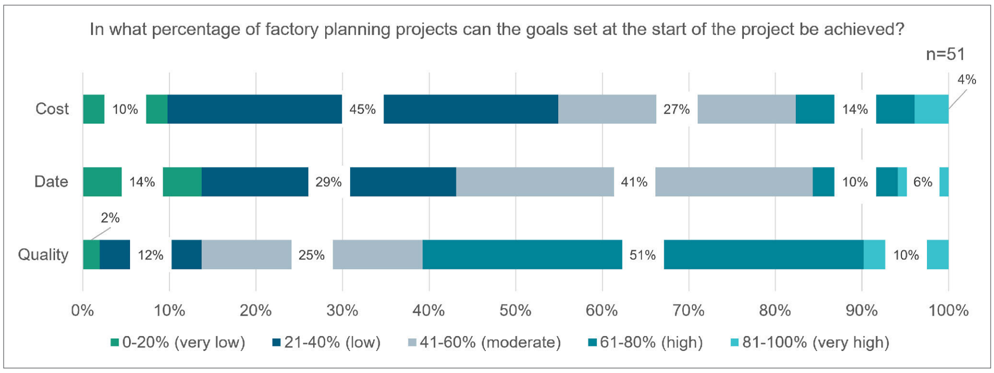


Fig. 2 Frequency of objective achievement in factory planning projects. *Source: Fraunhofer IGCV*

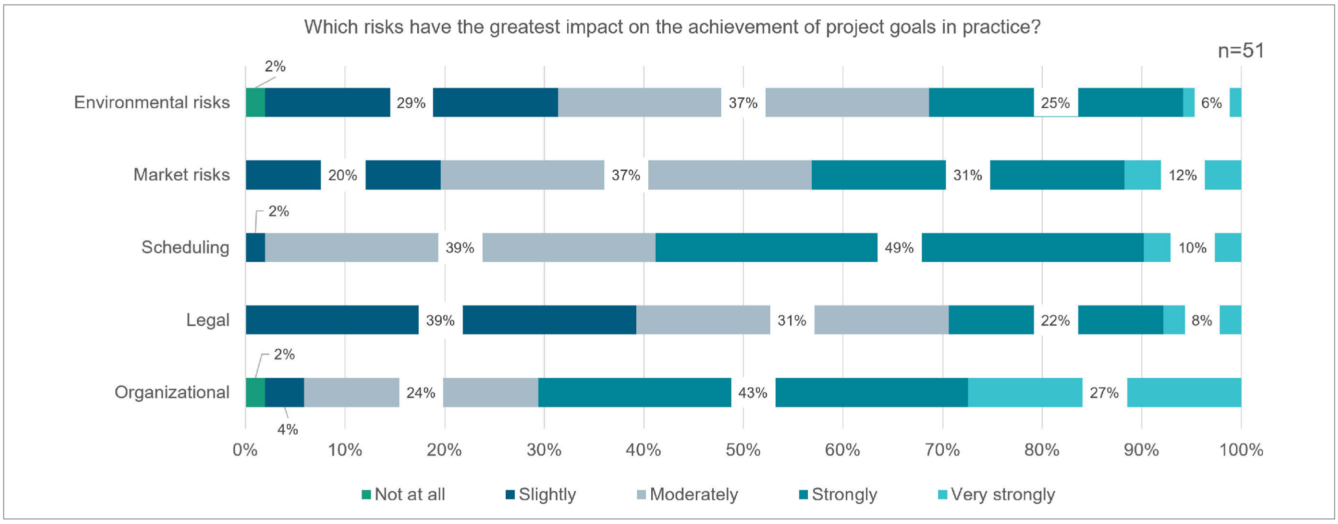


Fig. 3 Influence of different risk categories on factory planning projects. *Source: Fraunhofer IGCV*

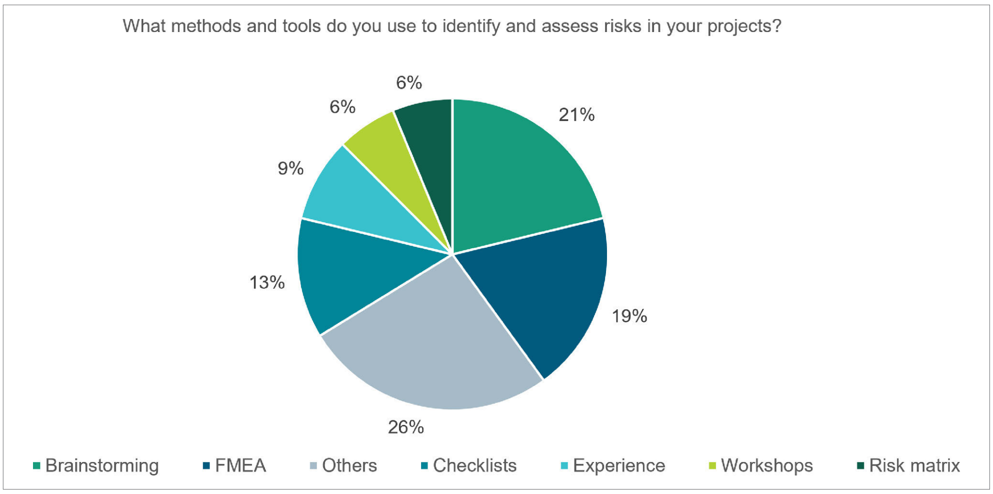


Fig. 4 Current methods used for identifying and assessing risks in factory planning. *Source: Fraunhofer IGCV*

For example, 29 % of respondents stated that the agreed deadlines were met in less than 40 % of their factory planning projects; a further 14 % even reported that deadlines were met in less than 20 % of projects. Similar patterns can be seen with cost targets. In contrast, quality targets are achieved much more frequently: 51 % of respondents stated that the required quality was achieved in 61–80 % of their projects.

