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DEVELOPMENT OF A MATURITY MODEL FOR THE DIGITAL TRANSFORMATION OF COMPANIES IN THE CONTEXT OF CONSTRUCTION INDUSTRY 4.0

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SUMMARY: *The construction industry is characterized by a low level of productivity and digitalization, as well as the critical perceived instability of costs, deadlines and quality. One way to address these challenges is to increase the use of digital methods and technologies in the future. Optimal use of these can help to improve the quality of planning and execution and optimize the operation of existing buildings. The challenge is the implementation and integration of these methods and technologies into existing company structures. In many cases, companies do not have a unified understanding of the current state of digitization in their organization. This article closes this research gap and presents the development of a novel maturity model for construction companies in the context of Construction Industry 4.0, the Digital Construction Company Maturity Model (DCCMM). Based on a literature review, the appropriate technologies used in the construction industry are identified and the basic requirements for the maturity model are defined. Once implemented, the model comprises five dimensions and 28 assessment parameters that describe digital transformation across six maturity levels. The conceptual model is tested and validated in eight construction companies. This is done in the context of qualitative interviews. The DCCMM serves as a holistic framework for the individual classification of companies in terms of digital transformation. This provides construction companies with a transparent and comprehensible indication of the degree of digitalization of their own structures. The result will make a significant contribution to further digitalization in the construction industry.*

KEYWORDS: *maturity model, digital transformation, construction industry, Construction 4.0, Industry 4.0, digitalization und automation, construction companies, strategy.*

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1. INTRODUCTION

The German construction industry has been struggling for several decades with nearly stagnating productivity (Abdel-Wahab and Vogl, 2011; Berlak et al., 2021) Compared to other sectors, such as the automotive industry or the manufacturing sector, the construction industry's development lags behind (Barbosa et al., 2017; Gerbert et al., 2016). The use of digital technologies and methods is seen as an opportunity to face this problem and increase productivity in the construction industry (Berlak et al., 2021) . In this context, the construction sector can adapt developments and standards from other sectors as inspirations for improvement (Dubois and Gadde, 2002; Ribeirinho et al., 2020; Uusitalo and Lavikka, 2021). In the manufacturing industry, "Industry 4.0", derived from the fourth industrial revolution, has become established in the context of digitalization and disruptive technologies, coming from the field of information and communication technology (Dalenogare et al., 2018; Ghobakhloo, 2020; Roth, 2016b). The term "Industry 4.0" is mainly used in Germany and the rest of Europe (Santos et al., 2017). In an international context, terms such as "cyber-physical systems", "smart factory" or "advanced/smart/digital manufacturing/production/industry" are often used instead (Bagnoli et al., 2022; Culot et al., 2020; Liao et al., 2017; Nagl and Bozem, 2018). Industry 4.0 is not a rigid concept. It is a multi-layered one consisting of numerous interacting, though not necessarily new, technologies and methods (Bécue et al., 2021; Moeuf et al., 2020; Pereira and Romero, 2017; Santos and Martinho, 2020). At the center of the concept is the integration of new information and communication technologies (ICT) into automated industrial production via cyber-physical systems (CPS) (Pereira and Romero, 2017). The accompanying digital transformation optimizes value creation and opens up new business potentials (Aquilani et al., 2020; Veile et al., 2022).

Although the requirements of the construction sector differ from those of the manufacturing sector, the concept of Industry 4.0 can be transferred to the construction industry in an adapted form (Hossain and Nadeem, 2019). The term "Construction 4.0" has become established to describe the adoption and implementation of the Industry 4.0 concept by the construction sector (Forcael et al., 2020). It includes the digitalization of the construction industry, together with an industrialization of processes along the entire value chain and over the complete life cycle of a structure (Kolaei et al., 2022). The goal of the construction industry through Construction 4.0 is to comprehensively increase energy and resource efficiency with the help of digitalization, and thus to increase productivity and effectiveness (Sawhney et al., 2020; Siriwardhana and Moehler, 2023). In contrast to the manufacturing sector, which has already integrated large parts of the Industry 4.0 concept into its processes (Kagermann and Wahlster, 2022), the various technologies of the Construction 4.0 concept are of widely varying degrees of maturity and still need time to be fully implemented (Bakalis et al., 2024).

To enable a systematic implementation and integration of "Construction 4.0" in the companies of the industry, it is necessary to determine the current position of these companies with regard to their digital transformation and their capabilities in connection with Construction 4.0. Only then will it be possible to develop appropriate recommendations for action and uncover potentials for the advancement of the digital transformation of construction companies and thus of the entire construction industry. In the manufacturing sector, maturity models are often used to measure the status quo of a company and to access further capabilities. This approach is also common in the construction industry. Maturity models are suitable for determining the position of a company with regard to its capabilities in a previously defined subject area. (Fraser et al., 2002).

The subject areas considered within the scope of maturity models in the construction industry range from traditional topics such as project management and occupational health and safety to topics that have become more relevant in recent decades, such as environmental protection, lean management, or digitalization (Das et al., 2022). The authors conducted a literature review to explore the status quo of maturity models in the construction industry for the specific topic of this paper. The following parts are based on this review. They cover the existing literature, starting with maturity models on Building Information Modeling (BIM). Furthermore, existing models about digitalization in general as well as Industry 4.0 in construction are analyzed and described in the last section.

BIM is seen as an enabling technology for digitalization in the construction industry (Borrmann et al., 2018; Hossain and Nadeem, 2019). Various models and tools based on the BIM-method have been developed in recent years (Adekunle et al., 2022; Kassem and Li, 2020). The most frequently cited models in the literature are the BIM Quick Scan (BIMQS) (Rizal and van Berlo, 2010) for application to organizations, the Capability Maturity Model

(CMM) (NIST, 2007) for application to projects, and Succar's BIM maturity matrix (Succar, 2010), which is mainly of theoretical interest (Alankarage et al., 2022). Even if BIM is seen as a key factor for the digitalization of the sector (Borrmann et al., 2018), these BIM maturity models only reflect one single aspect and therefore are not appropriate to measure digitalization as a whole, nor the “Construction 4.0” capabilities of a company.

Maturity models that generally deal with the digitalization of actors in the construction industry are rather rare, in comparison to the previously mentioned BIM maturity models. Only two publications with such approaches were identified (Aghimien et al., 2021; Wernicke et al., 2023). The first model was presented by (Aghimien et al., 2021). It does not have a specific name but is referred as a Conceptualised Digitisation Capability Maturity Model (DCMM) by the authors of the model. The authors state that their model is the first to assess the digitalization capabilities of construction organizations. The model comprises six dimensions, namely Technology, People, Process, Strategy, Digital Partnering and Environment, each of which contains so-called sub-attributes. In the Technology dimension, elements of Industry 4.0, e.g “Big Data Analytics” or “Additive Manufacturing”, are already included as sub-attributes. In the second publication by (Wernicke et al., 2023), the Digital Maturity Assessment Framework for Construction Site Operations is presented. The object of consideration is therefore limited to construction site processes. In the model, five assessment criteria are defined, which are comparable to the dimensions of a maturity model. The assessment criteria are Individuals, Technologies, Organizational Structure, Goals and Environment. A total of 11 evaluation areas are specified in the assessment criteria. Furthermore, there is no detailed breakdown into sub-attributes or similar classifications. In conclusion, both maturity models for the digitalization of a construction company are not able to assess all Construction 4.0 capabilities. This is due to the lack of reference of both authors to the fundamental and essential requirements of the Construction Industry 4.0.

(Das et al., 2022) and (Tuma Neto and Araujo de Souza Junior, 2022) stated in 2022 that a publication with a focus on maturity models for Construction 4.0 or models for Industry 4.0 in the construction industry does not exist. However, the previous mentioned literature review revealed one publication which, according to its title, appears to deal with the topic of Construction 4.0 maturity. The publication by (Wang et al., 2020) presents a Building Project-Based Industrialized Construction Maturity Model. After analyzing the article, however, it can be concluded that the model developed by (Wang et al., 2020) is more likely to be classified in the area of project management and prefabrication. Aspects of Construction 4.0 are not included in the model. In this way, the statement by (Das et al., 2022) and (Tuma Neto and Araujo de Souza Junior, 2022) about a research gap in tools to measure Construction 4.0 maturity could be confirmed. This research gap has been addressed by various authors since the second half of 2022. A current total of four publications in the area of maturity models for Construction 4.0 was identified. In the four publications (Das et al., 2022, 2023; Heidenwolf and Szabó, 2023; Tuma Neto and Araujo de Souza Junior, 2022), three maturity models for Construction 4.0 are presented. The three models are analyzed in more detail in the following sections. The first publication is the one already mentioned by (Das et al., 2022). In addition to a state-of-the-art analysis, the authors developed a maturity model called Smart Modern Construction Enterprise Maturity Model (SMCeMM). The maturity model includes seven dimensions - Data Management, People and Culture, Automation, Collaboration and Communication, Leadership and Strategy, Change Management, and Innovation. The categories are not described in more detail or characterized by criteria. Likewise, no maturity levels have been defined. Overall, in the publication of 2022, the model was rather conceptual. The missing parts of the maturity model were completed and validated in an article by the same authors published in 2023 (Das et al., 2023). Further criteria were established for the dimensions already mentioned. The maturity levels were classified using five levels from ad-hoc to innovative. Even if a fully developed maturity model is presented, there are open Construction 4.0 issues that are not addressed by the SMCeMM. First, the model was developed specifically for construction general contractors, so it is limited to just one group of stakeholders. Moreover, the model was not tested in case studies with construction firms and therefore lacks empirical validity (Das et al., 2023).This research gap has been addressed by various authors since the second half of 2022. A current total of four publications in the area of maturity models for Construction 4.0 was identified. In the four publications (Das et al., 2022, 2023; Heidenwolf and Szabó, 2023; Tuma Neto and Araujo de Souza Junior, 2022), three maturity models for Construction 4.0 are presented. The three models are analyzed in more detail in the following sections.

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In September 2022, another article was published by (Tuma Neto and Araujo de Souza Junior, 2022), which presents a maturity model for Industry 4.0 in construction. The model does not have a proper name. It was developed following the method of (Bruin et al., 2005) and based on existing maturity models from other industries. It was tested with seven Brazilian companies. The presented model includes four dimensions - Organisation, People, Technology and Sustainability. The dimensions are each characterized by three to five sub-dimensions or criteria. The maturity level is assessed using six different levels (from 0 to 5). From the description of the maturity model alone, it is not clear how the organizations can assign corresponding levels to the individual sub-dimensions. In addition, there is no individual explanation of the levels for each sub-dimension. Furthermore, although the model is based on various models from other industries, it does not consider any specifics relating to the requirements of Construction 4.0.

The fourth publication deals with a maturity model, called maturity tool for Construction 4.0, published by (Heidenwolf and Szabó, 2023). The model refers to the maturity of an organization. It was also developed following de Bruin's method (Bruin et al., 2005) and using ontology development. The maturity model was tested in a case study with a Hungarian company. Overall, the model consists of six dimensions - Technology Management and Business Applications, Culture and People Management, Collaboration and Communication, Technology for Automation, Innovation, Change Management and Processes. Detailed criteria and maturity levels are planned to be developed in future research. So, the maturity model is still in a conceptual phase and needs further work to be applicable for construction enterprises.

As the results of the literature analysis show, there are currently only a few approaches and no detailed maturity models for Industry 4.0 in the construction sector. Each paper has deficiencies in relation to the problem of designing a maturity model that fulfills the following three requirements: First, it deals explicitly with Construction 4.0 and the specific needs of the construction industry. Second, it is applicable to all types of construction enterprises. Third, the model has been tested and validated by application to construction enterprises in practice. Nevertheless, none of the existing models was designed or tested with a focus on the German construction sector, with its typically fragmented structure. (Kehl et al., 2022; Miozzo and Dewick, 2004) A new model therefore needs special considerations to depict the maturity of very different companies as well as varying stages of development. This leads to the need to present a complete maturity model, enabling all kinds of construction enterprises to measure their own capabilities in the specific domain of Construction 4.0. Therefore, an elaborate but clearly defined model including a catalogue of level descriptions for each criterion is necessary. The development of such a maturity model is presented in this article. This includes the entire development process through to implementation and evaluation with construction companies. The proposed model aims to use this approach to develop appropriate recommendations for action and uncover the existing potential of Construction 4.0 for companies. This can drive forward the digital transformation of German construction companies and counteract the aforementioned dilemma of stagnating productivity.

