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Introduction of a digital maturity assessment framework for construction site operations

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ABSTRACT

Digital technologies as enablers for more sustainable improvements of construction site processes contain interesting opportunities. Little is known how to, in a structured way, assess and implement digital technologies to support development and improvement of construction site operations. Maturity frameworks assess the status quo and guide decision makers to potential improvements. The purpose of this research is to develop a framework for assessing digital maturity of construction site operations. Literature and empirical data were utilized to develop and validate the framework. The framework contains assessment areas that specify the areas of potential improvements, maturity levels that indicate the progression towards maturity, assessment criteria that define organizational aspects of the assessment, and an assessment procedure to guide assessors. The maturity assessment framework contributes potentially to systematization of evaluative processes creating opportunities for a change within processes and organizations enabled by digital initiatives and to long-term improvements on project portfolio level.

KEYWORDS

Construction management; digitization; digitalization; digital transformation; change management

Introduction

Improvement objectives for operational processes on construction sites include time, cost (Johnson and Babu 2020), productivity (Ahmad et al. 2020), safety, job satisfaction (García de Soto et al. 2019), quality, and environmental impact as resource and energy consumption (Banawi and Bilec 2014). Construction sites are essential for managing sustainability of the overall construction process with their multifaceted sources for waste, safety risks, and economic challenges (Banawi and Bilec 2014; García de Soto et al. 2019; Johnson and Babu 2020).

Increased utilization of digital technologies can potentially transform the construction industry (Sezer and Bröchner 2019) through e.g., adopting approaches as Industry 4.0 (Oesterreich and Teuteberg 2016) or its counterpart Construction 4.0 (García de Soto et al. 2019). The denotation 'digital' refers to the use of electronic data sets which stays in contrast to analogue ones (Rachinger et al. 2018). Increased use of digital information in construction projects (Whyte 2019; Hall et al. 2020), in particular Building Information Modelling (BIM) in design, has led to a major shift in digital adoption (Bryde et al. 2013).

On a broad scale, the concept of maturity assessment models is increasingly being applied within the field of information systems and management science as an approach for continuous process improvement (Mettler 2011). Such models have been proposed to facilitate digital technology adoption in construction generally (Willis and Rankin 2012) but are concentrated on BIM (Succar 2010; Kassem et al. 2013; Hosseini et al. 2016) delivering insights in adoption behaviour and barriers on project, firm, or country level. However, few of these BIM maturity models deal contextually with construction site-specific issues (Kassem et al. 2013) and are instead concentrated on capabilities related to BIM for simulation and modelling in the design phase (Oesterreich and Teuteberg 2016). Maturity models aiming towards Industry 4.0 are associated with the use of cyber-physical systems and internet of things (IoT) services (Santos and Martinho 2019). They rely on stable supply chains, network connectivity reliability, high awareness of all partners, and a significant existence of digital competencies (Carolis et al. 2017; Ustundag and Cevikcan 2018). Production in construction with its temporary supply chains, producing one-off construction projects with a site setup around the single project (Vrijhoef and Koskela 2000) is far from this ideal situation. Caused by the dynamic and varying nature of construction projects managed in portfolios (Wernicke et al. 2019), a contextual adaption of maturity models is required (Mullaly 2014).

Digital maturity can be seen from a technological perspective and from a managerial perspective. A framework for assessing digital maturity would therefore, following (Hosseini et al. 2016), include if the organization adopts digital technologies and according to Chanias and Hess (2016) changes existing processes and creates new opportunities. Leaning on these two definitions, this research proposes that increased maturity supports construction site and project organizations to implement digital technologies. Increased maturity would then symbolise the institutionalization of evaluative processes that creates opportunities for a change within operational processes and organizations in line with Remane et al. (2017) or Berghaus and Back (2016) if maturity is: (1) managed in a systematic way (Chanias and Hess 2016), and (2) effects on capabilities and performance are measured (Rolstadås and Schiefloe 2017).

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Importantly, maybe with the exception of automation, robots, and additive manufacturing, few digital technologies do per se. improve operational processes on construction sites. For years, traditional and Lean construction approaches have been developed to improve productivity and process flow of site operations. Synergies from using Last Planner with digital approaches as BIM and virtual design are reported (Sacks et al. 2010; Fosse et al. 2017). Opportunities from implementing digital technologies can be expected if the technologies are aligned with site operations, prerequisites, and organizational aspects. This research therefore focuses on the construction site's operational processes including safety, environment, and efficiency with digital technologies as enablers. An implementation of digital technologies in this research includes both adopting processes and adapting processes if necessary for aligning technologies to contextual prerequisites.

The purpose of this research is to develop a framework for assessing digital maturity of construction site operations. The aim of the framework is to enable a systematic and continuous assessment to guide decision makers in digitally based improvement initiatives of site operations by considering organizational aspects (individuals, technologies, organizational structure, goals, and environment). A performed assessment could not only identify how digital technologies should be implemented as an enabler for improvements of operations at construction sites, but also present aspects of an organizations' capability to conduct active and goal-oriented digitally enabled short and long-term improvement processes. Potentially, such a framework contributes to continuous improvement processes (Banawi and Bilec 2014) enabled by opportunities of digital technologies ultimately spreading from single sites, to project portfolios, and the construction sector. To guide the framework development, three research questions are addressed:

1. How can construction site operations be categorized in assessment areas?
2. How can digital maturity levels be distinguished in the construction site context?
3. How can assessment criteria be defined for construction site organizations?