To identify the causes of project targets not being met, participants were asked to specify which risk categories have the greatest negative impact on target achievement in factory planning projects in practice. Organizational risks are the only risk category whose impact was rated as strong or even very strong by a significant majority of participants. The second most significant influence pertains to the risk associated with scheduling. The respondents indicated that legal and environmental risks exerted the least negative influence, with 20 % perceiving environmental risks as having only a minor influence and 39 % regarding legal risks as having only a minor influence. The detailed distributions of ratings are presented in **Figure 3**.

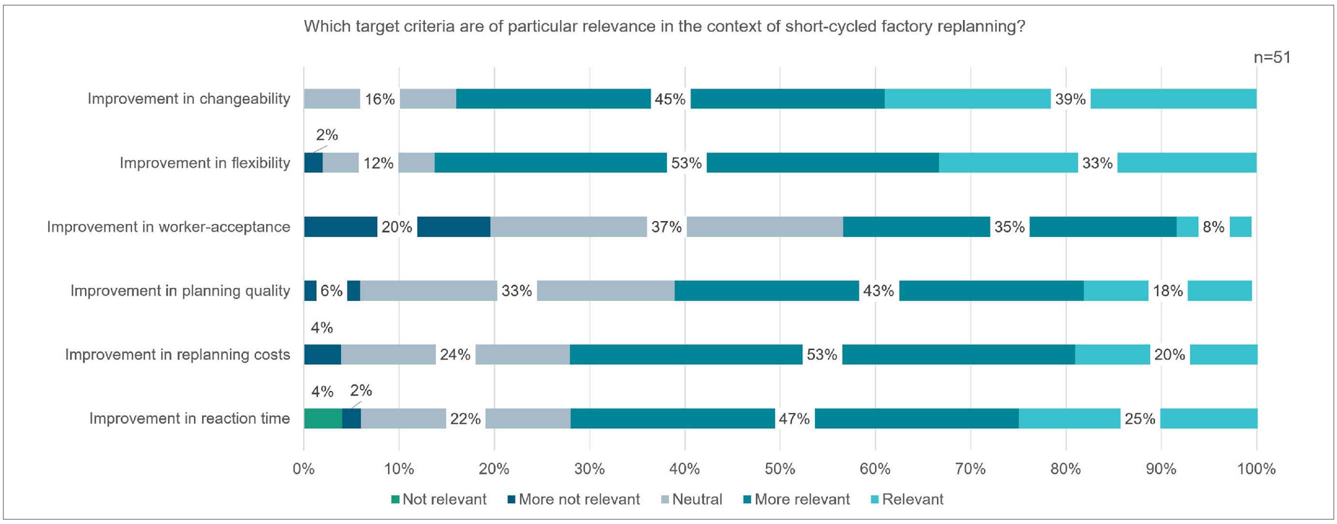


Fig. 5 Relevance of target criteria in the context of short-cycled factory replanning. *Source: Fraunhofer IGCV*

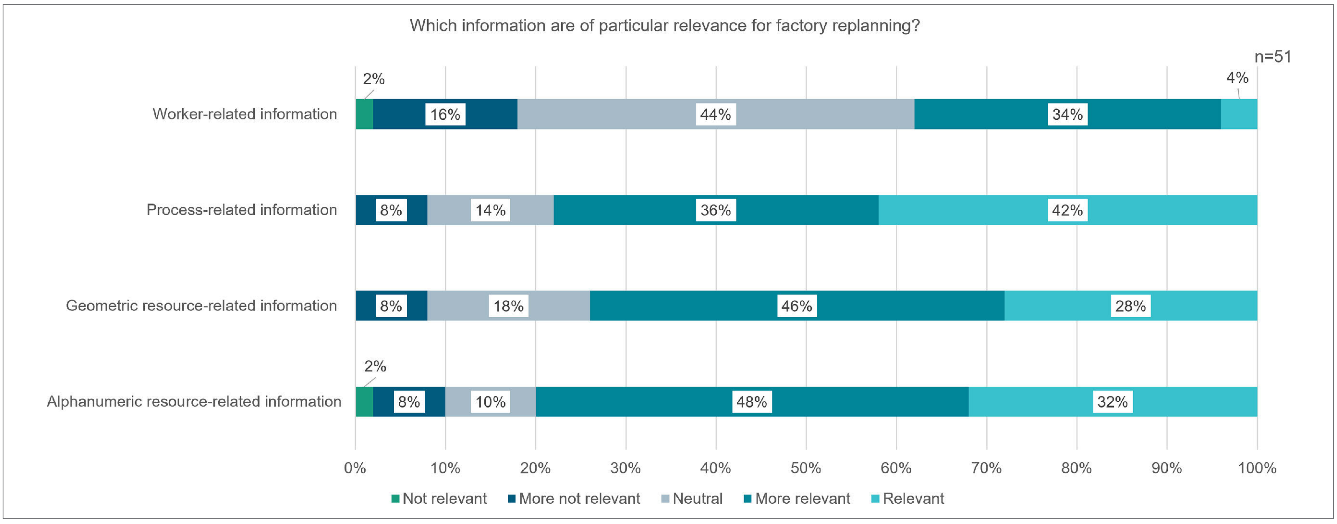


Fig. 6 Relevance of information in different classes for establishing a continuous, up-to-date factory planning basis for short-cycled factory replanning. *Source: Fraunhofer IGCV*

Finally, this section surveyed which methods and tools participants use to identify and assess project risks. The question was not limited to a specific number of responses; respondents were permitted to offer multiple answers. A total of 46 individuals contributed to the study by providing information (**Figure 4**).

No single method was mentioned in a significant majority of responses. The evaluation indicates a predominant emphasis on pragmatic, widely established methods. Brainstorming (37 %) and Failure Mode and Effects Analysis (FMEA, 33 %) were the most frequently cited methods. Concurrently, assessment based on experience remains a central component of risk assessment.

4.3.2 Continuous up-to-date factory planning basis

The analysis indicates that the primary objective in establishing a continuously updated factory planning basis is to improve flexibility. Beyond flexibility, improvements in changeability, replanning costs, and response time were each rated as "relevant" or "more relevant" by a statistically significant majority of respondents. The detailed distributions of ratings are presented in **Figure 5**.