2. METHODOLOGY

The article is structured into three parts - (i) Status quo of Maturity Models, (ii) Development of the DCCMM and (iii) Validation of the DCCMM. After a comprehensive insight into the concept of Construction 4.0 and the current status of maturity models in the construction industry, given in the introduction, the article presents the topic of maturity models, describing the basic characteristics of maturity models and existing development approaches. At the same time, established assessment methods are described. In the second part of the article, the DCCMM is developed. First, the goal of the maturity model is described, and the design area and basic requirements are defined. Second, the concept is implemented based on the defined fundamentals. In this course, the superordinate maturity levels are determined as well as the dimensions and individual assessment elements of the model. Furthermore, a consistent visualization is derived at the end of the process to ensure that the maturity model and its contents are understandable. Afterwards, the model is tested and validated. Eight companies are classified and compared in a direct model application. Qualitative and guideline-based expert interviews provide the information basis for optimizing the model and classifying the companies. The interviews are analyzed using qualitative content analysis according to (Mayring, 2015). Based on the results, the different companies are categorized directly by their level of maturity. In addition, a direct comparison is made between all eight companies in the discussion. Furthermore, the results of the development and validation are summarized, limitations and future research activities are highlighted, and a conclusion is provided at the end.

3. MATURITY MODELS

Maturity models are used to represent individual maturity using aspects that are considered within structured elements. In this way, both the current position of a company and possible subsequent action steps can be derived. Maturity models have an optimizing and evaluating function in addition to their descriptive function. As an established instrument of quality management, maturity models are used repeatedly. Applying a maturity model, the first step is to describe the current status quo, then to derive recommendations for optimal further development, and finally to evaluate the improvement process through regular checks. An iterative approach for continuous evaluation of the model must be used to ensure topicality. In addition, each model must be critically questioned during application. (Fraser et al., 2002; García-Mireles et al., 2012)

3.1 Characteristics and frameworks

In order to best represent the development status of the individual maturity levels, dimensions or process areas are represented by maturity levels that correspond to a characteristic performance (Fraser et al., 2002). The following components can be found in maturity models (Fraser et al., 2002):

- Number of levels or steps
- Characteristic expression per maturity level
- Description of specifications that represent the respective level
- Number of dimensions that adequately correspond to the observation and design area
- Elements that describe the respective dimension
- Explanation of element characteristics per maturity level

The number of levels and dimensions is freely selectable by the author representing the complexity of the model. General maturity models contain three to six maturity levels. (Fraser et al., 2002) Furthermore, maturity models can be differentiated by the specification of the development path. If this is explicitly specified in the model, it is an optimization model. If this is not the case and the mostly dynamic development path is unspecified in the model, it is an evaluation model. (Mettler, 2011; Tontini et al., 2016)

If maturity models are differentiated according to their structure, they can be either grid-based, formally structured or hybrid, depending on the type of explanation (Lee et al., 2019; Monteiro and Maciel, 2020; Sanchez-Puchol and Pastor-Collado, 2017). The generation process and design of maturity models depend on the author and the respective design area. Moreover, it is necessary to define a suitable design framework at the beginning of the development process. Already established methods and models such as the CMM and Software Process Improvement and Capability Determination (SPICE) can be considered as frameworks in the areas of product and software development. Regarding the quality management of the models, the Quality Management Maturity Grid (QMMG) can be used for orientation. (Dewi and Suhardi, 2014; Dorling, 1993; Fernandes et al., 2017; Mihajlović et al., 2021) If maturity models are differentiated based on their structure, these can be either grid-based, formally structured or hybrid, depending on their particular explanation type (Lee et al., 2019; Monteiro and Maciel, 2020; Sanchez-Puchol and Pastor-Collado, 2017).

3.2 Existing creation methods

The creation of maturity models is based on a process model. These may already exist specifically for different sectors and have been successfully applied. A process model represents the procedure in the development process and can be individually adapted to each maturity model to be designed. The starting point for the creation of a maturity model is always the problem definition, from which the relevance of the addressed problem can be determined. On this basis, successive phases of development are gone through finally evaluating and improving the model. The iterative procedure and the multiple repetitions of sub-steps form a central part of the development of maturity models. These sub-steps focus on the determination of the design area, choice of procedure, design of model range and review of the results. Based on this, various criteria can be worked out that need to be fulfilled. (Becker et al., 2009; Knackstedt et al., 2009; Raj et al., 2024)

The basis for the development of such a model is comprehensive literature research in the targeted design area. Already existing maturity models should be reviewed and compared prior to development. This allows weaknesses in existing models to be identified and gives rise to a new or further development of maturity models. Due to the iterative process, intermediate versions can be evaluated and modified on this basis. Further development of the model can then be carried out, the concept can be changed, or the entire model can be discarded. In the retrospective view of model development, the quality of the documentation plays a particularly important role and significantly influences the evaluation. (García-Mireles et al., 2012; Knackstedt et al., 2009) An established method for developing a maturity model is the approach of (Bruin et al., 2005), which comprises the following six phases of development and is used in the context of the article:

- Scope: the decisions on the scope of the maturity model are first made
- Design: a first draft of the structure or architecture of the maturity model is created
- Populate: this draft gets completed with descriptions of the previously identified structural levels
- Test: the previously conceptualized model is reconsidered, especially with regard to the aspects of relevance, validity, reliability and generalizability
- Deploy: the revised maturity model is made available for use
- Maintain: ongoing further development and updating of the model

Based on the creation methods described here, the iterative procedure and continuous further development should be particularly emphasized. In terms of traceability, various framework conditions that have a direct influence on the model are recorded for each evaluation step. Among these are the position of the modeler, the general and intended use of the model, the time required to create it and the underlying framework. This enables further insights and perspectives to be gained about the problem area, the target group and the people involved in the model (García-Mireles et al., 2012; Knackstedt et al., 2009; van Steenbergen et al., 2010).

3.3 Evaluation methods

Maturity models can be used to determine the current position of an organization in a specific topic area. For this purpose, it is necessary to apply a suitable method of assessment to determine the overall maturity level. The assessments can be quantitative or qualitative as well as weighted or unweighted. An established method of qualitative and unweighted assessment is the Likert scale (Döring, 2023; Joshi et al., 2015; Klooster et al., 2008). This comprises a gradual response scale for pre-formulated statements in questionnaires and thus maps on several levels how much the respective statement applies. It is suitable for evaluating any survey that includes the personal opinion of the respondent. In addition, a detailed evaluation is possible with its use, as the answer options are given at different levels. When using the Likert scale as a method of assessment, care must be taken to ensure that the items and characteristic values are formulated precisely. Misunderstandings can be avoided as there is usually no possibility of direct questioning. (Döring, 2023; Joshi et al., 2015; Klooster et al., 2008) The advantages of this assessment methodology are particularly evident in its informative value and versatility, as it can be used in almost any subject area. In addition, pre-formulated statements and given answer options allow for targeted and time-saving work with the option of branching. It is also advantageous that a very comprehensive picture of the respective characteristics can be made recognizable with the help of this analytical method. (Döring, 2023; Joshi et al., 2015; Klooster et al., 2008) On the other hand, the verbal anchoring is rather disadvantageous, as this means that the nuances between the expressions are not necessarily always the same as is the case with quantitative assessments, for example. In addition, by reflecting the opinion of the respondent, a subjective result is achieved in every case. These two aspects must be considered when interpreting the results to avoid a falsified or distorted presentation of the results. (Fink, 2003; Humble, 2020; Kanning et al., 2006)

Another method used in this context is the utility analysis, a quantitative and weighted method for evaluation and decision-making. It is particularly useful when there are many different aspects to be considered that cannot be assigned a clear ranking or when a large number of participants is involved in the decision-making process. The main challenge here is the great effort required for decision-making. Therefore, it is advisable to use this method mainly for concrete and complex questions. However, compared to simple survey results, this result is more reliable and more comprehensible. The advantages of the methodology lie in the detailed consideration of comprehensive aspects of the overall problem and thus a consideration of a multitude of perspectives. (Backhaus et al., 2021; Kühnapfel, 2019; Mishan and Quah, 2020)

Benefits and limitations of existing maturity models

4. Maturity models can be used in a variety of ways and are highly beneficial, but their weaknesses must always be critically examined. They form a scale for assessment and can thus be used to determine the position of companies on a specific issue. By the structured presentation of elements, the individual maturity of an organization can be determined based on previously denoted aspects which allows to answer various questions. The basis for this is the assessable units contained in the maturity model for measuring the achievement of objectives based on the defined maturity levels. Thus, it is possible to determine the current status and additionally orientate oneself via comparisons on the market. The main benefit of maturity models is the possibility of recording the current state, the derivation of suggestions for improvement, and recommendations for action based on the predefined stages. These stages are represented in the model at different levels, from the initial phase to full maturity. Through the application of questions and answer options, a specific issue can be examined in detail and concrete conclusions can be drawn from the results. However, it should also be noted that the result is influenced by these targeted questions and answer options, which is why their interpretation must always be included in the evaluation. (Adekunle et al., 2022; Kolukısa Tarhan et al., 2020).

The design of maturity models offers the creator various possibilities to customize the model. The type of maturity model as well as the number of levels and stages can be freely selected. In this way, they reflect the complexity of the issue and the aspects to be considered. Although this makes it possible to optimize the model individually about the expected results, the ensuing influence on the results must also be considered when interpreting them. (Aras and Büyüközkan, 2023) Furthermore, the results can also be influenced by the way they are applied. Maturity models can be used, for example, by an external auditor or as part of a self-assessment. This makes the models accessible to many companies and organizations, but the results from these two options of application differ significantly. In theit application, a dependency of the results and their quality on the respective model creator, model user, the underlying process model, the time of publication and the modeling language can be recognized. (bitkom, 2018; Boullauazan et al., 2023; Hein-Pensel et al., 2023) Therefore, it is important to take these aspects into account when interpreting the results and to carefully consider which problem area and target group are addressed and who was involved in the development of the model. (Bruin et al., 2005; Fraser et al., 2002; Rosemann and Bruin, 2005). In conclusion, maturity models should always be evaluated in terms of their objectivity, reliability and validity, and should be tested when used. It is also important to know when the model was published and thus to ensure that it is up to date or to critically question it. If the aforementioned aspects are taken into account in the evaluation and especially in the interpretation of the results, maturity models offer great benefits as the possibility of precisely determining the position of organizations and the associated depictability of development processes. (Crawford, 2021; Gökalp and Martinez, 2021; Ifenthaler and Egloffstein, 2020)

5. DEVELOPMENT OF THE DIGITAL CONSTRUCTION COMPANY MATURITY MODEL (DCCMM)

After the creation of a uniform understanding through the definition of the theoretical foundations as well as the presentation of the status quo, the Digital Construction Company Maturity Model is developed in the following section. At the beginning of the development process, the procedure and objective of the model development are defined, the design area is specified, and the frameworks used are determined. Subsequently, the concept of the maturity model is elaborated in a stepwise manner and the individual elements are described. At the end of the chapter, the transformation into a comprehensible visualization occurs.

5.1 Model definition

A maturity model serves as a framework for the classification of one of the certain objects in a specific circumstance (Wendler, 2012). The development process of this model is based on the approach of (Bruin et al., 2005). In in connection with this knowledge-based article, the development process pursues the goal of categorizing construction companies about digital transformation in the context of the construction industry 4.0. Construction companies are to be evaluated according to several technical, digital and strategic factors, classified into digitalization levels and compared with each other. Furthermore, the model also serves to derive recommendations for action for further development opportunities.