Maturity model development approaches

A generic maturity model consists of dimensions and criteria, which describe the areas of action, and maturity stages that indicate the evolution path towards maturity (Berghaus and Back 2016) by addressing a series of goals (Mettler 2011). A majority of generic maturity models have their roots in quality management and continuous improvement movements. One of the most recognized maturity models is the capability maturity model for software developed by Paulk et al. (1993). The underlying premise of process maturity modelling is that the quality of a product is directly related to the quality of the process used to develop that product (Willis and Rankin 2012). It is presumed that better processes deliver improved results and therefore embrace an expectation that maturity is good, and more maturity is better (Mullaly 2014). Relying on Paulk et al. (1993), a maturity-based measure is a normative approach that attempts to measure the effectiveness and quality of the processes to develop a product whereas ISO-standards are an example of a normative but non-maturity approach (Saleh and Alshawi 2005). Therefore, capability maturity models have the ability to go beyond an assessment of a system's adoption of an ISO-standard (Eadie et al. 2012).

Process based maturity models have been criticized for overemphasizing the process perspective and focusing on formalization of improvement activities accompanied by extensive bureaucracy that not necessarily guarantee organizational success (Mettler 2011). Maturity models have a number of inherent presumptions embedded into their structure and application, by far the largest concern is the assumption that all projects within a specific organization should be managed in the same fashion (Mullaly 2014). Remane et al. (2017) contradict that digital transformations can take idiosyncratic paths, which acknowledges the dynamic and varying nature of construction projects and sites. While maturity models most typically are static and define one path of implementation and progression, the evolution of maturity models should recognize that changes in contexts must be reflected by changes in implementations to ensure the realization of value (Mullaly 2014). In the same path of reasoning, but in a more indirect way of criticizing the linearity and formalization of maturity models, Berghaus and Back (2016) indicate that digital transformation seems to be intuitively managed rather than strategically planned. This indicates that at the beginning of the transformation process, firms tend to experiment with digital innovations or react to external changes, while firms at a later stage perform more systematic planning. Maturity models therefore, at best, provides some guidance by representing an overview of different areas and mapping out typical paths (Berghaus and Back 2016).

Based on the capability maturity approach, Meng et al. (2011) propose a maturity model for construction supply chain relationships containing five components: (1) Assessment areas, (2) Assessment criteria, (3) Maturity levels, (4) Framework matrix, and (5) Assessment procedure. This general design is followed in this research:

1. Assessment areas (areas of action, improvement range) are contextual depended on the specific processes to be improved by implementing digital technologies.
2. Assessment criteria define aspects of analysis when determining the maturity level and should specify contextual aspects to consider when improving assessment areas (Saleh and Alshawi 2005; Ivert and Jonsson 2014; Mullaly 2014).
3. Maturity levels indicate the progression towards maturity and are normally categorized into five levels e.g. Paulk et al. (1993), but variants exist e.g. four levels (Eadie et al. 2012) or Santos and Martinho (2019) Industry 4.0 maturity model with six stages. Each level is the foundation for the next one and contains goals to be achieved before movement up to the next level (Paulk et al. 1993).
4. The framework matrix aggregates assessment areas, assessment criteria, and maturity levels.
5. The assessment procedure guides assessors how to apply the suggested framework in assessment practice (Meng et al. 2011).

Improvement approaches for construction site operations

Different improvement approaches for construction processes are available. Lean construction is one approach that is based on the adaption of Lean principles onto construction settings through utilization of Lean tools and the development of construction specific practices (Koskela 2020). Examples on development and utilization of Lean construction methods are reported in practice and literature. Last planner is a system developed to support planning and control at construction sites based on collaboration and commitment of front line supervisors (Ballard and

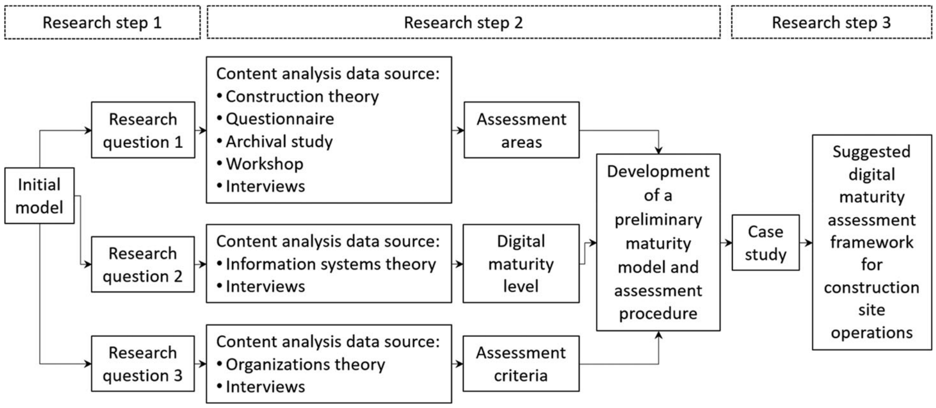

Figure 1. Research design.

Tommelein 2016). Stretching the use of Lean, Banawi and Bilec (2014) suggest to integrate Lean, Green and Six sigma to address the different improvement objectives of the approaches regarding waste reduction, environmental impact, and the elimination of variation. There are also reported examples that increased utilization of digital technologies can potentially improve construction industry operations for e.g., resource consumption registration and monitoring, schedule and budget follow-up, administration of site diaries, and waste management (Sezer and Bröchner 2019). Synergies of combining e.g., the Last planner with digital approaches as BIM and virtual design are reported (Sacks et al. 2010; Fosse et al. 2017).

Digital technologies as Internet of Things, robotics, cloud and edge computing, cyber-physical systems, or additive manufacturing are joined within the concept of Industry 4.0 (Ustundag and Cevikcan 2018; Santos and Martinho 2019). Large-scale adoption of the potential benefits of Industry 4.0 in terms of improved productivity, safety and quality to the construction industry has not taken place yet (Oesterreich and Teuteberg 2016). Similarly, García de Soto et al. (2019) proposes digital technologies (e.g., robotics, automation) under a concept called Construction 4.0 and conclude that the adoption of such technologies will impact workforce, roles and organizational structures in construction.