In accordance with these objectives, the study identifies alphanumeric, geometric, and process-related information as particularly relevant for factory planning. For each information category, a statistically significant majority of respondents rated the information as "relevant" or "more relevant" to establishing a continuously up-to-date factory planning basis. The detailed distributions and significance results are presented in **Figure 6**.

The technologies most relevant to establishing a continuously updated factory planning basis are the DFT, laser scanning, BIM, and the Industrial Metaverse (IM). Across the 51 participants, a total of 115 selections were recorded due to the allowance of multiple responses. The distribution of selections and relative prominence of each technology are presented in **Figure** 7.

4.3.3 Implementation of new technologies for indirect organizational processes

In the context of implementing new technologies for indirect organizational processes, such as factory planning, a statistically significant majority of participants report a substantial (high or very high) gap between the theoretical potential and the potential realized in practice. Additionally, a statistically significant majority considers it relevant or more relevant to determine the economic value of a new innovation before making an investment decision. The detailed answer distributions are visualized in **Figure 8**.

Regarding the timing and rationale for discontinuing the development of innovations like the DFT, the data suggest that most participants make this decision before the investment stage, with an unclear return on investment (ROI) being cited as the primary reason. However, these proportions do not attain statistical significance. The detailed results are presented in **Figure 9**.

4.3.4 Uncertainties at the interface between product development and factory planning

Considering the interface between product development and factory planning, a wide range of information objects that impact factory planning can be identified. Especially the product geometry, information regarding necessary manufacturing processes, and the Bill of Materials (BOM) seem to be of high relevance. Additionally, the approaches to counteract planning uncertainties vary. Here, the high importance of communication between both domains can be emphasized. **Figure 10** provides a detailed visualization of the answers.

4.3.5 Relation to socio-demographic background

Figure 11 presents the sociodemographic background in the rows and the responses to the questions in the columns. The resulting matrix reports c²-test p-values for associations between these nominal variables. A value below $\alpha = 5\,\%$ (highlighted in green) is indicative of a potential association. However, such values may occur by chance and must be evaluated for plausibility on a case-by-case basis. Due to the limited number of participants, these associations are not statistically significant.

5 Discussion

5.1 Comparison to literature

Several significant contrasts emerge when the present study is compared to the existing literature on the subject. The methods most frequently cited in this study for identifying and assessing risks in factory planning projects differ significantly from the findings of a comparative study completed in 2022, which focused on construction projects as a whole and is therefore only comparable to a limited extent. While the FMEA method was utilized by a mere 1 % of the companies surveyed in the aforementioned study, it was mentioned in 33 % of the responses in the present study, thereby becoming the second most frequently used method.

A notable similarity exists between the pervasive utilization of brainstorming and checklists. However, *Helmus et al.* report a higher prevalence of checklist use (45 %) in contrast to the 22 % observed in the present study [15]. However, other results align more closely with existing literature on the subject. For instance, the findings support the conclusions of *Reinema et al.*, who indicated that quality targets in factory planning projects are predominantly met, while schedule and cost targets are frequently not met [43]. Moreover, the conclusion that organizational risks currently exert a substantial negative influence on factory planning projects aligns with the findings of *Neuhäuser et al.* and *Bermpohl et al.*, who identify deficiencies in coordination and cooperation as fundamental challenges in factory planning projects [6, 17]. Regarding the subjects of short-cycled factory planning and the implementation of new technologies in indirect business processes, the study's findings largely align with existing literature and offer further insights into specific aspects. In addition to response time and costs, supplementary target variables relevant to short-cycle factory planning were identified. Additionally, the findings clearly indicate that the primary factor hindering the implementation of technical innovations is an unclear ROI. This outcome aligns with the findings of a 2024 study that examined the implementation status of Industry 4.0 in companies within the DACH region (Germany, Austria, Switzerland). As identified in the literature review, PLM systems are currently not utilized to describe and assess the uncertainties associated with product development.

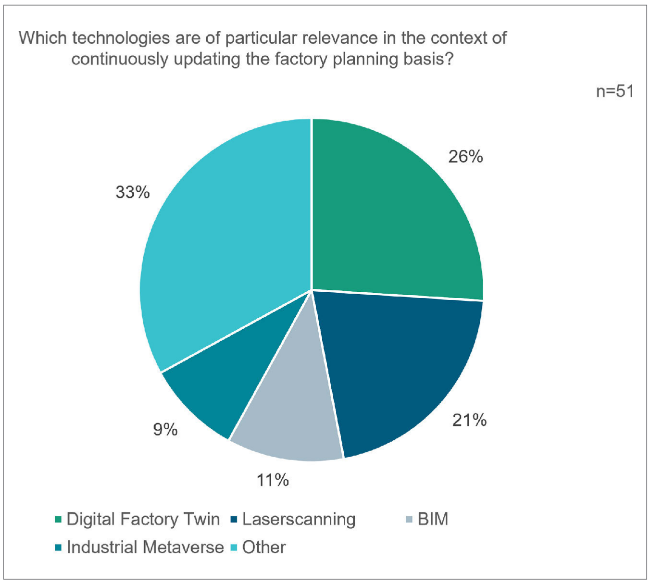


Fig. 7 Relevant technologies for establishing a continuous, up-to-date factory planning basis. *Source: Fraunhofer IGCV*

5.2 Critical reflection of the study design

The present study is subject to specific methodological limitations. Firstly, the survey's scope is extensive, yet the number of survey items is limited. This potential limitation may result in the examination of irrelevant dimensions and the allocation of disproportionate interpretive weight to individual questions.

Secondly, the recruitment of participants via the Fraunhofer IGCV network may introduce selection bias, thereby constraining external validity. Thirdly, the sample size is inadequate for testing correlations with adequate statistical power. Therefore, observed associations should be interpreted as indicative rather than conclusive. Future research endeavors should utilize a larger and more diverse sample size, along with a broader range of items, to enhance the study's robustness, validity, and generalizability.