The design scope of the maturity model focuses on the three main components of digital transformation, construction companies, and Construction Industry 4.0. The aspect of digital transformation specifies that the model examines digital methods and technologies that can be used in the construction industry. Their use can sustainably increase the efficiency and productivity of construction companies (Barbosa et al., 2017; Ribeirinho et al., 2020). In addition, the relevance of digital data and its management becomes apparent from this. Another boundary condition is the applicability of the model to construction companies. This results in limitations on the digital methods and technologies that should be meaningful and useful for construction companies. Furthermore, it can be deduced that the model to be developed should be oriented toward the specifics and complexity of the construction industry (Sacks et al., 2020). The focus lies on companies involved in the construction execution phase. To ensure that the development of the new maturity model is efficient and that the strategic model ultimately guarantees a high level of consistency and comprehensibility, the basic structure is derived from existing and already established maturity models from other industries. The design scope of the maturity model focuses on the three main components of digital transformation, construction companies, and Construction Industry 4.0. The aspect of digital transformation specifies that the model examines digital methods and technologies that can be used in the construction industry. Their use can sustainably increase the efficiency and productivity of construction companies (Barbosa et al., 2017; Ribeirinho et al., 2020). In addition, the relevance of digital data and its management becomes apparent from this. Another boundary condition is the applicability of the model to construction companies. This results in limitations on the digital methods and technologies that should be meaningful and useful for construction companies. Furthermore, it can be deduced that the model to be developed should be oriented toward the specifics and complexity of the construction industry (Sacks et al., 2020). The focus lies on companies involved in the construction execution phase. To ensure that the development of the new maturity model is efficient and that the strategic model ultimately guarantees a high level of consistency and comprehensibility, the basic structure is derived from existing and already established maturity models from other industries. The DCCMM is based on the following existing maturity models (s. Tab. 1)

Table 1: Maturity Models for the DCCMM.

Name	Akkronym	Source
Capability Maturity Model	CMM	(Shen et al., 2021)
Software Process Improvement and Capability Determination	SPICE	(Dorling, 1993)
Digital Analytics & Optimization Maturity Index	DAOMI	(bitkom, 2018; Zumstein et al., 2022)

System Integration Maturity Model Industry 4.0	SIMMI 4.0	(Leyh et al., 2016)
The Digital Readiness Assessment Maturity Model	DREAMY	(Carolis et al., 2017)
Maturity Model for Digitalization	-	(Klötzer and Pflaum, 2017)
Maturity Levels for Cyber-Physical Systems	-	(Westermann et al., 2016)
Industry 4.0-Maturity Model	-	(Gökalp et al., 2017)
Industry 4.0 maturity model for machine tool companies	-	(Rafael et al., 2020)
Industry 4.0 readiness and maturity of manufacturing enterprises	-	(Schumacher et al., 2016)
Industry 4.0 Maturity Model - Environmental Attributes of Manufacturing Company	-	(Zoubek et al., 2021)
ISO 9004 maturity model	-	(Glogovac et al., 2022)

5.2 Model conception

In the definition phase of the model, the first step is to determine the maturity levels for the subsequent categorization. The individual assessment dimensions and their parameters are then determined. Furthermore, the DCCMM is enriched with a calculation system including the weighting of the individual dimensions. In this way, the evaluation of the companies and their classification into the corresponding maturity levels can be presented in a conclusive manner. (Fraser et al., 2002) recommend defining three to six maturity levels for the design of a maturity model.

The DCCMM is aligned with this recommendation and has a total of six maturity levels - (i) Level 0: Pre, (ii) Level 1: Initial, (iii) Level 2: Managed, (iv) Level 3: Established, (v) Level 4: Integrated, and (vi) Level 5: Optimized - are defined. These are presented in table 2 (Tab. 2).

Table 2: Definition of the maturity levels.

Maturity Level	Description
Level 0: Pre	In the case of companies classified in the "Pre" maturity level, neither a current orientation nor an endeavor toward digital transformation is discernible. The companies do not yet use any digital methods and technologies. Furthermore, there is also no effort to integrate transformation processes into the long-term strategy of the companies.
Level 1: Initial	The "Initial" maturity level includes companies that are not currently oriented toward a digital transformation of the company. Nevertheless, these companies have a direct ambition to implement initial transformation activities within a medium-term time horizon and already agreed on a strategic level.
Level 2: Managed	At the "Managed" maturity level, initial approaches to the application of technologies or methods are already being planned as part of the company's digital transformation. These transformation processes are already being tested in individual pilot studies and are being integrated into the operational structures of the company within a short-term time horizon and are being actively driven forward by senior management.
Level 3: Established	If a company is at the "Established" maturity level, individual technologies or methods are already being used successfully in individual structures in the operational area. At the same time, efforts are being made to expand digitization in the company and successively. Locally applicable procedures and approaches prevail as isolated solutions in proprietary data formats.
Level 4: Integrated	Companies at the "Optimizing" maturity level are already successfully using various technologies along several isolated process sequences with isolated interfaces in several interdependent areas. The company aims to continuously improve the efficiency and automation in a short-term time horizon. This results from cross-company and cross-technology networking with the creation of interoperable interfaces along the value chain.
Level 5: Optimized	In companies at the "Optimized" maturity level, all relevant technologies are successfully used throughout the company for construction. In addition, the technologies are networked and the interfaces are interoperable. Furthermore, a company uses open data exchange formats and interacts interorganizational with partners in the construction ecosystem.

As the next step, the assessment dimensions considered in the maturity model are specified. In Chapter 5.1, the three main components - Digital Transformation, Construction Industry 4.0 and the digital methods and technologies used - were defined for the design of the model. These are particularly important for the subsequent dimensioning. The holistic introduction of Industry 4.0 is based on the five central levels - projects, processes, technologies, organization and employees according to (Roth, 2016a; Santos and Martinho, 2020). These levels serve as the basis for deriving the model dimensions. As a result, the five dimensions (i) Technologies, (ii) Organization & processes, (iii) Culture & personnel, (iv) Data management and (v) Interconnectivity - are determined for the maturity model.

The first dimension “Technologies” forms a central consideration level in the introduction and implementation of Industry 4.0 in the company. It provides support, while the central role is fulfilled by the people as the final decision-makers. The technologies used also play a major role in the possibilities for data collection and processing. Only through the interaction of a wide range of technologies and services, the added value of digital transformation can fully be exploited. (Santos and Martinho, 2020; Westermann et al., 2016) The selection of the technologies under consideration is based on the typical technologies of Industry 4.0. These must also represent a direct benefit and added value for construction companies. In this context, the application of technologies such as robotics, cloud computing, the Internet of Things, immersive technologies (virtual & augmented reality) and artificial intelligence in the project structure of the construction companies will be addressed for the assessment. In the context of the DCCMM, the robotics assessment parameter considers the use of mobile, collaborative industrial robots in processes along the entire value chain (Jäkel et al., 2022).

The robot systems can be used, for example, for manufacturing processes of building systems on-site or in industrial prefabrication (Agustí-Juan and Habert, 2017; Bruckmann and Boumann, 2021; Wong Chong et al., 2022) as well as for scanning and monitoring work (Kim, Chen, Cho, 2018; Kim, Chen, Kim, Cho, 2018). The second parameter of the Technologies domain focus on the use of cloud computing in different service models. This implies both the storage of data as well as the use of software applications (software-as-a-service), platforms (platform-as-a-service) and holistic infrastructures (infrastructure-as-a-service). (Srinivasan, 2014) The third assessment parameter includes the use of sensor technology in the context of the IoT approach in the areas of a construction company or on construction sites. For example, IoT is used for tracking materials in construction logistics (Kumar and Shoghli, 2018; Zhao et al., 2021), integration into safety management (Chung et al., 2023; Kim et al., 2019) on the construction site or for construction progress monitoring (Qureshi et al., 2021; Wang et al., 2023). Immersive technologies focus on the use of virtual, augmented or extended reality for various processes within the company and individual projects. These can be used in the planning, execution and operational phases. Possible capabilities are monitoring and control tasks (Ratajczak et al., 2019; Zollmann et al., 2014), the use in meetings to increase cooperation (Jahnke et al., 2023; Jäkel, Jahnke, Meyer Westphal, 2023) or employee training (Osti et al., 2021; Sacks et al., 2013; Wolf et al., 2019). The final assessment parameter in the domain of technologies involves the use of artificial intelligence for analyzing and evaluating data sets within the company or automating individual subprocesses. For example, there are approaches for analyzing documents (Faltin et al., 2023; Gölzhäuser et al., 2023; Peng et al., 2023; Schönfelder et al., 2024), automating construction progress checks (Greeshma and Edayadiyil, 2022; Reja et al., 2022) or supporting the digital reconstruction of existing structures (Chrysoulakis et al., 2022; Jäkel, Gölzhäuser et al., 2023; Schönfelder et al., 2023; Stemmler et al., 2022) and surfaces (Reiterer et al., 2020). All of these parameters together provide an overview of the level of digitalization of construction companies and the degree of implementation and use in connection with new disruptive technologies. For the evaluation, companies can be classified for each technology according to Tab. 3 below. A cumulative score for the dimension “Technologies (T)” is then obtained from the classification.

The second dimension considers the ”Organization & processes” of the construction company. The concept of the organization includes the components of institutional, functional and instrumental organization. At this point, the functional organization is in the foreground, which includes activities for planning and enforcing organizational rules. (Schulte-Zurhausen, 2014) Processes describe sequential operations and thus support value creation. They can be used to analyze data and optimize operations and thus drive continuous change in the company as part of the digital transformation. This involves investigating the existing processes and designing them digitally as well as establishing new processes in the company to implement innovative methods and technologies. (Klötzer and

Pflaum, 2017; Shen et al., 2021) In this dimension, the parameters Team structure, Responsibilities, Data access, the use of BIM as well as Process automation and Performance management are evaluated (s. Tab. 4).

In the first assessment parameter, "Team structure," attention is drawn to the presence of agile methods in the way of working, such as SCRUM (Maximini, 2018), SAFE (Block, 2023; Knaster and Leffingwell, 2020), etc., as well as agile teams and the sharing of knowledge and resources (Santos et al., 2017; Schumacher et al., 2016). The next parameter "Responsibilities" considers the definition and distribution of specific responsibilities and competencies in the process-oriented organizational structure. This is relevant for the frictionless coordination of projects and processes. (Santos et al., 2017; Schumacher et al., 2016) In the context of this maturity model, the aspects of defining responsibilities and organizational units are considered. The parameter "Data access" examines the regulations for data access in the company. The focus here is on initiating and using a secure authorization concept for access to the relevant company data and checking compliance. (bitkom, 2018; Pentek, 2020). The “Use of BIM” in the company and individual construction projects also plays an important role in the evaluation as a further parameter. In this context, it is evaluated whether a digital model is used in the construction company's projects under consideration of the single source of truth approach (Disney et al., 2024; Jäkel and Klemt-Albert, 2023). In addition, the communication and collaboration with other project participants along the process chain using the BIM model plays an important role (Borrmann et al., 2018). Subsequently, the parameter "Process automation" describes the degree of automation concerning the existing processes and linked subprocesses in the company. The interoperability of processes in the company and within construction projects is also considered. Through complete automation, an increased agility of the processes can be determined, which has a positive effect in the case of structural changes (Zoubek et al., 2021) The parameter "Performance management" describes if the company has performance management on the strategic management level and operative project level and if the achievement of goals and effects are recorded data driven. For this purpose, it is checked whether the company has defined relevant key performance indicators (KPIs) and whether these can be measured. It is also considered whether measures for improvement are initiated and implemented based on the KPIs so that continuous improvement is achieved. (bitkom, 2018; Naeem and Garengo, 2022)

Table 3: Description of the dimension – Technologies.

Level	0	1	2	3	4	5
Robotics	Not existing; implementation not planned	Not available; use is being evaluated or is planned for the medium term	Local use in specific use cases; partially integrated	Local integration into internal company processes	Holistic active deployment; integrated along company-internal digital interfaces	Holistic active deployment; along possible digital interfaces
Cloud Computing	Not existing; implementation not planned	Not available; use is being evaluated or is planned for the medium term	Isolated local use of cloud technology for data storage	Use for connectivity within a business unit	Use for linking all areas of the company	Use for cross-company networking
IoT	Not existing; implementation not planned	Not available; use is being evaluated or planned for medium term	Integration of clearly identifiable objects and interfaces along process chains of specific use cases	Integration of clearly identifiable objects and interfaces within a business unit	Holistic integration of all possible uniquely identifiable objects and interfaces	Holistic integration of all possible uniquely identifiable objects and interface; Possibility of cross-company integration of project participants
Immersive technologies	Not existing; implementation not planned	Not available; use is being evaluated or is planned for the medium term	Local integration of AR/VR in specific use cases	Local integration of AR/VR in internal company processes	Holistic integration of AR in internal company processes	Use for collaboration and communication within all company divisions and across companies
Artificial intelligence	Not existing; implementation not planned	Not available; use being evaluated or planned for medium term	Isolated localized implementation	Localized implementation for linking selected processes	Project-related implementation and use	Active use of holistically implemented and networked AI systems

Table 4: Description of the dimension – Technologies.