Research design

The research design follows Meredith (1993), who argues for a need for descriptive, empirical investigations within operations management to create findings and propositions relevant for managers. Meredith (1993) suggests a research cycle of describing, explaining, and testing of models in their fields towards a definition of valid frameworks. This research study is designed as a process of: (1) identification of an initial model proposed in practice, (2) development of a preliminary maturity model based on Meng et al. (2011) by incorporating literature and empirical findings, (3) testing of the preliminary maturity model in its practical context to provide understanding through face validation (Brahma 2009), and thereby suggesting a digital maturity assessment framework for construction site operations. Figure 1 visualizes the research design.

Research step 1 – initial model identification

All authors of this study are involved in a Swedish R&D project aiming to facilitate and evaluate digital initiatives on construction sites. More than 50 companies from the construction and IT-sectors collaborate together with academic partners in the project. Within the R&D project, a model was internally utilized by a contractor to evaluate digital development of certain construction site improvement areas. This model, generated in practice by McKinsey & Company (Blanco et al. 2017), is called the 'initial model' in this research. The initial model stems from analysis of the attention of construction technology start-ups that develop tools and solutions for addressing or eliminating different operational problems at construction sites. From the definition of the initial model, the first research question arose, pin-pointing the necessity to contrast this practical view with issues identified in construction management literature. Criteria for assessing how digital technologies are implemented in site organizations are not considered in the initial model. In order to develop a scientifically based framework for assessing digital maturity of construction site operations, these aspects were considered essential. To adapt the maturity model design as defined by Meng et al. (2011) to construction site operations, this gap in the initial model was operationalized in research question two and three.

Research step 2 – preliminary maturity model development

The analysis follows the qualitative content analysis process as suggested by Mayring (2014). According to that method, texts from different qualitative sources as interviews, focus groups, open questionnaires, and documents are analysed in iterations by extracting content-bearing components and category formulation. In this research, the categories are the assessment areas, maturity levels, and assessment criteria as formulated in the research questions. The analysis process can be supported with theoretical sources either deductive with categories defined by theory, inductive with categories formulated from empirical data, or abductive as a mix of both (Mayring 2014). The data was cross analysed by the authors independently and then discussed in group to reduce the risk of confirmation bias.

For research question one, a mixed approach was chosen to incorporate empirical data to potential construction site assessment areas proposed in literature. The different sets of data (Figure 1) were iteratively added, cross-checked compared to the initial model, and the categories were adapted (Table 1) as a restructured set of assessment areas. The analysis aimed to provide both categories and contextual content. Propositions of assessment areas originating from the empirical data (questionnaire, archival study, workshop and interviews) were contrasted to literature (Illingworth 2000; Bowden et al. 2004; Mohamed 2006; Mäki and Kerosuo 2015; Sezer and Bröchner 2019). In

Table 1. Defined assessment areas for construction site operations (research question one).

Assessment areas	Data source	Examples of activities
Design management	Initial model	Visualize drawings and 3D models on-site on mobile platforms Update digital drawings, models and technical information with notes and as-built records
Scheduling	Initial model	Create, assign, and prioritize tasks in real time and distribute to mobile devices Plan and simulate site progress in 4D-software Maintain a digital construction site disposition plan
Logistics	Illingworth (2000); interviews	Identify, track and locate material and equipment on-site with digital tools Digitally monitor procurement orders, receipts, use, and quality issues Maintain digital bill of quantities
Production	Illingworth (2000); interviews	Automation and robotization of production processes Utilization of advanced production technologies e.g., additive manufacturing
Human resource management	Mohamed (2006); Bowden et al. (2004); questionnaire; interviews	Track productivity digitally on trade or worker level Monitor skills, competences, and training plans on digital platforms Digitally monitor staff health status
Quality control	Initial model	Digitally collect and monitor progress reports Perform quality inspections with mobile devices
Contract management	Initial model	Digitally update and follow-up contracts towards clients Digitally track sub-contractor and supplier progress including payment management
Work safety	Bowden et al. (2004); Mohamed (2006); questionnaire	Track and report incidents through mobile devices Announce safety massages to staff through mobile devices
Security	Bowden et al. (2004); questionnaire; interviews	Monitor staff and visitors presence through digital entrance security Handling of cyber-threats and data security
Environmental impact	Archival study; workshop; questionnaire; interviews	Digitally plan, monitor and track environmental impact Digital authority involvement in environmental issues
Information management	Mohamed (2006); Bowden et al. (2004); Sezer and Bröchner (2019); Mäki and Kerosuo (2015); archival study; workshop	Utilize digital communication opportunities with stakeholders Collect, update, and distribute project documents through digital platform Computer-aided calculation, optimization, and simulation Utilize IoT-solutions, advanced analytics, or artificial intelligence Digitally monitor problem issues and solving process

order to strengthen the construct validity of assessment areas, three different data gathering activities were performed:

- A three hour workshop was organized with eleven external participants representing construction clients, logistics providers, one IT-supplier, contractors, construction engineering consultants, one sub-contractor for plumbing and ventilation work, and one additional researcher. The participants discussed challenges and opportunities of digital technologies related to relevant construction processes.
- A questionnaire, based on the initial model, was sent to contractors' representatives in the R&D project. Six senior managers representing project portfolio level (e.g., regional production managers) and operational level (site management) completed the questionnaire form. They were asked about the status of ongoing or finished digital initiatives in the areas. Qualitative data was captured by asking respondents to comment on the assessment areas and exemplified site activities.
- The 'digital plan' for a major construction site of a contractors, participating in the R&D projects, was utilized as archival material. The 'digital plan' governs digital initiatives and their purpose for improving site operations and is structured in activities by a digital leader, a role to directly support digital initiatives at major projects.