5.3 Relation to the research hypotheses

Considering the study's results, the previously established hypotheses can be addressed. The hypotheses concerning risk management in factory planning projects can only be partially accepted. While a significant majority of participants indicated that costs and deadlines are frequently unattainable, no significant

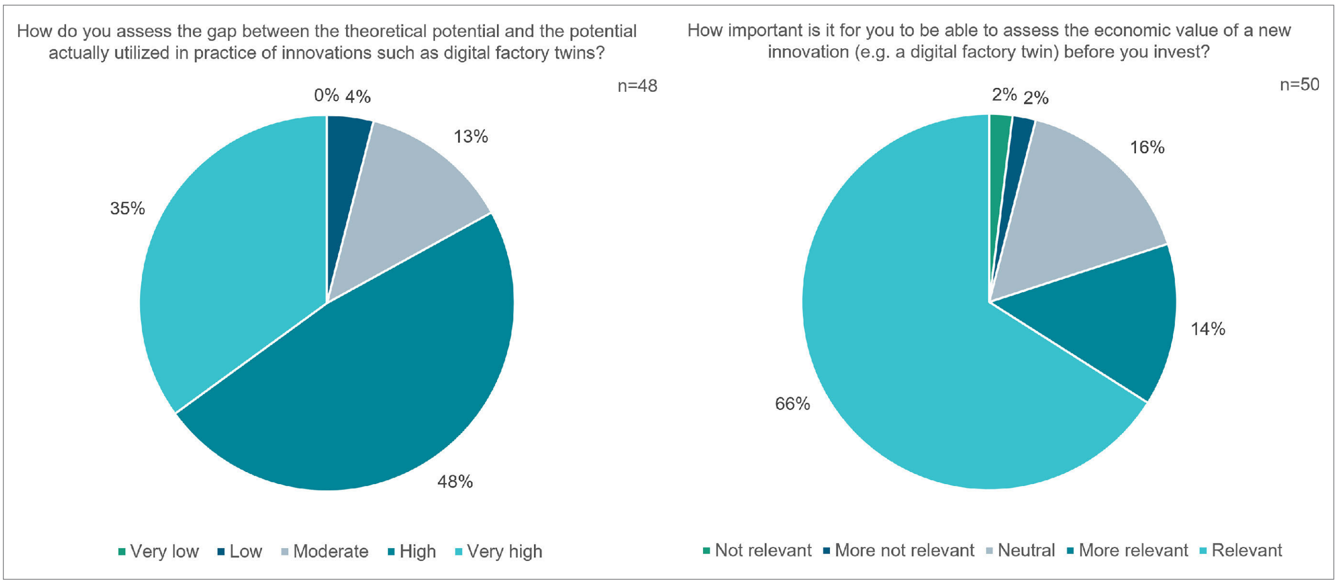


Fig. 8 Potential and decision criteria for the implementation of new technologies for indirect organizational processes. *Source: Fraunhofer IGCV*

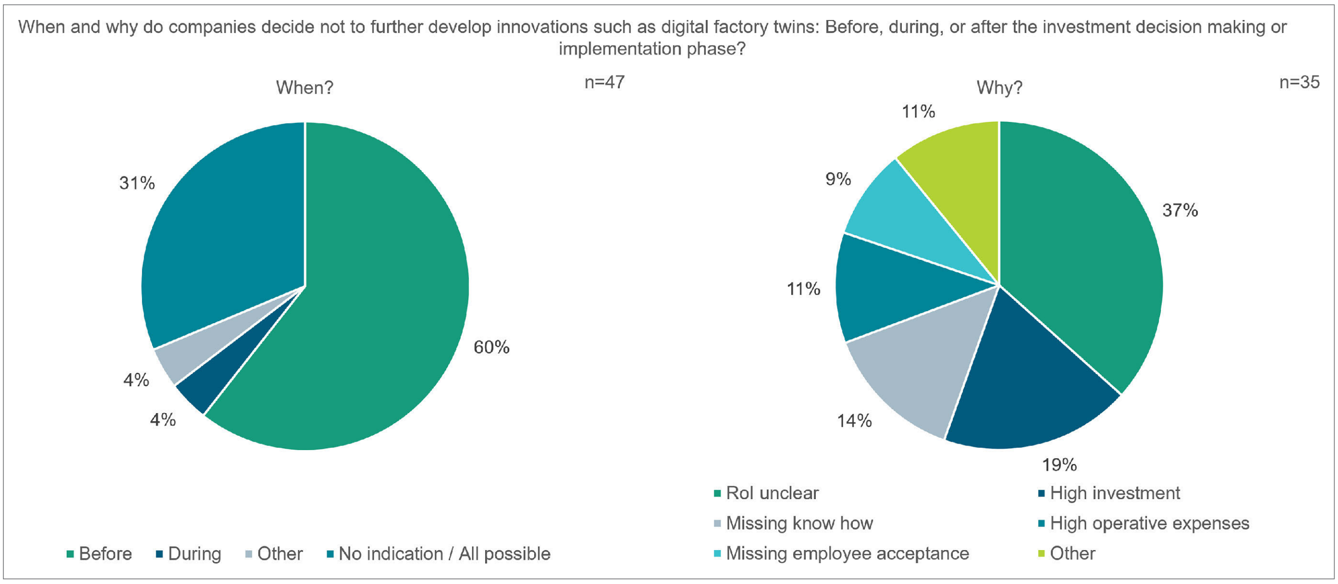


Fig. 9 Timing and rationale for discontinuing the development of innovations for indirect organizational processes. *Source: Fraunhofer IGCV*

majority reported frequently attaining quality targets. Moreover, it has been proven that organizational risks have a significant negative impact on the accomplishment of objectives in factory planning projects. In the context of a continuously updated factory planning basis, hypotheses H3 and H4 can be accepted. This suggests that additional target values should be considered within the framework of short-cycle factory planning, and that process-related information should be updated between replanning cycles.