Level	0	1	2	3	4	5
Team structure	No team structure recognizable	Rigid teams without cross-functional collaboration	Rigid teams, but cross-functional collaboration	Agile team structures within a division; cross-divisional knowledge exchange at isolated interfaces	Agile team structures within a division; cross-divisional knowledge exchange	Agile dynamic team structures; cross-divisional exchange of knowledge and resources
Responsibilities	No organizational units identifiable; no regulations defining responsibilities	No organizational units identifiable; responsibilities are assumed without regulations to define them	Bundling of competencies and areas of responsibility recognizable without regulations for definition	Vague adherence to departmental rules for definition and responsibilities	Rules for defining organizational units and responsibilities are defined and applied internally within the division	Application of company-wide regulations for the definition of organizational units and responsibilities
Data access	No concept for data access authorizations available	Vague guidelines based on an authorization concept exist; no verification of access authorizations	Definition, application and review of authorization concepts for specific processes and use cases	Intra-departmental definition, application and review of an authorization concept for departmental access portal	Access to data via central portal, implementation of a comprehensive authorization concept that is managed and checked manually	Access to data via central portal, implementation of a comprehensive authorization concept with automatic adaptation to and review of changing access requirements
The use of BIM	No application of BIM	No application of BIM; starting from planned introduction, prerequisites are created	Object-based use of BIM for collabo-ration and communication within a business unit	Net-work-based use of BIM within a business unit	Net-work-based cross-divisional use of BIM methodology in all areas of the company	Holistic use of BIM in all areas of the company and across all project life cycle phases
Process automation	No automation; processes and transitions are triggered manually	Isolated automation of sub-processes; processes and transitions are triggered manually	Automation of sub-processes; coordination of process interfaces; processes are triggered manually	Automation of process chains; processes are initiated manually	Complete automation of process chains possible	Complete automation of process chains possible; implementation of autonomous sub-processes
Performance management	No performance management system in place	If required, sporadic local measurements without derivation of improvement measures	Local identification and definition of key performance indicators; local measurement of processes to derive local improvement measures	Intra-unit determination and definition of key performance indicators; unit-wide measurement of processes to derive improvement measures	Company-wide implementation of a comprehensive performance management system based on regular measurements and improvement measures derived from them	Company-wide implementation of a comprehensive performance management system based on automatic regular measurements and improvement measures derived from them

For a long-term and holistic digital transformation of the company, a corporate culture must be targeted. In general, corporate culture can be described as the collection of patterns of assumptions that are defined, developed and shared by a group of people and organizations. This allows the company to adapt to a changing environment. The corporate culture is mainly characterized by the internal implementation and interpretation of digital artifacts, norms, values and basic assumptions. In addition to the informational, organizational and process-related parameters in the two dimensions presented above, the third dimension considers the aspects of ”Culture & personnel” (s. Tab. 5). This implies looking at the assessment parameters of digitalization strategy, Initiative at management level, Error culture, Acceptance of digital methods, Further training & qualification, and Resources. (Rafael et al., 2020; Santos and Martinho, 2020; Wagire et al., 2021)

The first assessment parameter is the construction company's "digitalization strategy". The holistic approach and feasibility of the strategy are assessed. The existence of a specific digitalization strategy in the company and the integration of aspects of digital transformation into the overarching corporate strategy are evaluated. The implementation of this strategy to achieve the company's goals is also considered. The next assessment parameter is the “Initiative of the management” level with regard to digital transformation in the company. This element indicates the level of support and encouragement provided by executives for the digital transformation of the company. The element focuses on the scope of the management level's involvement in digital transformation and how this is supported and fostered by the executives. (Rafael et al., 2020; Santos and Martinho, 2020; Wagire et al., 2021) A central aspect of this element is the anchoring of digital leadership about a mature concept of change management in the company. In order to successfully lead a company into a transformational stage, the following five basic leadership qualities should be targeted (Andelfinger, 2017):

Openness to disruptive approaches

- Innovative approach
- Courageous attitude
- Social competence
- Determination to act

This is further supported by self-reflective and self-acknowledging actions on the part of the management level as well as clear communication regarding behavior and working methods. Based on this, the third parameter "Culture of failure" is established. The culture of failure describes how the company deals with mistakes, how it communicates them and how it learns from them. The main aspects of this culture are error acceptance and error tolerance. The error culture is a central component of the corporate culture. In the context of digital leadership, it is important to establish an error culture in which employees can and should try out new things. (Glogovac et al., 2022) The culture of failure practiced in the company is regarded as essential for holistic and sustainable implementation due to the changes and implementation of innovative methods and technologies to be made as part of the digital transformation. The next parameter deals with the general “Acceptance of digital methods” in the construction company. The acceptance of digital methods by employees contributes significantly to their sustainable implementation. This reflects the motivation of employees to implement digital methods and the recognition of added value. Another parameter is “Further training and qualification”. This parameter reflects the status and organization of employee training.

Further qualification can take place in various ways and is not limited to classic trainings. Training of employees can take place both internally by experts and by additional external training sessions. (Glogovac et al., 2022; Wagire et al., 2021) For the comprehensive implementation and use of digital methods and technologies, it is necessary to train employees sufficiently in these areas. Furthermore, general acceptance must be increased. The options for further training in terms of the scope offered, the regularity of the offerings and the user group addressed are considered here. The dimension "Culture & personnel" is supplemented by the last assessment parameter "Resources". This focuses on the number of resources available for use in the transformation processes. Time, monetary and personnel resources are all included in the evaluation. The time resources consider the estimated duration of the individual transformation steps and the monetary resources in the available budget. Furthermore, the human resources consider the number of employees in the departments involved in the digital transformation.

Table 5: Description of the dimension - Culture & personnel.

Level	0	1	2	3	4	5
Digitalization strategy	No anchoring of aspects of digital transformation in the corporate strategy	No anchoring of aspects of digital transformation in the corporate strategy; Isolated documentation of digital approaches	No anchoring of aspects of digital transformation in the corporate strategy; Digital strategy approaches are held at management level; growing understanding	Aspects of digital transformation are anchored in the strategy of individual business units	Aspects of digital transformation are anchored in the overarching corporate strategy	Aspects of digital transformation are anchored in the corporate strategy and integrated into strategic goal achievement
Initiative of the executive level	No promotion of digital transformation by management level	No involvement of management level in digital transformation, but demand from employees	Active participation of the management level in processes for digital transformation and demand from employees	Promotion of digital transformation by managers in the respective team	Promoting digital transformation through leaders to collaborate across teams	Development and implementation of digital transformation at the executive level
Culture of failure	No error tolerance	No official error tolerance; very low error tolerance	Low error tolerance and acceptance; trial and error in individual cases after coordination	Negative evaluation of errors despite tolerance and acceptance of errors; trial and error on a limited scale without coordination	Neutral evaluation of errors; error tolerance and acceptance given; trial and error possible on a larger scale	Errors are tolerated and integrated into processes; trial and error is also established on a larger scale
Acceptance of digital methods	Digital methods are tolerated due to company policies but not accepted	Digital methods are implemented based on corporate guidelines; acceptance and trust are low	Implementation of digital methods is accepted; trust is low	The implementation of digital methods is accepted; added values are recognized	The implementation of digital methods is supported; trust in added values	Implementation of digital methods is supported and self-driven; Full confidence in digital methods
Further training & qualification	No support regarding opportunities for further training or qualification in digital transformation	Responsible employees are sporadically supported in opportunities for further training and qualification in digital transformation	Responsible employees are offered the opportunity for further training or qualification in the area of digital transformation if required	Responsible employees are offered opportunities for further training and qualification in digital transformation from time to time	All employees are offered opportunities for further training and qualification in digital transformation from time to time	All employees are regularly offered a wide range of opportunities for further training and qualification in digital transformation
Resources	The company has no resources to implement and maintain digital infrastructure	The company has few resources to implement digital infrastructure, but not to maintain it	The company has sufficient resources to implement and maintain digital infrastructures in individual areas	The company has sufficient resources to maintain the existing digital infrastructure in the long term	The company has sufficient resources to maintain the existing digital infrastructure in the long term and to further expand it in some areas.	The company has sufficient resources to maintain the existing digital infra-structure in the long term and to further expand it holistically

In the context of the dimension "Data management", the company's data bases, and internal handling of data are assessed. Data has an important role in the digital transformation of a company. It forms the digital basis for a wide range of processes and technologies. (Gökalp and Martinez, 2021; Rafael et al., 2020; Santos et al., 2017) All parameters are defined in the Tab. 6. The first assessment parameter focuses on the ”Data governance” of the company. At this point, Data governance describes a framework for the handling and management of data by all stakeholders in the company. This should include at least the aspects of people, processes and technologies. For a more comprehensive view of data handling, the framework can be extended individually. (Krotova and Eppelsheimer, 2019) The maturity model considers the existence and regularity of a review of the framework in the company. The next aspect implies the “Timeliness” of the existing and used data in the company. On the basis of this element, the methodology as well as the intervals of data updating are evaluated. In parallel, the prevailing “Data quality” in the company is also evaluated as another parameter. It is to be determined whether the quality of the data is regularly checked. At the same time, the existence of a catalogue of criteria for quality measurements will be considered. This should define the exact quality of data in individual areas of the company and a procedure for achieving and continuously maintaining a high level of Data quality. Furthermore, the degree of “Data coverage” in the company is considered as an additional assessment parameter in the dimension. This parameter depicts the degree to which digital mechanisms are used to generate and consistently manage data in the company. It is determined to what extent these mechanisms are already in use and whether the generation and consistent management of data takes place automatically. The next parameter “Utilization of data value” also depends on the degree of coverage of data generation in the company. The parameter shows whether the value of data is recognized in the company and consequently used to increase efficiency and for optimization measures along the value chain. A central aspect of data management is the parameter "Data storage". The type (centralized, decentralized, hybrid) and duration of storage (short-, medium- or long-term) as well as the scope of the data are considered. Furthermore, the compatibility of the data formats and the contribution to interoperability along linked process structures are evaluated. The last parameter to be examined is the establishment of and compliance with “Data security”. In this context, uniform data protection guidelines as well as existing authorization concepts and responsibilities in the company structures are examined. (Gökalp and Martinez, 2021; Rafael et al., 2020; Santos et al., 2017)

Table 6: Description of the dimension - Data management.