A deductive approach was utilized for research question two and three to formulate: (1) potential definitions of maturity levels, primarily based on literature from information systems, and (2) potential assessment criteria, primarily based on organizational literature, since construction firms, projects, and sites are considered as organizations.

To increase the understanding of all aspects of the suggested framework, two in-depth interviews were performed to further contrast and ad content validity to all three research questions (Figure 1). Both interviews lasted for about one hour, were transcribed and then sent to the interviewees for approval. Interviewee A has 11 years' experience as a consultant in the construction industry with the main focus in recent years on digital implementations and change management. The interview consisted of prepared questions about potential assessment areas, regional dissimilarities, and potential benefits and challenges with digital maturity assessments. Interviewee B holds a PhD in construction IT and has 30 years' experience from working in the construction sector as project engineer, project manager, consultant, and with strategical research and innovation. The interview consisted mainly of prepared questions about methodological advantages and disadvantages of questionnaire-based IT-assessment and developments in the construction industry that correlate with IT-usage or digital maturity.

Research step 3 – case study validation

A case study was chosen to visualize the functionality of the preliminary maturity model. The case was a new-build construction site for a 100 000 m2 hospital project executed by one of the largest contractors in Sweden. The assessor was the manager for support and digital activities, reporting directly to the site manager and responsible for testing and follow-up of digital initiatives. The assessment was moderated by one of the authors and performed according to the suggested 'Assessment procedure' chapter. Follow-up questions about the preliminary maturity model and the procedure were discussed. The assessment procedure lasted for 75 minutes plus subsequent 30 minutes for follow-up questions and discussions.

Suggested digital maturity assessment framework for construction site operations

The suggested framework in this research is normative by asking site and portfolio management to relate relevant aspects when evaluating the initial status regarding digital maturity, thus guiding what to include ahead. According to interviewee A, such an evaluation creates an '*awareness of starting point, priorities, and challenges to be imbedded in decision-making*'. Interviewee B adds, '*Measurements about how maturity is developing are extremely interesting for the industry to figure out in which direction we are going, how good we are in adapting new technologies and working methods and how far we have come in the industry*'.

Assessment areas

As summarized in Table 1, this research suggests 11 assessment areas (research question one). Table 1 indicates that four problem areas of the initial model were strengthened as characterizing site key areas by the other data sources without conflicting issues and are therefore proposed as assessment areas. Seven assessment areas were found or restructured during the analysis process. Important to note are two assessment areas: 'Logistics' (as a summary of materials and equipment management) and 'Production' which includes issues related to the transformational site activities, its potential automation or utilization of advanced production technologies as additive manufacturing (Oesterreich and Teuteberg 2016; García de Soto et al. 2019).

Maturity levels

In information systems literature, maturity levels indicate the progression towards maturity (Berghaus and Back 2016). Following this but from a construction site perspective, maturity levels in this research indicate the progression towards increasing capabilities to evaluate and implement digital technologies supporting the improvement of construction site operations. Digital initiatives can be distinguished in three categories according to their purpose: (1) digitization as a process of converting analogue information to digital, (2) digitalization as the use of digitized information in operations to create value e.g., increased efficiency or decreased error rates, and (3) digital transformation which refers to the restructuring of business processes, thus changing the way firms do business (Gobble 2018; Rachinger et al. 2018). Four maturity levels are proposed (research question two).

Level 0: initial - no, unspecific, or sporadic digital initiatives

According to Valdez-de-Leon (2016), an initial level describes organizations that have decided to move towards a digital business and have taken initial steps in that direction. Succar (2010) terms this level 'ad-hoc', in line with Paulk et al. (1993) and Meng et al. (2011), leading to an absence of continuous improvements. Development processes are not controlled with reactive management lacking proper organizational and technological prerequisites for building the needed infrastructure that enables repeatability and usability of the solutions (Carolis et al. 2017). In this research, 'Level 0′ is summarized by sporadic digital initiatives in terms of pilot actions performed (Santos and Martinho 2019) without specific addressment of organizational issues (individuals, structure, goals), e.g., technologies launched because of offerings from tech companies. Interviewee B exemplifies this by stating, '*to only buy new technology because others do, then you have high usage but low maturity*'.

Level 1: digitization of construction sites - central IT led pilot projects

Digitization is the process of converting analogue information to digital (Gobble 2018). At this level, implementations of actions are started to support site operations with digital data, with primary benefits being observed (Santos and Martinho 2019), but limited to the information flow. Interviewee A exemplifies this level with '*the leaders at the construction site could have that information in real time and thus make better decisions*'. As described by Ustundag and Cevikcan (2018), digital initiatives at this level are launched by central IT departments or roles to coordinate a few stakeholders in pilot initiatives to investigate potential benefits. However, cost/benefit-analysis with common performance measures are not conducted (Meng et al. 2011), interactions between departments are limited, and generally involve just technology heavy areas and interested employees, a structure unsuitable for transformation (Ustundag and Cevikcan 2018). Carolis et al. (2017) highlight the absence of the organization in this maturity level to manage infrastructure development and responsibilities for adopting technologies. Applied on the construction site settings, there is a lack of integration between digital initiatives and site operations. Consequently, 'Level 1′ is characterized by central IT departments or roles leading digital initiatives, supported by the sites when objectives are compatible with operations and available resources.