Conversely, the fifth hypothesis must be rejected considering the study's findings. The necessity of updating information related to workers between replanning cycles has not been validated. In the context of introducing new technologies for indirect business processes, the sixth and seventh hypotheses can be accepted. This finding suggests a noticeable discrepancy between the theoretical potential and the practical utilization of innovations such as DFTs. Furthermore, the importance of evaluating the economic value of an innovation before making an investment decision is emphasized. Hypothesis H8 can be accepted, as there is no significant proportion of participants who indicate using PLM systems to describe and assess uncertainties in product development during factory planning.

6 Conclusion and outlook

This paper presents a mixed-methods study on current trends in factory planning. Based on a literature review, existing challenges and future needs were identified, and hypotheses were derived. Subsequently, the questionnaire results were used to test these hypotheses and gather new data on current trends in factory planning. The central findings of the study can be concluded in six key points:

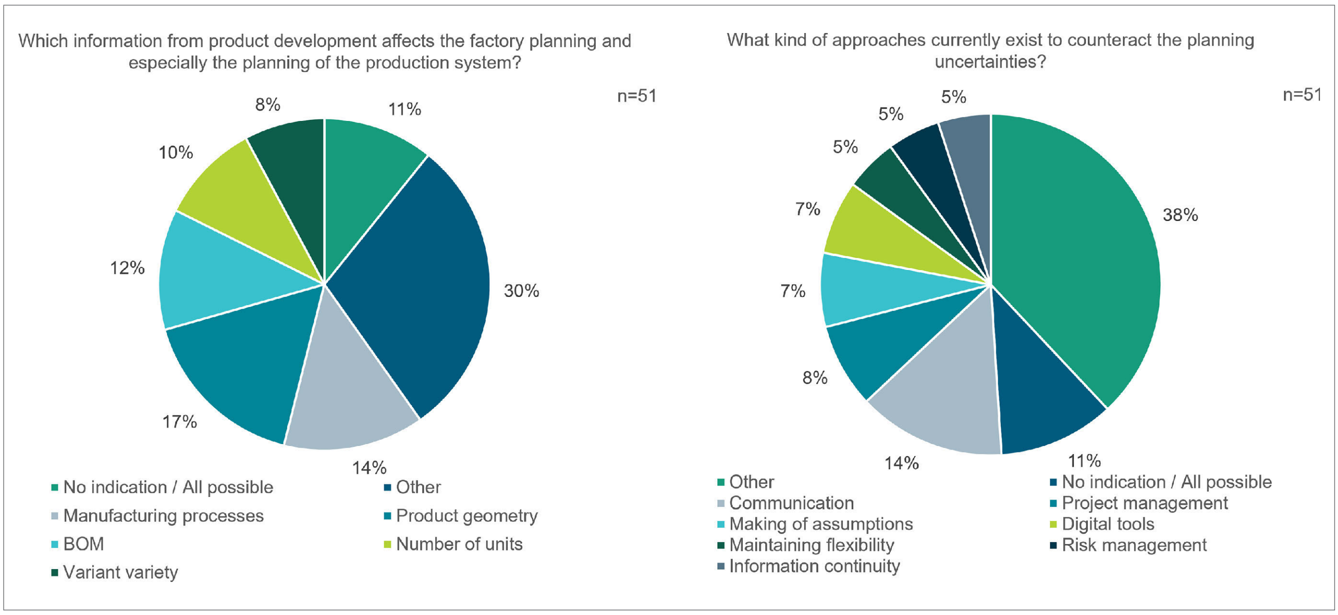


Fig. 10 Information from product development affecting factory planning and approaches to counteract planning uncertainties. *Source: Fraunhofer IGCV*

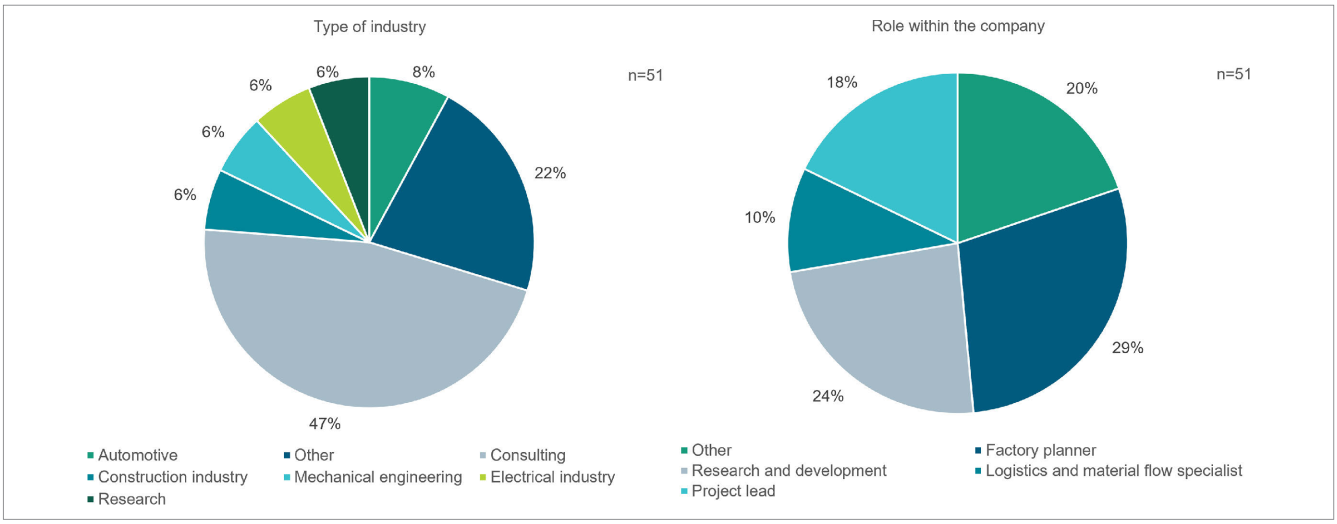
Question	Q1			Q2	Q3					Q4						Q5				Q6	Q7	Q8	Q9		Q10	Q11
Description	Quality	Cost	Date	Methods and Tools	Organizational	Legal	Scheduling	Market	Environmental	Reaction time	Replanning costs	Planning quality	Worker acceptance	Flexibility	Changeability	Alphanumeric	Process	Geometric	Worker	Technologies	Existing gap	Potential assessment	When	Why	Information	Existing Approaches
Industry	0,85	0,86	0,99	0,00	1,00	0,55	0,90	0,99	1,00	0,82	0,89	0,29	0,00	0,96	0,41	0,16	0,33	0,76	0,00	1,00	0,13	0,03	0,99	0,99	1,00	0,05
Role	0,96	0,91	0,03	0,05	0,03	0,53	0,70	1,00	0,16	0,90	0,94	0,99	0,64	0,91	0,00	0,95	0,58	0,99	0,79	1,00	0,61	0,07	0,02	1,00	0,00	0,08
Size	0,30	0,29	0,23	0,93	0,49	0,52	0,00	0,42	0,20	0,92	0,51	0,00	0,00	0,29	0,80	0,55	0,99	0,16	0,00	0,60	0,00	0,38	0,00	0,82	0,91	0,69
Location	0,24	0,19	0,02	0,95	0,00	0,00	0,00	0,32	0,32	0,00	0,07	0,00	0,05	0,57	1,00	0,00	0,90	0,39	0,00	0,93	0,07	0,00	0,41	0,50	0,93	0,91
Experience	0,19	0,96	0,07	0,83	0,43	0,94	0,00	0,26	0,93	0,24	0,99	0,36	0,43	0,17	0,00	0,77	0,89	0,17	0,24	0,75	0,02	0,11	0,42	0,40	0,46	0,68