Level	0	1	2	3	4	5
Data governance	No data management framework in place or envisioned	No data management frame-work in place, but is worked out	Establishment and partial application of an internal corporate frame-work without review	Establishment and partial application of an internal corporate framework with sporadic review	Application and regular review of a defined frame-work including 3 main components (people, processes, tech-nologies)	Application and regular review of a de-fined frame-work including the company-wide definied regulations od data governance
Timeliness of the data	Timeliness of the data is not considered	Timeliness of data is checked sporadically with no anchored methodology	Timeliness of data is checked regularly without anchored methodology	Regular review of the timeliness of the data, differentiated by department/level, based on the methodology set up in each case	Company-wide periodic review of data timeliness based on company-wide anchored review methodology	Automatic check of the timeliness of the data
Data quality	No data quality assurance system in place	If required, occasional review of data quality without uniform definition of quality	If required, occasional review of data quality with regard to defined quality criteria	Regular review of data quality with regard to prioritized quality criteria	Regular comprehensive review of data quality with regard to all defined quality criteria	Automatic checking of data quality with regard to criteria adapted to general conditions
Degree of coverage	No digital mechanisms for data generation available	No digital mechanisms for data generation available, implementation is planned	Use of isolated mechanisms for data generation	Use of digital mechanisms for data generation within a business unit	Use of digital mechanisms for data generation in all areas of the company	Full integration of digital mechanisms for automated data generation

Utilization of data value	No value added to the data	Recognition of the data value regarding projects	Sporadic use of data to derive measures for improvement	Use of data to optimize subareas	Derivation of holistic optimization measures based on complete data	Automatic analyses and evaluation of data to derive holistic optimization measures
Data storage	Short-term local storage of data specific use cases	Longer-term local storage of data of specific use	Longer-term central storage of data generated there; additionally, collected data is stored locally at the relevant location	Longer-term, centralized storage of all data generated and collected there	Longer-term central storage of all data generated in the company; additional data is stored locally at the relevant location	Longer-term, central storage of all data generated and collected in the company
Data security	Data protection is not considered; no awareness of data protection guidelines and corresponding laws	Data protection is not considered despite awareness of data protection guidelines and corresponding laws	Data protection is not consciously perceived and strived for; knowledge of consequences for non-compliance	Implementation of data protection guidelines in relevant processes; knowledge of consequences of non-compliance	Company-wide data protection-compliant processing of data	Automatic detection of changes in privacy policies and process data accordingly

The next dimension is called “Interconnectivity”. The interconnectivity of a company on a vertical and horizontal level forms the basis for realizing a networked system and production landscape in the company. In the context of Industry 4.0, the aim is to achieve complete networking of production and logistics to increase efficiency. (Andelfinger, 2017; Zoubek et al., 2021) Transferred to construction companies, the possibilities of networking are thereby considered for vertical and horizontal networking along the value chain to adapt this central aspect of Industry 4.0 in the construction industry. The first parameter assesses the ”Use of platforms” in the company for interorganizational networking. The use of platforms as part of the IT infrastructure and is an important component for bringing together all stakeholders within a project or company. Platforms enable digital interaction between several people within the company or with external stakeholders. This takes place under the central aspect of data exchange and communication. The type of platform can be individually adapted to the respective application. A distinction can be made between the types of platforms – transaction platform, innovation platform and integrated platform. By combining platforms with the IoT and cloud technology, data can be accessed and networked in any scalable way. (Leyh et al., 2016; Westermann et al., 2016) The second parameter considers the existing “Human-machine interfaces” in the company's value chain. Interfaces for human-machine interaction are important to involve humans directly and indirectly in the control process. The human being acts as a higher-level decision-making and control instance, which represents a new range of requirements and tasks for him. The omnipresent networking and the availability of mobile data in real-time in the aspired Industry 4.0 simultaneously increase the responsibility and sphere of action of the human control instance. (Roth, 2016a) In this context, the design and type of computer-based user interfaces are evaluated.(Johannsen, 1994; Preim and Dachselt, 2010) The stages of the maturity model for human-machine interfaces aim to increase the intuitiveness of the interaction. The next parameter reflects the ”Machine-machine interfaces”, whereby the human factor is not considered. This parameter enables an automated exchange of information between technical systems. As a result, an overall company network capable of communicating between the technical systems is created. An important prerequisite for this is the use of established automation technology standards and the creation of continuous interoperability along the process chain. With the help of industry-standard, platform-independent communication as well as the exchange of data and information is enabled. (Bartodziej, 2017) The definition of uniform standards in the company and the industry will ensure the qualitative exchange of information in the future. (Ghobakhloo, 2020; Gilchrist, 2016) The last assessment parameter considers the “Use of AutoID technologies”. These contribute significantly to the networking of processes. According to the principles of Industry 4.0, each object should have its own digital and real identity. This creates a self-identification of systems, for example via Radio Frequency Identification Chips (RFID chips) or optical processes such as the attachment of QR codes. (Mostaccio et al., 2023) The parameters of the dimension Interconnectivity are shown in Tab. 7 below. The next dimension is called “Interconnectivity”. The interconnectivity of a company on a vertical and horizontal level forms the basis for realizing a holistically networked system and production landscape in the company. In the context of Industry 4.0, the aim is to achieve complete networking of production and logistics to increase efficiency. (Gökalp et al., 2017; Gökalp and Martinez, 2021; Schumacher et al., 2016) The parameters of the dimension Interconnectivity are shown in Tab. 7 below.

Table 7: Description of the dimension – Interconnectivity.

Level	0	1	2	3	4	5
Usage of platforms	No uniform form for collecting and managing data	No standardized form for collecting and managing data; use of platform forums is planned	Platforms as local stand-alone solutions for collecting and managing data	Use of platforms within a business unit to collect and manage data	Active use of a central platform that is fully integrated and net-worked for the collection and management of data	Active use of central and net-worked platform for collecting, managing and evaluating data
Human-machine interfaces	Predominant use of graphical user interfaces and character-oriented user interfaces	Isolated use of speech-based user interfaces	Predominant use of speech-based user interfaces	Isolated use of natural user interfaces via touch	Predominant use of natural user interfaces via touch	Holistic use of natural user interfaces, sporadically through extended reality systems
Machine-machine (M2M) interfaces	No interfaces between machines available	No use of interfaces between machines available; implementation is planned	Isolated use of M2M interfaces in specific use cases	Active use of M2M interfaces within a business unit	Active use of M2M interfaces in all areas of the company	Use of intelligent editing systems
Use of AutoID technologies	No use of AutoID technologies; use not planned	No use of AutoID technologies; use planned	Isolated use of AutoID in specific use cases	Use of AutoID for net-working within a business unit	Use of AutoID for cross-divisional net-working	Use of AutoID for holistic internal company net-working as well as possibilities for cross-company net-working

5.3 Assessment method

To classify a company in the maturity model, a scoring system is used to calculate an overall index. The DCCMM's scoring system is based on the calculation method and the dimensional weightings of the DAOMI (bitkom, 2018) and adopted with the results of the expert interviews. Using the overall index, companies are classified to six maturity levels. A point range of 0.0 – 50.0 points can be achieved. This can be applied per element, dimension and for the overall index. For each element, the company is assigned a maturity level based on the responses to the expert interview and the explanations of the element characteristics. The points per level and element are staggered in ten-step increments (s. Tab. 8).

Table 8: Point scale of the maturity levels.

Level	Points
Level 0	0.0 Point
Level 1	10.0 Points
Level 2	20.0 Points
Level 3	30.0 Points
Level 4	40.0 Points
Level 5	50.0 Points

Within a dimension, an average value of the included elements is determined. All elements have the same weighting. Thus, an average value between 0.0 and 50.0 points can be achieved per dimension. Based on these average values, the overall index of the company is determined. In the calculation of the overall index, the dimensions are weighted. The selected weighting of the respective dimension can be seen in Tab. 9.

Table 9: Weightings of the maturity dimensions.

Maturity Dimension	Abbreviation	Weighting
Technologies	T	15.0 %
Organization & processes	O	20.0%
Culture & personnel	C	20.0 %
Data Management	D	30.0 %
Interconnectivity	I	15.0 %

Applying the weighting factors for each dimension, the following equation results for determining an overall maturity score, the "DCCMM Index" of a company:

$$0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I = DCCMM\ Index$$

Finally, the maturity levels of the model were assigned to point ranges, with the help of which the companies can be classified into one of the five maturity levels based on their DCCMM Index. The chosen point ranges per maturity level result from an as even as possible distribution of the maximum 50.0 points to the six maturity levels (s. Tab. 10).

Table 10: Point allocation of the Maturity level.

Maturity level	Points
Maturity level 0	0.0 - 8.0 points
Maturity level 1	> 8.0 - 16.5 points
Maturity level 2	> 16.5 - 25.0 points
Maturity level 3	> 25.0 - 33.5 points
Maturity level 4	> 33.5 - 42.0 points
Maturity level 5	> 42.0 - 50.0 points

6. VALIDATION

To validate the maturity model, it is tested on eight application examples. Eight construction companies are classified, evaluated and compared with each other according to their maturity model. Large construction groups, as well as small and medium-sized construction companies were included in the survey (s. Tab. 11). At the same time, construction companies from both the building and infrastructure sectors are considered to demonstrate the general validity of the maturity model. The evaluation of the companies is performed through guideline-supported expert interviews. The individual evaluation dimensions are applied and the companies are evaluated in the maturity levels for each parameter. At the same time, the expert interviews also ask about the fit and consistency of the maturity model. All experts confirm the validity and relevance of the DCCMM.

Table 11: Point allocation of the Maturity level.

Identifier	Size of the company	Expert area
Construction company A	Large enterprise	Digitalization
Construction company B	Large enterprise	Digitalization
Construction company C	Large enterprise	Digitalization
Construction company D	Medium enterprise	Digitalization
Construction company E	Medium enterprise	Digitalization/AI
Construction company F	Large enterprise	Digitalization/BIM/Lean
Construction company G	Large enterprise	Digitalization/Innovation
Construction company H	Small enterprise	Commercial manager

The individual final results of the company valuations are shown to the article in table 12. Due to the large scope of the individual evaluations, the results for each evaluation domain of the companies are attached to the scientific article in the appendix (appendix 01 – 08).

Table 12: Results of the company assessments.

Domain	Technologies (T)	Organization & processes (O)	Culture & personnel (C)	Data Management (D)	Interconnectivity (I)	Overall maturity index	Maturity Level
Company A	20.00	40.00	45.00	35,71	36,67	36.21	Level 4
Company B	8.00	36.67	41.67	25.71	15.00	26.83	Level 3
Company C	30.00	45.00	48.33	44.29	40.00	42.45	Level 5
Company D	28.00	35.00	41.67	34.29	20.00	38.82	Level 3
Company E	22.00	28.33	35.00	31.43	20.00	28.40	Level 3
Company F	40.00	43.33	48.33	45.71	40.00	44.05	Level 5
Company G	24.00	40.00	41.67	32.86	22.50	33.17	Level 3
Company H	16.00	23.33	33.33	28.57	17.50	24.92	Level 2

Subsequently, an enhanced comparison is made between the companies (see Figure 1). In particular, similarities and differences between the companies in the individual dimensions are identified and the influence of company size on the level of maturity is analyzed. In total eight companies are individually analyzed in the previous chapter and evaluated according to the DCCMM, the results are consolidated in the following section, considering all company analyses collectively. For an initial overview of the final ranking, the classification of the eight companies into the six maturity levels of the DCCMM is shown in Figure 9. Within this context, two companies (companies C and F, 25.00%) achieve maturity level 5 and are therefore considered an intelligent construction company. They are digitized company-wide and even have individual technologies linked. In addition, digitalization does not only take place at a technological level but is implemented across all company levels - processes, organization, data and application systems - from a strategic and operational level. One company (Company A, 12.50%) has reached maturity level 4 and already has a mature level of digitalization within the company. This can be seen at both strategic and operational company levels. The largest number of companies - 4 out of 8 companies (50.00%) - are assigned to maturity level 3 (companies: B, D, E, G) These companies already use digital technology in individual areas of the company or actively apply digital methods in their operations. However, comprehensive integration and networking are still lacking. Furthermore, only one company (Company H, 12.50 %) was awarded maturity level 2. The general comparison of all analyzed companies (s. Figure 1) reveals differences between the characteristics in individual assessment domains and also between the degree of digitalization of the company sizes. All companies show strengths in the process-related and organizational dimensions. These two dimensions are the most pronounced domains in all individual company analyses. In contrast, the companies demonstrate deficiencies in the dimensions “Technologies”, “Data management” and “Interconnectivity”. In a direct comparison including the size of the company, it also gets clear that the larger companies achieve a higher level of maturity in global comparisons than the medium-sized and small companies. While the large companies (Company A, B, F, G) have at least maturity level 3, two companies (50% of the large companies) also reach level 5 and the small company is assigned to maturity level 2. This indicates that the maturity level of a company's digitalization is related to its size and the resources available. It must be emphasized that the companies took part in the maturity assessment interviews voluntarily.

They merely represent the initial validation of the DCCMM to demonstrate its usability and validation. To achieve integration and usability for all companies in the economy, the maturity model needs to be tested and further optimized with many more companies as case studies.

7. DISCUSSION

This article presents the development of a holistic maturity model for the classification of companies in the context of Construction Industry 4.0. At the beginning, the theoretical foundations for creating a uniform understanding of the topic of maturity models as well as Industry 4.0 and Construction Industry 4.0 are presented. Subsequently, the current status quo on the topic of maturity levels in the area of digital transformation in the construction industry is presented employing a literature review. Based on this, the conception of the maturity level model follows in the next chapter. In the first sub-process, the framework conditions are defined. The DCCMM is based on existing frameworks. Subsequently, the contents of the maturity model are elaborated. This implies the definition of superordinate maturity levels, the assessment domains and the assessment parameters contained therein. As a result, the DCCMM contains six maturity levels, five assessment domains and 29 individual assessment parameters. In addition, the weighting of the dimensions is characterized in a further sub-process. After its conception, the DCCMM is validated through its implementation on eight real construction companies. The implementation and simultaneous evaluation of the companies are carried out through guideline-based expert interviews. Finally, the companies are compared with each other and the results are discussed, as well as critically reflected.