Level 2: digitalization of construction sites - project/site responsible for digital initiatives

Digitalization is the use of digitized information enabled by digital technology to create value (Gobble 2018). Comparable levels in some generic maturity models are explained with 'integration'. Valdez-de-Leon (2016) highlights the integration of operations across the organization as enabler of capabilities. Carolis et al. (2017) recommend integration to be based on common and shared standards within the firm or industry. Paulk et al. (1993) ask for an integration of engineering process and operations management, a view compliant to the distinction of project and site organizations in construction settings. It is assumed that both units utilize relevant resources in an integrated manner to enable successful implementation of digital technologies into site operations. In this research, an integration of digital initiatives into project or site organizations is seen as a development from 'Level 1′ (central IT responsible for digital initiatives) to 'Level 2′, characterized by site or project organizations to be responsible for digital initiatives, integrated with and supported by central IT. Such responsibility includes the determination of goals and measurements and facilitate sustainable effects on site operations including its formal structure, operational processes, culture, interaction, or social relations. Interviewee A states that '*successful implementations are those that have gone beyond individual pilots, impact way of working, have realized an effect, and display human relation aspects such as employee development and work satisfaction*'. Increased responsibility of project and site organizations enables site specific digital strategies for operations improvements and integration of partners and stakeholders directly with responsible organizational roles (Ustundag and Cevikcan 2018).

Level 3: digital transformation of construction sites - long-term development in project portfolio

Digital transformation refers to a fundamental change process within an organization (Berghaus and Back 2016) that

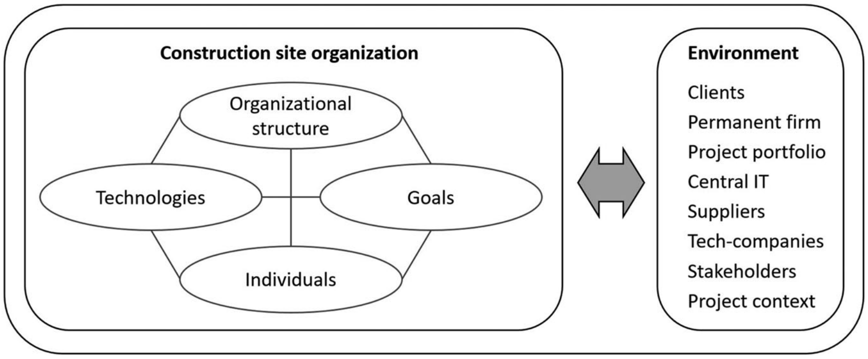

Figure 2. Organizational model for construction sites (adapted from Scott 2003; Rolstadås and Schiefloe 2017; Lin et al. 2007).

restructures business processes and change the way firms do business (Gobble 2018; Rachinger et al. 2018) as continuous or discontinuous, fast or slow, patchy or systemic, imported from the outside or created internally (Besson and Rowe 2012). Applied to general construction settings, specific projects and their sites do normally not represent the long-term perspective of an organization due to their temporary character, i.e., a single site has limited options to affect business processes. Ideally, the permanent firm with its projects portfolio (Wernicke et al. 2019) represents the long-term perspective. An important aspect of digital transformation as expressed by interviewee A, is the '*scaling up of many use cases … to get a significant benefit*'. Consequently, digital transformation of the construction site links the project/site to long–term development and symbolize institutionalization of evaluative processes that creates opportunities for a fundamental change. The highest maturity level refers to the long-term development in project portfolios to increase overall firm performance (Valdez-de-Leon 2016) taking into account the demand for digital infrastructure for information exchange (e.g., speed, robustness, and security) and the integration and collaboration among all firm functions within the decision-making (Carolis et al. 2017). Thus, the framework does not assess if digital transformation occurs on a specific site because this refers to the firm or sector level, but it assesses established conditions, which links the single site to a long-term development in the project portfolio, consequently enabling transformation processes on firm level.

Assessment criteria

Interviewee A states that '*change management through digital initiatives is about complementing conventional software and hardware developments with the strategic change work of how organizations and people adopt it*'. Interviewee B adds, that '*many benefits are observed, but the difficulties of measuring economic benefits occur due to the high number of parameters, organizations and actors involved*'. Following this reasoning, organizational literature (Scott 2003; McAuley et al. 2007; Hatch and Cunliffe 2013) has been utilized to inform the assessment criteria. Scott (2003) suggests that organizations in their environment can be explained by four elements: social structure, goals, participants, and technology. In an equivalent line, adapted to analyse project management in construction, Rolstadås et al. (2014) and Rolstadås and Schiefloe (2017) specify organizations to contain of formal aspects (structure, technologies), informal aspects (culture, interaction, social relations and networks), external relations, and organizational capabilities and performance. Observations from maturity model development point to the importance to involve the entire organization into continuous improvement processes (e.g., Chanias and Hess 2016), based on experience (Carolis et al. 2017), skills of individuals, and the relevance of stakeholder involvement (Ustundag and Cevikcan 2018). Overlaps in the taxonomy between organizational literature and maturity model development has been found. Importantly, Saleh and Alshawi (2005) highlight IT-infrastructure, people, process, and work environment as areas likely to require improvements to sustain success when implementing information system projects. In the same line, the criteria of individual, technological, and organizational dimensions were discovered in implementations of advanced scheduling systems within the theory field of information systems (Berglund and Karltun 2007; Ivert and Jonsson 2014).

Figure 2 visualizes the model of a site organization which is the base for the proposed assessment criteria. Additionally, Figure 2 clarifies the unit of analysis in this research to be the site organization and how its organizational dimensions integrate with its environment in the context of digital initiatives. While assessment areas describe the scope of action and maturity levels indicate the progression, assessment criteria define analysis aspects when evaluating the maturity progression thus specifying contextual aspects to consider when improving potential assessment areas (Saleh and Alshawi 2005; Ivert and Jonsson 2014; Mullaly 2014). This research suggests to consider the organizational aspects individuals, technologies, organizational structure, goals, and environment as assessment criteria (specified in Table 2, research question three) i.e., how digital initiatives are integrated with these five aspects at the site organization and within its environment.