Fig. 11 Correlation of answers and sociodemographic background. *Source: Fraunhofer IGCV*

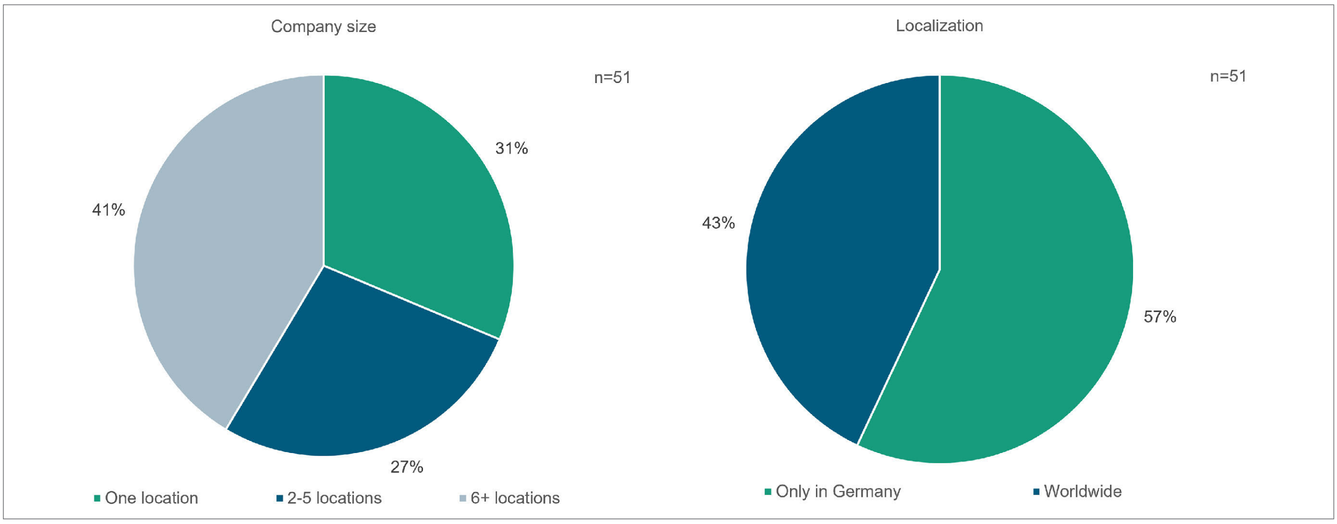
1. Considering the risk management, the objectives defined at the start of the project cannot currently be fully met in factory planning projects.
2. While knowledge regarding the specific risks in the domain of factory planning is already being gathered in analog form, this information has yet to be used systematically. Currently, it is primarily linked to individual experiences.
3. In the future, it will be necessary to develop specific approaches to address the organizational challenges encountered in factory planning projects.
4. In the context of shorter-cycle factory replanning, a continuously updated factory planning basis that primarily includes alphanumeric and geometric resource-specific information, as well as process-related data, is highly relevant. The study identified four main technologies: DFT, BIM, laser scanning, and IM. The actual implementation of this constantly updated factory planning basis remains an area for future research.
5. The implementation of innovations, such as a continuous, up-to-date factory planning basis, is closely linked to ROI, and in order to be applied, ex-ante evaluations may be necessary. This could also be an area of future research.
6. Regarding the uncertainties at the interface between product development and factory planning, PLM systems are currently rarely used to describe and assess the uncertainties of product development in factory planning. Therefore, further research on this topic is necessary. In this context, it seems sensible to also fully identify the relevant information that needs to be transferred between the two domains.

As shown in these key findings, further research is necessary to address the four trends in factory planning considered in this paper. The data collected in this study can serve as an additional database in this context.