Using the DCCMM, construction companies can identify their current state of digital transformation and classify themselves into a specific maturity level. In the course of this, the degree of digitalization and automation becomes ascertainable and measurable for the company. Furthermore, companies can compare the current status quo with other organizations and learn from the experience of those already further digitized. In addition, the barriers and obstacles to dealing with the topic of digital transformation are minimized by identifying fields of action. At the same time, companies can improve their current strengths and weaknesses in processes, on organizational, technical and information technology levels. Furthermore, the DCCMM offers companies the opportunity to present further impulses for measures toward increasing digitalization within the company.

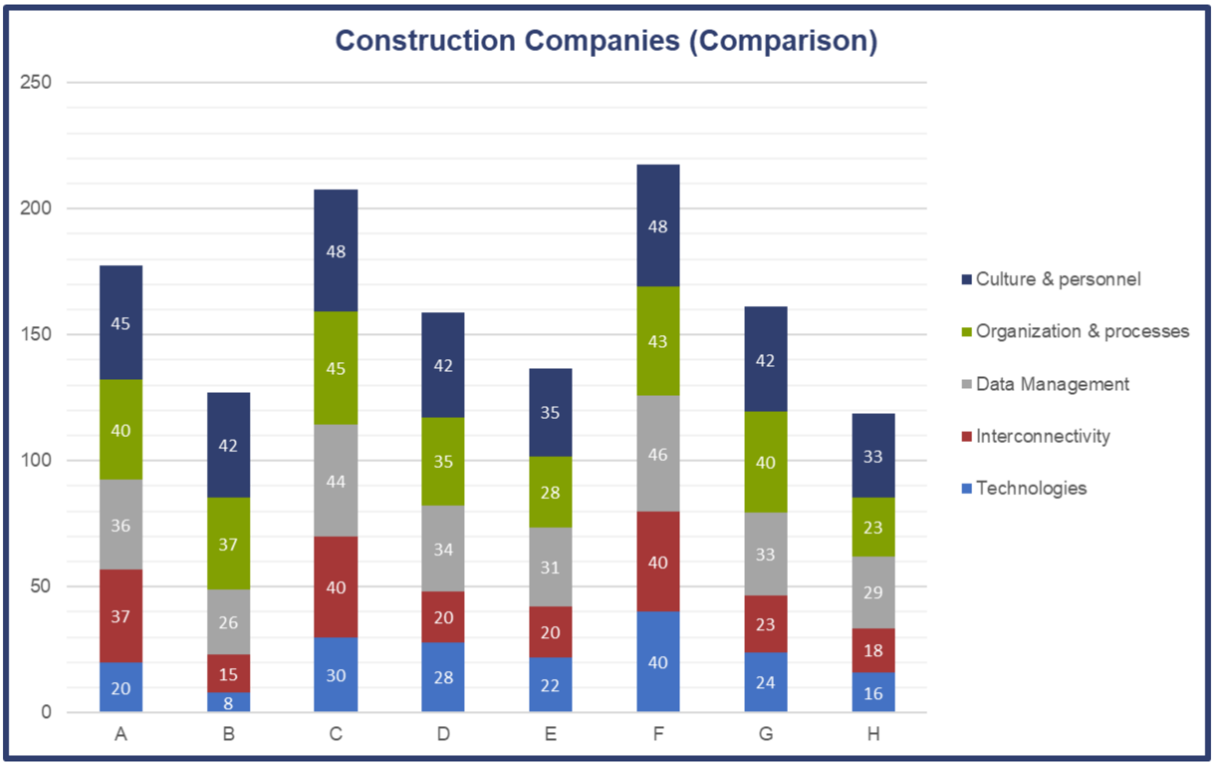

Figure 1: Comparison of the companies' maturity levels according to the DCCMM.

Consequently, a clear trajectory is established for enterprises engaged in digital transformation, toward a smart construction company. In addition to the positive effects for individual companies, the DCCMM also contributes to a further increase in digitalization and automation throughout the construction industry.

Apart from the added value, there are also limitations in setting up and using the maturity level. The first limitation is the validation of the maturity model. Although the applicability is shown through the implementation at eight companies, not all dimensions and criteria were tested for their compatibility. There is a need to validate the weightings and individual criteria as well as the domains in the assessment algorithm. This can be done either through a qualitative approach by integrating further experts in another round of interviews or through a quantitative approach by empirical investigation. Furthermore, the DCCMM in its current version is a very general model that looks at many facets of the digitalization assessment generically. Another limitation is the achievement of higher maturity levels after an initial corporate evaluation. Based on the criteria and the individual levels, the companies can recognize the need for an increase in the maturity level, but there are still no concrete instructions for specific actions for each domain at the individual levels.

In further research activities, a more detailed validation of the maturity model will be carried out. Either a qualitative approach with further expert interviews or an empirical subway as a quantitative approach will be conducted. In addition, a mix of both approaches could be considered. In this way, the DCCMM can be further specified in the dimensions, parameters and evaluation procedure. Furthermore, periodic tests will be carried out at companies. This ensures practicability even in subsequent iterative optimization cycles. Another research topic is the derivation of specific recommendations for actions for companies in the individual maturity levels of each dimension. This provides organizations with a concrete roadmap for further strategic and operational steps to improve their maturity level in individual areas. Once the DCCMM has been optimized, fully validated and established in practice, consideration will be given to developing further sector-specific maturity levels.

8. CONCLUSION

This article presents a maturity model for digital transformation in the context of Construction Industry 4.0, the DCCMM. Processual and organizational as well as technical and information technology factors are considered in the evaluation. At the beginning, the state of the art in the construction industry 4.0 is elaborated by means of a literature research and the basics of maturity models and their already identified added value in other industries are described. Thereafter, the DCCMM is designed. The DCCMM builds on already established maturity models from other industries and is enhanced by important components of the construction industry 4.0. It features five dimensions - (i) Technologies, (ii) Organization & processes, (iii) Culture & personnel, (iv) Data management and (v) Interconnectivity - with a total of 28 parameters for an assessment of construction companies in connection with the degree of digital transformation. At the same time, the assessment results can be used to categorize construction companies into six maturity levels. In the next step, the DCCMM is validated in a series of interviews with a total of eight experts, representing eight different construction companies. This confirms the fundamental usefulness and suitability of the DCCMM. At the same time, all eight companies are individually assessed and subsequently classified into a suitable maturity level. These assessments enable the companies to gain an insight into the current degree of digitalization in their structures and provide further orientation for establishing the intelligent construction company. In addition, the validation identifies that the smaller the construction company is in terms of employee numbers and turnover, the lower the current level of digitalization maturity.

The development and use of the DCCMM in the course of the scientific article provides companies with an initial tool for analysing the current level of digitalization and automation and a guide for further orientation on the path to becoming an intelligent company. This promotes a general understanding of the complex topic of digitalization among companies of all sizes. In addition, existing barriers to knowledge acquisition are broken down to enable small and medium-sized enterprises to focus on the future. Companies in other industries are already benefiting from the added value of a maturity model. However, this aspect of digital transformation at a strategic corporate level in the construction industry, considering the specifics and complexities relevant to the construction sector, has not yet been addressed qualitatively. The DCCMM closes this existing gap for science and business in the construction industry. In addition, the maturity model also serves as a basis for the development of further maturity models for individual life cycle phases of a construction project or newly established disruptive technologies in construction companies. In further research activities, the maturity model is constantly being optimized and its practical suitability ensured through further tests.

This will be achieved through further testing at construction companies and the collection of suggestions for improvement. Once broad acceptance of the DCCMM has been achieved, the DCCMM will be made available to the public and disseminated widely in cooperation with associations, organizations and stakeholders in the construction industry. The widespread use of the DCCMM will facilitate access to knowledge about the company's digitalization status in the near future. Furthermore, companies are provided with guidelines for continuous self-optimization. This creates incentives for further efforts towards digitalization and automation in the construction industry.

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APPENDIXES

APPENDIX 01: DETAILED RESULTS OF THE COMPANY A EVALUATION

According to the assessment, Company A has a total score of 36.21 points and is classified in maturity level 4. This level places the company among the advanced companies in the digital transformation (s. Fig 2).

$$DCCMM - Index\ (company\ A) = 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I$$
$$= 0.15 * 20.00 + 0.20 * 40.00 + 0.20 * 45.00 + 0.30 * 35.71 + 0.15 * 36.67$$
$$= 36.21\ points = maturity\ level\ 4$$

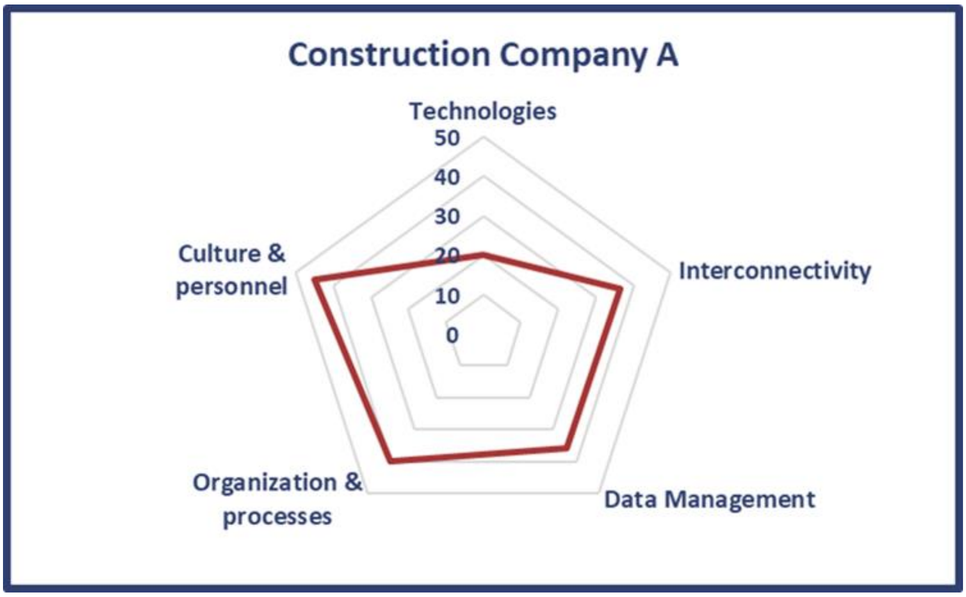

Figure 2: Results - Company A.

The detailed results of the assessment of company A are shown below in Tab. 13.

Table 13: Detailed Assessment Results Company A.