Framework matrix

When combining assessment areas, criteria, and maturity levels, the digital maturity assessment framework for construction site operations emerges as a two dimensional matrix (Table 3). Two additional framework elements are elaborated by a collaborative reasoning process of the researchers: (1) assessment questions based on the criteria and (2) assessment conditions to link the maturity level to the criteria in the framework matrix. The conditions describes the maturity levels applied on the specific criteria. The assessment questions are designed as multiple-choice questions to ask assessors to choose between one of four conditions. A maturity level is achieved for a single criteria, if assessors choose the condition that best characterizes how digital initiatives are performed in a specific assessment criteria. The assessment areas are evaluated as the sum of all five criteria. All areas are assessed with identical assessment questions and conditions.

Table 2. Defined assessment criteria for construction site organizations (research question three).

Assessment criteria	Definition as applied in framework (source)
Individuals	Organizational participants who in return for incentives contribute to the organization (Scott 2003)
	Aspects of individual humans considered important to perform a task or a change (Berglund and Karltun 2007) as education, experience, knowledge (Ivert and Jonsson 2014), and engagement (Lin et al. 2007)
Technologies	Refer to mechanism for transforming inputs into outputs that emerge in utilization of machines, equipment, and technical skills of individuals (Scott 2003)
	Range from IT infrastructure to technologies used for core operations e.g., manufacturing; enables members to work effectively and to control the system (McAuley et al. 2007)
	Technical system divided into two parts; production equipment as primary and administration (not directly associated with the value-adding activities) as secondary e.g., information system, hardware, software (Berglund and Karltun 2007)
	Different tools and infrastructures utilized by members of an organization to perform their activities (Rolstadås and Schiefloe 2017)
Organizational structure	Design of the organization to fits its purpose (McAuley et al. 2007)
	Physical and social structure (Hatch and Cunliffe 2013)
	Existing patterned or regularised relationships among participants in an organization (Scott 2003)
	Represents the individuals in an aggregated sense and comprises how activities are organized and structured, both formally and informally including rules, procedures, cultural factors, and relations between system components (Berglund and Karltun 2007; Ivert and Jonsson 2014)
	Humans immersed in socio-technical network (Lin et al. 2007)
	Organizations as socio-cultural systems with defined roles, responsibilities and authority in the formal organization, defined procedures, regulations, and working requirements (Rolstadås and Schiefloe 2017)
Goals	'Tentatively defined as conceptions of desired ends' that individuals attempt to achieve through their performance of activities (Scott 2003)
	Organizational capabilities and performance including an organization's ability to manage a project to meet defined goals e.g., time, cost, and quality (Rolstadås and Schiefloe 2017)
Environment	Elements outside the organization but with relations to it (McAuley et al. 2007)
	Physical, technological, cultural, and social context where organizations exist in and must adapt to for survival (Scott 2003)
	Relationships of the site internal organization to external contexts and stakeholders (Rolstadås et al. 2014)

Assessment procedure

The assessment is meant to be proceeded in rows of the 11 assessment areas, stepwise according to the following procedure:

1. Choose the assessment area (1 to 11) to be assessed.
2. Review each assessment criteria (I, T, O, G and E) by answering the respective assessment question with the appropriate assessment condition that best characterizes the situation on-site according to Table 3. The assessment condition determinates the achieved maturity level for any given single area-criteria-combination.
3. Document results for each assessment criteria in an assessment table.
4. Optionally, an assessment area score up to 15 points (sum of five criteria with one point for reached maturity level 1, two points for level 2, and three points for level 3 for single criteria) and an area average score from 0 to 3 (score divided by five) can be calculated, and
5. Restart with step 1.

The assessment framework is meant to be performed by site managers or accomplished alternatives within the site organization with insights into operations and digital initiatives. The assessment procedure can be mediated by researchers or permanent firm delegates, which allows detail questions and discussions within specific area-criteria-combinations. The highest positive effect of the framework for long-term improvements of site operations can be expected if permanent firm delegates are involved in long-term development of the project portfolio, because maturity level three advocates high responsibility of portfolio management within decision-making fare beyond site managers' opportunities. An assessment table can be maintained to support the procedure based on Table 3 with areas, criteria, and respective maturity levels. After completion, a total score for all 11 assessment areas, i.e., a total digital maturity score, can be calculated by adding all area scores.

Two important state points should be noted. Firstly, the score per se. is not the important outcome. However, it can be used to generate visual profiles (e.g., Figure 3) to 'create an awareness of the starting points of assessed site organizations, the priorities and challenges to be imbedded in decision-making, and to start discussions about potential improvements related to digital initiatives' (interviewee A). Secondly, a high score is not a preferred or 'advanced' organizational state, it is an indicator of possessed capabilities to evaluate and implement technologies for digital enhanced site improvement processes.

Case study

The functionality of the suggested framework was examined in a case study. The maturity levels were calculated as assessment scores (following step 4 in the assessment procedure) of each 11 assessment areas (Figure 3). The site reached (at the time of the demonstration) an average maturity level of 'two', which was commented by the assessor: *'we have the luxury in our project to have my role [manager for support and digital activities], a role of a digital leader [digital support function permanently located on-site], and a quality coordinator. We have many who can drive the questions in the project and have an organization to operate which not all projects have'*. The lowest score was achieved for the 'Production' assessment area, accomplished by a pilot project for augmented reality, led by the central IT with only sporadic involvement of site personnel. In general, the assessor could evaluate the site according to the assessment procedure and commented the usability of the framework to be *'good, since you have divided it into relevant areas and questions, otherwise it becomes superficial. It was relevant to break it down into people, techniques, and stakeholders. Very good with five criteria to go deeper.'* Thus, the case study indicates evidence of face validation of the suggested framework, i.e., its content is regarded relevant in the researched context (Brahma 2009), albeit the validation is

Table 3. Digital maturity assessment framework for construction site operations.