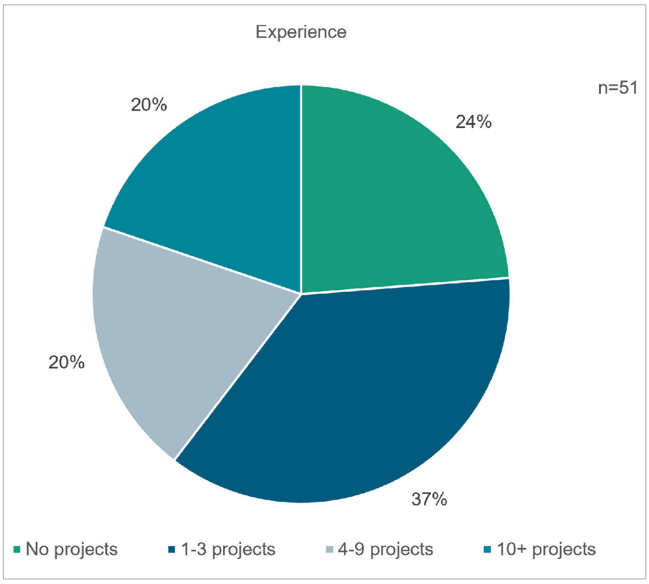
Appendices



Appendix 1 Type of industry and role within the company. *Source: Fraunhofer IGCV*



Appendix 2 Company size and localization. *Source: Fraunhofer IGCV*



Appendix 3 Experience. *Source: Fraunhofer IGCV*

LITERATUR

[1] Statistisches Bundesamt: Baufertigstellungen im Hochbau. Deutschland, Jahre, Bautätigkeiten, Gebäudeart. Stand: 2026. Internet: www-genesis.destatis.de/datenbank/online/table/31121–0001. Zugriff am 19.02.2026

[2] Bermpohl, F.; Schäfer, S. F.; Hohmann, A. et al.: Short-cycled factory planning – motivation and existing challenges. Procedia CIRP 130 (2024), pp. 1708–1713

[3] Burggräf, P.; Adlon, T.; Schupp, S. et al.: Die Modullandkarte des Aachener Fabrikplanungsvorgehens. Zeitschrift für wirtschaftlichen Fabrikbetrieb 116 (2021) 12, S. 866–871

[4] Deutsches Institut für Normung: DIN ISO 31000:2018. Risikomanagement. Deutsche Fassung, Ausgabe 10/2018

[5] International Electrotechnical Commission: IEC 31010:2019. Risk management – Risk assessment techniques. Ausgabe 06/2019

[6] Neuhäuser, T.; Spiegelsperger, S. M.; Hohmann, A. et al.: Relevanz von BIM in der Fabrikplanung. wt Werkstattstechnik online 113 (2023) 03, S. 93–100. Düsseldorf: VDI Fachmedien, https://doi.org/10.37544/1436–4980–2023–03

[7] Bermpohl, F.; Schäfer, S. F.; Neumann, O. et al.: Industrial study on holistic digital factory models. Production Engineering 19 (2025), pp. 1093–1118, https.//doi.org/10.1007/s11740–025–01344-z

[8] Burggräf, P.; Adlon, T.; Schupp, S. et al.: Risk Management in Factory Planning – A Literature Review. Procedia CIRP 104 (2021), pp. 1191–1196

[9] Unzeitig, W.; Rubesa, J.; Schafler, M. et al.: Eine Methode zur Berücksichtigung von Unsicherheit im Zuge der frühen Fabrikplanung in der