Company A							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
			Technologies (T)				
Robotics			20				20.00
Cloud Computing				30			
IoT			20				
Immersive technologies			20				
Artificial intelligence		10					
			Organization & processes (O)				
Team structure					40		40.00
Respons-ibilities					40		

Data access						50	
The use of BIM methodology						50	
Process automation			20				
Performance management					40		
Culture & personnel (C)							
Digitalization strategy						50	45.00
Initiative of the executive level						50	
Culture of failure						50	
Acceptance of digital methods				30			
Further training & qualification						50	
Resources					40		
Data Management (D)							
Timeliness of the data				30			35.71
Data governance					40		
Data quality					40		
Data security						50	
Degree of Coverage			20				
Utilization of data value			20				
Data storage						50	
Interconnectivity (I)							
Usage of platforms						50	36.67
Human-machine interface	0						
Machine-machine interface			20				
Use of AutoID technologies					40		

APPENDIX 02: DETAILED RESULTS OF THE COMPANY B EVALUATION

According to the assessment, Company B has a total score of 26,83 points, is classified in maturity level 4 and thus has a digital transformation in the early stages. The company valuation of Company B is presented in detail below (s. Figure 3).

$$
\begin{aligned}
DCCMM - Index\ (company\ B) = &\ 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\
= &\ 0.15 * 8.00 + 0.20 * 36.67 + 0.20 * 41.67 + 0.30 * 25.71 + 0.15 * 15.00 \\
= &\ 26.83\ \ points = maturity\ level\ 3
\end{aligned}
$$

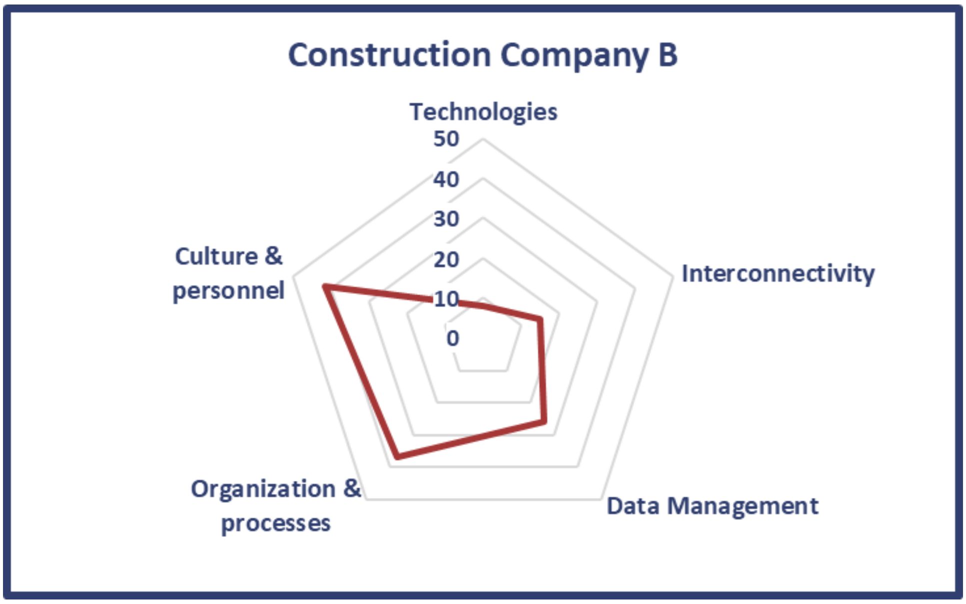

Figure 3: Results of the evaluation of company B.

The detailed results of the assessment of company B are shown below in Tab. 14.

Table 14: Detailed Assessment Results Company B.

Company B							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
				Technologies (T)			
Robotics	0						
Cloud Computing	0						
IoT			20				8.00
Immersive technologies			20				
Artificial intelligence	0						
				Organization & processes (O)			
Team structure					40		
Respons-ibilities						50	36.67
Data access						50	

The use of BIM methodology				30			
Process automation			20				
Performance management				30			
Culture & personnel (C)							
Digitalization strategy						50	
Initiative of the executive level					40		
Culture of failure						50	
Acceptance of digital methods					40		41.67
Further training & qualification				30			
Resources					40		
Data Management (D)							
Timeliness of the data				30			
Data governance					40		
Data quality		10					
Data security					40		25.71
Degree of Coverage			20				
Utilization of data value			20				
Data storage			20				
Interconnectivity (I)							
Usage of platforms			30				
Human-machine interface	0						15.00
Machine-machine interface	0						
Use of AutoID technologies				30			

APPENDIX 03: DETAILED RESULTS OF THE COMPANY C EVALUATION

According to the assessment, Company C has a total score of 42,42 points and is classified in maturity level 5. The company is thus classified in the top level of the maturity model and is considered a "smart company" in the very mature stage of the digital transformation.

The company valuation of Company C is presented in detail below (s. Figure 4).

Calculation of the maturity index:

$$\begin{aligned} DCCMM - Index\ (company\ C) &= 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\ &= 0.15 * 30.00 + 0.20 * 45.00 + 0.20 * 48.33 + 0.30 * 44.29 + 0.15 * 40.00 \\ &= 42.45\ \ points = maturity\ level\ 5 \end{aligned}$$

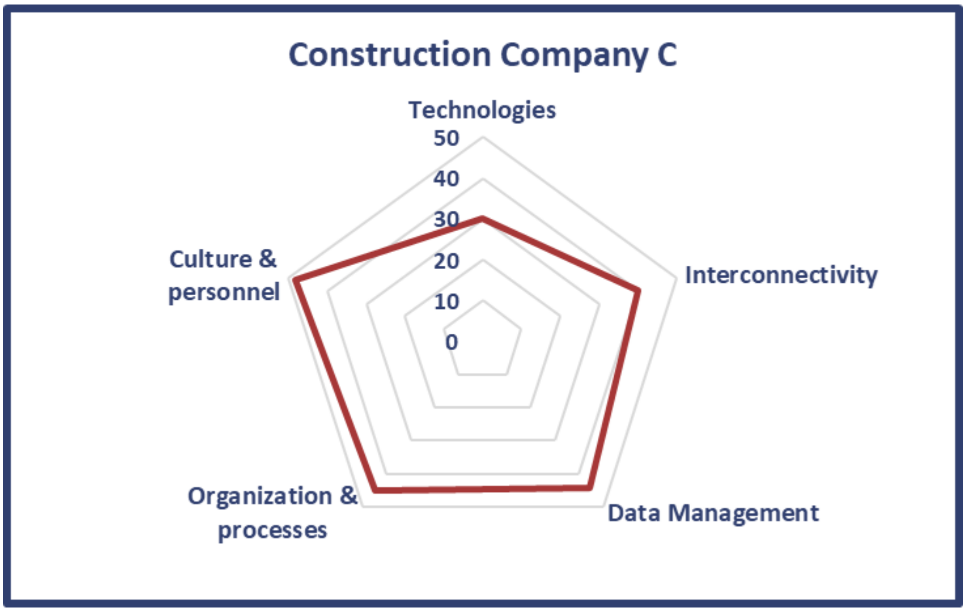

Figure 4: Assessment Results Company C.

The detailed results of the assessment of company C are shown below in Tab. 15.

Table 15: Detailed Assessment Results Company C.

Company C							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
				Technologies (T)			
Robotics				30			30.00
Cloud Computing				30			
IoT				30			
Immersive technologies				30			
Artificial intelligence				30			
				Organization & processes (O)			
Team structure					40		45.00

Responsibilities			50	
Data access			50	
The use of BIM methodology			50	
Process automation			50	
Performance management	30			
Culture & personnel (C)				
Digitalization strategy			50	48.33
Initiative of the executive level			50	
Culture of failure			50	
Acceptance of digital methods			50	
Further training & qualification			50	
Resources		40		
Data Management (D)				
Timeliness of the data	30			44.29
Data governance			50	
Data quality			50	
Data security			50	
Degree of Coverage		40		
Utilization of data value		40		
Data storage			50	
Interconnectivity (I)				
Usage of platforms		40		40.00
Human-machine interface		40		
Machine-machine interface			50	
Use of AutoID technologies	30			

APPENDIX 04: DETAILED RESULTS OF THE COMPANY D EVALUATION

According to the assessment, Company D has a total score of 38,82 points and is classified in maturity level 5. It classifies company D in the medium segment (maturity level 3) This means an advanced digital transformation but with still existing optimization potential in the company (s. Figure 5).

Calculation of the maturity index:

$$\begin{aligned} DCCMM - Index\ (company\ D) = &\ 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\ = &\ 0.15 * 28.00 + 0.20 * 35.00 + 0.20 * 41.67 + 0.30 * 34.29 + 0.15 * 20.00 \\ = &\ 38.82\ \ points = maturity\ level\ 3 \end{aligned}$$

The detailed results of the assessment of company D are shown belown in Tab. 16.

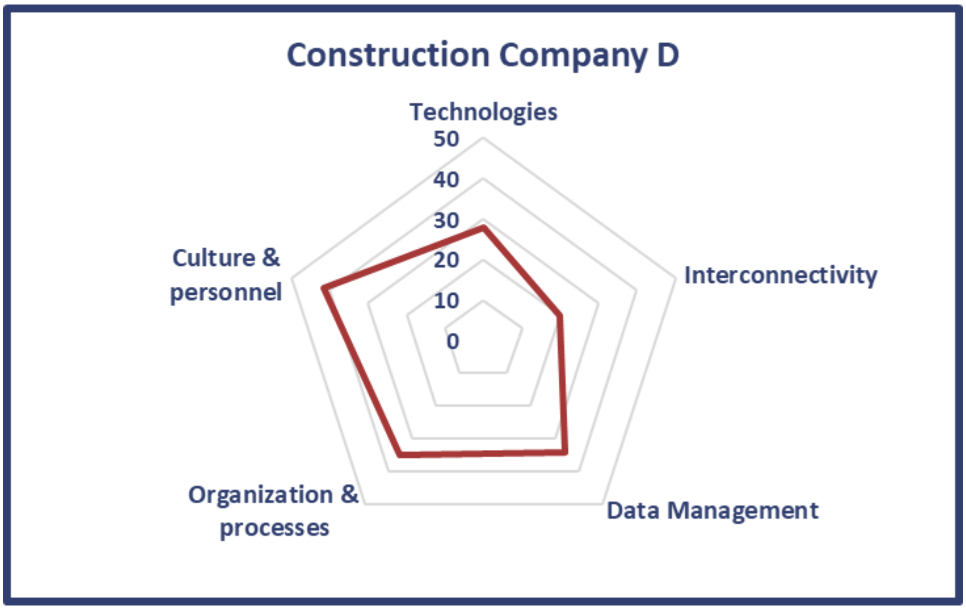

Figure 5: Assessment Results Company D.

Table 16: Detailed Assessment Results Company D.

Company D							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
			Technologies (T)				
Robotics			20				28.00
Cloud Computing						50	
IoT	10						
Immersive technologies					40		
Artificial intelligence		20					
			Organization & processes (O)				
Team structure					40		35.00

Responsibilities				40		
Data access					50	
The use of BIM methodology					50	
Process automation	10					
Performance management		20				
			Culture & personnel (C)			
Digitalization strategy					50	
Initiative of the executive level			30			
Culture of failure					50	41.67
Acceptance of digital methods			30			
Further training & qualification					50	
Resources				40		
			Data Management (D)			
Timeliness of the data			30			
Data governance			30			
Data quality			30			
Data security				40		34.29
Degree of Coverage			30			
Utilization of data value			30			
Data storage					50	
			Interconnectivity (I)			
Usage of platforms		20				
Human-machine interface		20				
Machine-machine interface	10					20.00
Use of AutoID technologies			30			

APPENDIX 05: DETAILED RESULTS OF THE COMPANY E EVALUATION

Construction company E achieves a total score of 28.40 points. As a result, it can be classified in maturity level 3 and has a moderate development stage in terms of digital transformation (s. Figure 6).

Calculation of the maturity index:

$$
\begin{aligned}
DCCMM - Index\ (company\ E) &= 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\
&= 0.15 * 22.00 + 0.20 * 28.33 + 0.20 * 35.00 + 0.30 * 31.43 + 0.15 * 20.00 \\
&= 28.40\ points = maturity\ level\ 3
\end{aligned}
$$

The detailed results of the assessment of company E are shown belown in Tab. 17.

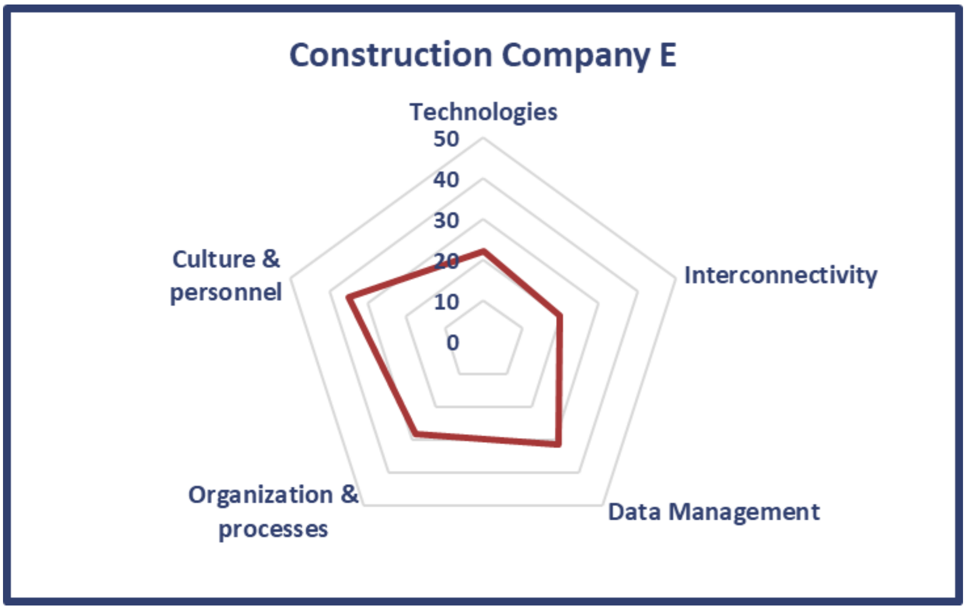

Figure 6: Assessment Results Company E.