			Assessment conditions to determine digital maturity level 0, 1, 2, or 3			
		Maturity level Level name Level outline	0 Initial No, unspecific, or sporadic digital initiatives	1 Digitization Central IT led pilot projects	2 Digitalization Project/site responsible for digital initiatives	3 Digital transformation Long-term development in project portfolio
Assessment areas	Assessment criteria	Assessment questions				
1. Design management 2. Scheduling 3. Logistics 4. Production 5. Human resource management 6. Quality control 7. Contract management 8. Work safety 9. Security 10. Environmental impact 11. Information management	Individuals (I)	Within '*Assessment area*', which condition characterizes best how individuals on-site are involved in digital initiatives?	0) unspecific, no, or sporadic involvement	1) invited and/or led by central IT	2) defined roles and activities integrated in project/site	3) long-term project-independent development
	Technologies (T)	Within '*Assessment area*', which condition characterizes best how digital technologies for sites are selected?	0) unspecific, no, or sporadic selection	1) selection by central IT	2) selection based on project or site demands	3) selection based on long-term portfolio development
	Organizational structure (O)	Within '*Assessment area*', which condition characterizes best how digital initiatives are integrated with the organizational structure on-site?	0) unspecific, no, or sporadic integration	1) central IT responsible for integration	2) project or site organization responsible for integration	3) portfolio management responsible for integration
	Goals (G)	Within '*Assessment area*', which condition characterizes best how goals for digital initiatives are defined and evaluated?	0) unspecific, no, or sporadic definition and evaluation	1) central IT defines and evaluates goals	2) project or site organization defines and evaluates goals	3) long-term definition and evaluation on portfolio level
	Environment (E)	Within '*Assessment area*', which condition characterizes best how the site environment is involved in digital initiatives?	0) unspecific, no, or sporadic involvement	1) central IT responsible for involvement	2) project or site organization responsible for involvement	3) involvement based on long-term collaboration on portfolio level

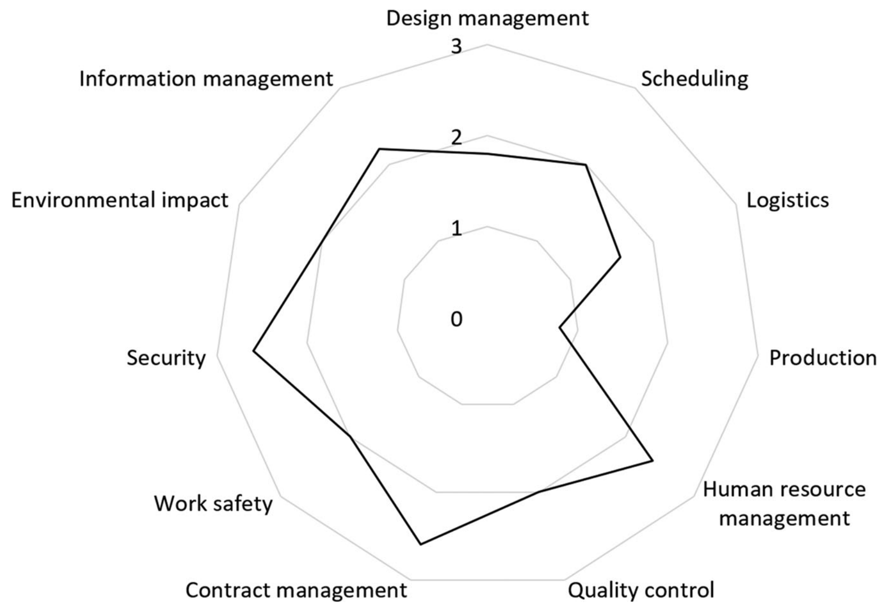

Figure 3. Quantitative case study results (line profile displays area average score; scale figures represent digital maturity levels: 0 = Initial, 1 = Digitization, 2 = Digitalization, 3 = Digital transformation).

neither large-scale nor quantitative. Finally, the framework was found to be a representation of the site and its relationship to central IT and the permanent firm. The assessor found the assessment '*eye-opening that we choose to do things in the project or at the firm level. When we have something that works well here, we should tell others to benefit from it without restarting from zero.*'

Implication and discussion

By visualizing framework results in a matrix or chart (e.g., Figure 3), decision makers can compare achieved maturity levels for different assessment areas or sites, follow-up, and set goals for future improvements. The framework is meant to be performed on site level with a clear link to a bottom-up perspective on digital development following that digital transformations take idiosyncratic paths (Remane et al. 2017) and that digital transformation seems to be intuitively managed in the start rather than strategically planned (Berghaus and Back 2016). The framework includes how the site organization integrates with its environment, e.g., permanent firm, project, and portfolio (Figure 2) in the context of digital initiatives extending the propositions by e.g., Rolstadås and Schiefloe (2017). Whether digital initiatives lead to improvements depends on the quality of the integration of digital technologies in relation to the organizational aspects (individuals, technologies, organizational structure, goals, and environment). Success of digital enabled improvements is therefore connected to maturing of the capabilities to utilize the implemented digital technologies for e.g., enhanced planning, data analysis, or decision-making. This research argues that higher quality of that integration could be expressed by higher digital maturity. The highest maturity level is characterized by long-term improvements with a clear link of single sites to long-term developments in the project portfolio (Wernicke et al. 2019). Potentially, this allows effective integration of partners and stakeholders and site specific digital strategies (Ustundag and Cevikcan 2018). Long-term improvement is usually not a responsibility of site management, but decisions taken on portfolio level (permanent firm) require consideration of site demands and prerequisites. Following Remane et al. (2017), that digital transformations take idiosyncratic paths, implies to select digital technologies with respect to specific site and project conditions, where in each situation decision makers should consider the different aspects of the assessment criteria in Table 2:

- Individuals, e.g. workforce skills, competences, and their development,
- Technologies, e.g. relations of exiting to new,
- Organizational structure, e.g. permanent firm, project, site, central IT,
- Goals, e.g. of permanent firm, project, site, central IT, and
- Environment, e.g. how to involve clients, suppliers, and subcontractors.