Auftragsfertigung von Gesamtfahrzeugen. e & i Elektrotechnik und Informationstechnik 131 (2014) 7, S. 212–218
[10] Burggräf, P.; Adlon, T.; Schupp, S. et al.: Risk Assessment in Factory Planning Projects – An Empirical Evaluation of Industrial Practice. In: Andersen, A.-L.; Andersen, R.; Brunoe, T. D. et al. (eds.): Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems. Cham: Springer International Publishing 2022, pp. 543–550
[11] Urschel, O.: Risikomanagement in der Immobilienwirtschaft. Ein Beitrag zur Verbesserung der Risikoanalyse und -bewertung. Karlsruher Institut für Technologie (KIT), Dissertation, 2010
[12] Marzouk, M.; Enaba, M.: Text analytics to analyze and monitor construction project contract and correspondence. Automation in Construction 98 (2019), pp. 265–274
[13] Alsubaey, M.; Asadi, A.; Makatsoris, H.: A Naïve Bayes approach for ews detection by text mining of unstructured data: a construction project case. 2015 SAI Intelligent Systems Conference (IntelliSys), London, 2015, pp. 164–168
[14] Zou, Y.; Kiviniemi, A.; Jones, S. W.: Retrieving similar cases for construction project risk management using Natural Language Processing techniques. Automation in Construction 80 (2017), pp. 66–76
[15] Helmus, M.; Meins-Becker, A.; Eilers, M. et al.: BIM-basiertes Risikomanagement. Maßnahmen zur Umsetzung eines effizienten Risikomanagements bei Bauprojekten. Internet: www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/bbsr-online/2023/bbsr-online-04–2023.html. Zugriff am 19.02.2026
[16] Neuhäuser, T.; Michaeli, P.; Lenz, L. et al.: Collaborative Factory Layout Planning With Building Information Modeling. Hannover: publish-Ing 2021
[17] Bermpohl, F.; Eckart, C. J.; Neuhäuser, T. et al.: Method for Digital Information Continuity in Factory Design. Procedia CIRP (2026), Status: Accepted, doi.org/10.24406/PUBLICA-5993 (Preprint)
[18] Moretti, N.; Xie, X.; Merino, J. et al.: An openBIM Approach to IoT Integration with Incomplete As-Built Data. Applied Sciences 10 (2020) 22, #8287, doi.org/10.3390/app10228287
[19] Feldmann, K.; Reinhart, G.: Simulationsbasierte Planungssysteme für Organisation und Produktion. Modellaufbau, Simulationsexperimente, Einsatzbeispiele. Heidelberg: Springer 2000
[20] Bermpohl, F.; Eckart, C. J.; Forte, S. et al.: Method for Digital Information Continuity in the Context of Short-Cycled Factory Replanning. Springer Journal of Intelligent Manufacturing (2026), Status: Under Review. Exptected to be published in 2026
[21] Kaucher, C.; Erlach, K.; Bauernhansl, T.: Planning Method for Future-Proof Factory Buildings. Procedia CIRP 120 (2023), pp. 15–20
[22] Wiendahl, H.; Heger, C.: Justifying Changeability. A Methodical Approach to Achieving Cost Effectiveness. Journal for Manufacturing Science and Production 6 (2004) 1–2, pp. 33–40
[23] Dombrowski, U.; Karl, A.; Imdahl, C.: The Role of Participation in the Factory Planning Process. 2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bangkok, 2018, pp. 957–960
[24] Luber, M.; Neuhäuser, T.; Bank, L. et al.: Die Konvergenz des Building Information Models und des Digitalen Zwillings im Fabriklebenszyklus. Zeitschrift für wirtschaftlichen Fabrikbetrieb 119 (2024) 1–2, S. 101–107
[25] Gan, V. J.; Hu, D.; Zhai, R. et al.: Automated As-built 3D Reconstruction Using Quadruped Robot and 3D LiDAR Sensor. 41st International Symposium on Automation and Robotics in Construction (ISARC 2024) (2024), pp. 129–135, https://doi.org/10.22260/ISARC2024/0018
[26] Lind, A.; Högberg, D.; Syberfeldt, A. et al.: Evaluating a Digital Twin Concept for an Automatic Up-to-Date Factory Layout Setup. Advances in Transdisciplinary Engineering 21 (2022) SPS2022, https://doi.org/10.3233/ATDE220166
[27] Hellmuth, R.; Wehner, F.; Giannakidis, A.: Approach for an Update Method for Digital Factory Models. Procedia CIRP 93 (2020), pp. 280–285
[28] Raber, A.; Bermpohl, F.; Böck, J. et al.: Method for Continuously Updating Holistic Digital Factory Models in Learning Factory Operation. Conference on Learning Factories CLF 2026. Springer Lecture Notes in Networks and Systems (2026). Status: Under Review
[29] Spitzhirn, M.; Ullman, S.; Bauer, S. et al.: Digital production planning and human simulation of manual and hybrid work processes using the ema Software Suite. Proceedings of the 7th International Digital Human Modeling Symposium Archive 7 (2022) 1, #2, https://doi.org/10.17077/dhm.31740
[30] Pimenta, M. L.: Cross-functional integration in product development processes in the era of industry 4.0. Revista Produção e Desenvolvimento 5 (2019), https://doi.org/10.32358/rpd.2019.v5.350
[31] Kober, C.; Algan, B. N.; Fette, M. et al.: Relations of Digital Twin Fidelity and Benefits: A Design-to-Value Approach. Procedia CIRP 119 (2023), pp. 809–815
[32] Sommer, M.; Stjepandić, J.; Stobrawa, S. et al.: Improvement of Factory Planning by Automated Generation of a Digital Twin. In: Pokojski, J.; Gil, M.; Newnes, L. et al. (Hrsg.): Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications. Amsterdam: IOS Press 2020
[33] Pires, F.; Souza, M.; Ahmad, B. et al.: Decision Support Based on Digital Twin Simulation: A Case Study. In: Borangiu, T.; Trentesaux, D.; Leitão, P. et al. (Hrsg.): Service Oriented, Holonic and Multi-Agent Manufacturing Systems for Industry of the Future. Cham: Springer International Publishing 2021, pp. 99–110
[34] Liepert, C.; Stary, C.; Lamprecht, A. et al.: Improving Interoperability in the Exchange of Digital Twin Data Within Engineering Processes. In: Elstermann, M.; Dittmar, A.; Lederer, M. (Hrsg.): Subject-Oriented Business Process Management. Models for Designing Digital Transformations. Cham: Springer Nature Switzerland 2023, pp. 131–150
[35] Neto, A. A.; Deschamps, F.; Da Silva, E. R. et al.: Digital twins in manufacturing: an assessment of drivers, enablers and barriers to implementation. Procedia CIRP 93 (2020), pp. 210–215
[36] Fuller, A.; Fan, Z.; Day, C. et al.: Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access 8 (2020), pp. 108952–108971
[37] Malik, A. A.: The Economic Impact of Digital Twin Technology on Manufacturing Systems. 2024 Winter Simulation Conference (WSC), Orlando, FL, USA, 2024, pp. 1623–1633
[38] Day, G. S.; Schoemaker, P. J. H.: Avoiding the Pitfalls of Emerging Technologies. California Management Review 42 (2000) 2, pp. 8–33
[39] Bracht, U.; Geckler, D.; Wenzel, S.: Digitale Fabrik. Methoden und Praxisbeispiele. Heidelberg: Springer Vieweg 2018
[40] Verein Deutscher Ingenieure: VDI 4499 Blatt 3: Digitale Fabrik – Datenmanagement und Systemarchitekturen. Deutsche Fassung 02/2023
[41] Nyhuis, P.; Wulf, S.; Klemke, T. et al.: Integrative factory, technology, and product planning-systemizing the information transfer on the operational level. Production Engineering 4 (2010) 2–3, pp. 231–237
[42] Stade, D.; Spoor, J. M.; Manns, M. et al.: Process time distribution simulation in robotic assembly line balancing. International Journal of Production Research 63 (2025) 10, pp. 3467–3484
[43] Reinema, C.; Pompe, A.; Nyhuis, P.: Agiles Projektmanagement. Zeitschrift für wirtschaftlichen Fabrikbetrieb 108 (2013) 3, S. 113–117
[44] Döring, N.: Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften. Heidelberg: Springer 2023
[45] Molina-Azorin, J.; Cameron, R.: The Application of Mixed Methods in Organisational Research: A Literature Review. Electronic Journal of Business Research Methods 8 (2010), pp. 95–105
[46] Hunziker, S.; Blankenagel, M.: Research design in business and management. A practical guide for students and researchers. Heidelberg: Springer Gabler 2024
[47] Döring, N.; Bortz, J.; Pöschl, S. et al.: Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften. Heidelberg: Springer 2016

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