Table 17: Detailed Assessment Results Company E.

Company E							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
				Technologies (T)			
Robotics	0						
Cloud Computing					40		
IoT		10					22.00
Immersive technologies				30			
Artificial intelligence				30			
				Organization & processes (O)			
Team structure	0			30			28.33
Responsibilities				30			

Data access	50	
The use of BIM methodology	30	
Process automation	10	
Performance management	20	
Culture & personnel (C)		
Digitalization strategy	30	
Initiative of the executive level	30	
Culture of failure	40	35.00
Acceptance of digital methods	30	
Further training & qualification	40	
Resources	40	
Data Management (D)		
Timeliness of the data	30	
Data governance	30	
Data quality	20	
Data security	50	31.43
Degree of Coverage	20	
Utilization of data value	30	
Data storage	40	
Interconnectivity (I)		
Usage of platforms	30	
Human-machine interface	30	
Machine-machine interface	0	20.00
Use of AutoID technologies	20	

APPENDIX 06: DETAILED RESULTS OF THE COMPANY F EVALUATION

The DCCMM index of Construction Company F has 44.50 points and corresponds to the highest possible maturity level 5. Thus, the company has implemented the digital transformation very well and is very digitized in the context of the construction industry (s. Figure 7).

Calculation of the maturity index:

$$
\begin{aligned}
DCCMM - Index\ (company\ F) &= \ 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\
&= \ 0.15 * 40.00 + 0.20 * 43.33 + 0.20 * 48.33 + 0.30 * 45.71 + 0.15 * 40.00 \\
&= 44.05\ \ points = maturity\ level\ 5
\end{aligned}
$$

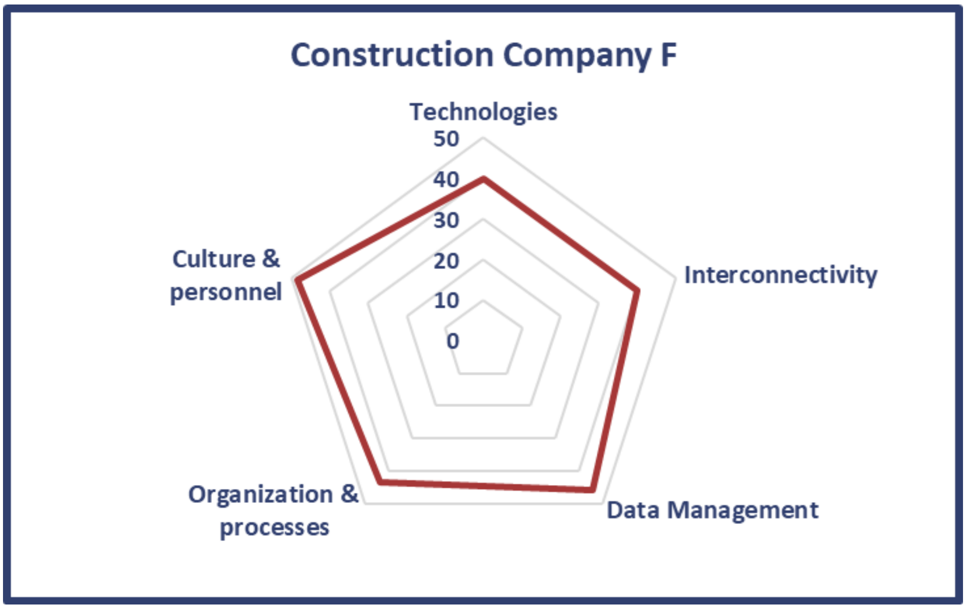

Figure 7: Assessment Results Company F.

The detailed results of the assessment of company F are shown belown in Tab. 18.

Table 18: Detailed Assessment Results Company F.

Company F							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
			Technologies (T)				
Robotics			20				
Cloud Computing						50	
IoT					40		40.00
Immersive technologies						50	
Artificial intelligence					40		
			Organization & processes (O)				
Team structure						50	43.33

Responsibilities				40		
Data access					50	
The use of BIM methodology					50	
Process automation				40		
Performance management			30			
Culture & personnel (C)						
Digitalization strategy					50	
Initiative of the executive level					50	
Culture of failure					50	48.33
Acceptance of digital methods				40		
Further training & qualification					50	
Resources					50	
Data Management (D)						
Timeliness of the data					50	
Data governance				40		
Data quality					50	
Data security					50	45.71
Degree of Coverage				40		
Utilization of data value				40		
Data storage					50	
Interconnectivity (I)						
Usage of platforms					50	
Human-machine interface				40		40.00
Machine-machine interface			30			
Use of AutoID technologies				40		

APPENDIX 07: DETAILED RESULTS OF THE COMPANY G EVALUATION

Construction company G achieves an overall score of 33.17 points and is assigned to maturity level 3. In the context of the maturity model, the company is one of the established transformations that have already tested individual digitization projects. Nevertheless, the company still has a lot of untapped potential on the way to becoming a smart company (s. Figure 8).

Calculation of the maturity index:

$$DCCMM - Index\ (company\ G) = 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I$$
$$= 0.15 * 24.00 + 0.20 * 40.00 + 0.20 * 41.67 + 0.30 * 32.86 + 0.15 * 22.50$$
$$= 33.17\ points = maturity\ level\ 3$$

The detailed results of the assessment of company G are shown below in Tab. 19.

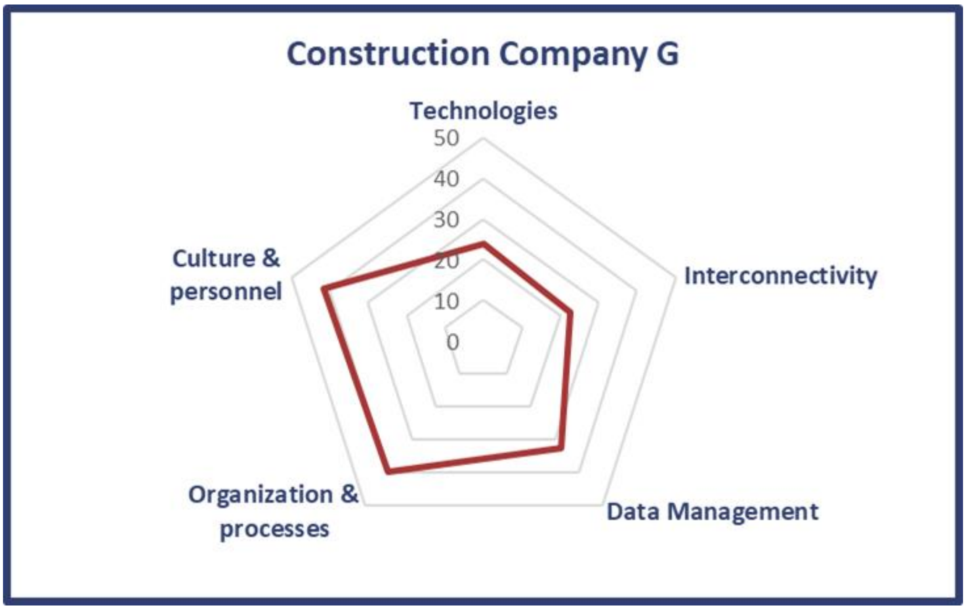

Figure 8: Assessment Results Company G.

Table 19: Detailed Assessment Results Company G.

Company G							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
				Technologies (T)			
Robotics			20				24.00
Cloud Computing					40		
IoT			20				
Immersive technologies			20				
Artificial intelligence			20				
				Organization & processes (O)			
Team structure				30			40.00

Respons ibilities					40		
Data access						50	
The use of BIM methodology					40		
Process automation					40		
Performance management					40		
Culture & personnel (C)							
Digitalization strategy						50	
Initiative of the executive level					40		
Culture of failure					40		41.67
Acceptance of digital methods				30			
Further training & qualification						50	
Resources					40		
Data Management (D)							
Timeliness of the data				30			
Data governance				30			
Data quality				30			
Data security					40		32.86
Degree of Coverage				30			
Utilization of data value			20				
Data storage						50	
Interconnectivity (I)							
Usage of platforms						50	
Human-machine interface	0						22.50
Machine-machine interface		10					
Use of AutoID technologies				30			

APPENDIX 08: DETAILED RESULTS OF THE COMPANY H EVALUATION

Construction company H receives a total score of 24.92 points at the end of the assessment cycle. This means a maturity level 2 for the company. The company is testing initial projects in the context of digital transformations and has implemented them in individual process structures in operations (s. Figure 9).

Calculation of the maturity index:

$$\begin{aligned} DCCMM - Index\ (company\ H) &= 0.15 * T + 0.20 * O + 0.20 * C + 0.30 * D + 0.15 * I \\ &= 0.15 * 16.00 + 0.20 * 23.33.00 + 0.20 * 33.33 + 0.30 * 28.57 + 0.15 * 17.50 \\ &= 24.92\ points = maturity\ level\ 2 \end{aligned}$$

The detailed results of the assessment of company H are shown below in Tab. 20.

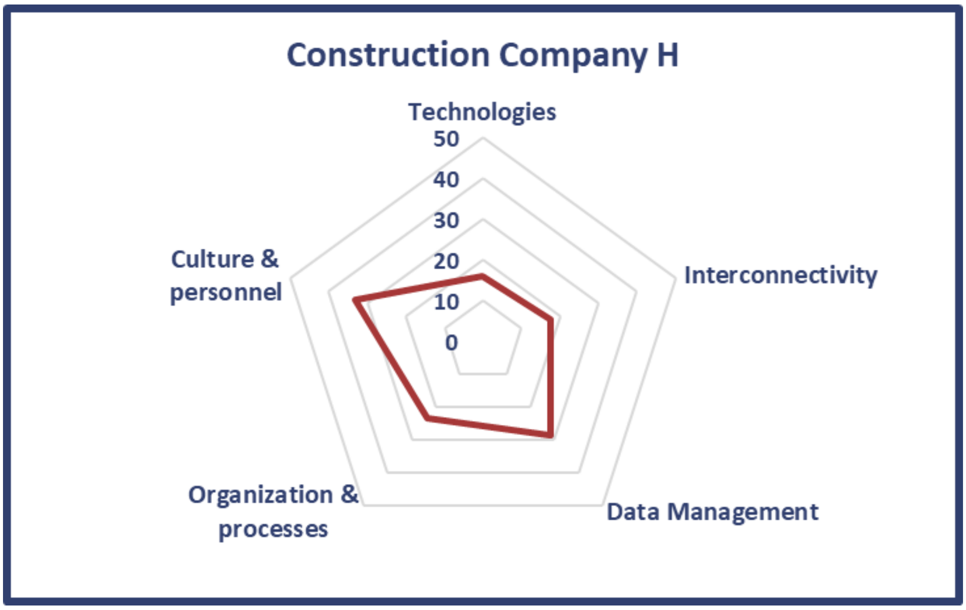

Figure 9: Assessment Results Company H.

Table 20: Detailed Assessment Results Company H.

Company H							
Level	**0**	**1**	**2**	**3**	**4**	**5**	**Ø**
				Technologies (T)			
Robotics	0						16.00
Cloud Computing						50	
IoT	0						
Immersive technologies		10					
Artificial intelligence		20					
				Organization & processes (O)			
Team structure					40		23.33

Responsibilities					40		
Data access					40		
The use of BIM methodology	0						
Process automation	0						
Performance management			20				
Culture & personnel (C)							
Digitalization strategy					40		
Initiative of the executive level			20				
Culture of failure						50	33.33
Acceptance of digital methods				30			
Further training & qualification				30			
Resources				30			
Data Management (D)							
Timeliness of the data						50	
Data governance				30			
Data quality	0						
Data security					40		28.57
Degree of Coverage			20				
Utilization of data value		10					
Data storage						50	
Interconnectivity (I)							
Usage of platforms				30			
Human-machine interface			20				
Machine-machine interface		10					17.50
Use of AutoID technologies		10					