An assessment of how site operations' digital maturity develops implies repetition in certain time intervals. Connected to potential drawbacks of maturity assessments such as extensive bureaucracy (Mettler 2011) and maturity models' limitation just providing guidance and outlining typical paths (Berghaus and Back 2016), there is a concern when to perform assessments (Meng et al. 2011). It is suggested to perform the assessment depending on the number, speed and intensity of digital initiatives influencing the site and the possibilities of site and portfolio management to utilize assessment outcomes for further development.

Additionally, a strategy to support the progression of digital maturing for specific sites and the project portfolio should be developed. Two insights are considered: firstly, construction projects are repeated reconfigurations of project organizations where the site is established for single projects (Vrijhoef and Koskela 2000) including a corresponding organizational setup according to Figure 2. Secondly, the assumption that all projects within a specific organization should be managed in the same fashion, as criticized by Mullaly (2014). Therefore, this research argues that maturity levels are targets, contingently dependent on firm, site, and project. To target high maturity levels in all assessment areas might be irrational in a specific project e.g., leading to disproportionate high costs or delaying project schedules. A high maturity level is an indicator of possessed capabilities to evaluate and implement technologies for digital enhanced site improvement processes.

In reasonable scenarios, high maturity levels in specific projects are targeted based on potentials of digital initiatives in selected assessment areas (e.g., design management and scheduling) corresponding to site, project, permanent firm, and central IT. Consequently, a suitable firm strategy supports a stepwise, gradual maturing of capabilities applied on different projects, assessment areas, and activities. Reaching maturity level three (digital transformation) which indicates involvement of several projects of the project portfolio, requires experiences and a learning of how these experiences can be applied in a long-term to the project portfolio.

Moreover, overlapping of assessment areas and criteria exists. As stated by interviewee A, the assessment areas *'are interconnected, some things cannot be done unless you have a scheduled plan, because you lose the effect. They enable each other e.g., if you have a BIM-model in place and good planning, it is easy to hook in more things'*. This statement is certainly relevant from an Industry 4.0 perspective because automation and robotics requires high information flow quality and integration of involved processes (Oesterreich and Teuteberg 2016). Hypothetically, fully integrated and collaborative real-time project models (Hosseini et al. 2016) and advanced production technologies as additive manufacturing (Santos and Martinho 2019) on construction sites could melt together assessment areas. From an assessment model definition perspective, continuous maintenance and evolution (Mettler 2011) of the framework in its utilized context is essential for useful guidance of decision-making in organizations.

Conclusions

The purpose of this research is to develop a framework for assessing digital maturity of construction site operations. The suggested framework (Table 3) contains assessment areas, which describe the improvement range (Research question one, Table 1), maturity levels that indicate the progression towards increasing capabilities to evaluate and implement digital technologies supporting the improvement of site operations (Research question two), assessment criteria that define organizational aspects of the assessment (Research question three, Table 2, Figure 2), and an assessment procedure to guide assessors. The aim of the framework is to enable a systematic and continuous assessment to guide decision makers in digitally based improvements of site operations by considering organizational aspects (individuals, technologies, organizational structure, goals, and environment). The framework enables a definition of digital maturity for site operations. Digital maturity includes site organizations capabilities to evaluate and implement digital technologies, that the technology has an impact on construction site processes, and is managed in a systematic way within the permanent firm e.g., with a long-term perspective and that effects on capabilities and performance are measured. Digital maturity is therefore not only the actual implementation of digital technologies themselves, it is also about the capability to assess and integrate organizational effects within digital enhanced site improvement processes. On its highest maturity level, the framework assesses if a single site is integrated in long-term developments within the project portfolio on firm level which potentially enables digital transformation. Digital maturing is therefore seen as an organizations' increasing capability to, in a standardized and structured way, conduct active and goal-oriented digitally enabled short and long-term improvement processes under consideration of individuals, technology, organizational structure, and environment.

The empirical data within this study is extracted from a Swedish context. Albeit, the theoretical background forming the framework is based on international studies, an international generalization requires evaluation in specific contexts. Suggestions for further investigations also include how digital maturity of site operations effects (bottom–up) or are affected by (top-down) business model transformation on firm level.

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References

Ahmad SB, Mazhar MU, Bruland A, Andersen BS, Langlo JA, Torp O. 2020. Labour productivity statistics: a reality check for the Norwegian construction industry. Int J Constr Manage. 20(1):39–52.

Ballard G, Tommelein I. 2016. Current process benchmark for the last planner system. Lean Constr J. 2016:57–89.

Banawi A, Bilec MM. 2014. A framework to improve construction processes: Integrating Lean, Green and Six Sigma. Int J Constr Manage. 14(1):45–55.

Berghaus S, Back A. 2016. Stages in digital business transformation: results of an empirical maturity Study. In Mediterranean Conference on Information Systems, 22.

Berglund M, Karltun J. 2007. Human, technological and organizational aspects influencing the production scheduling process. Int J Prod Econ. 110(1–2):160–174.

Besson P, Rowe F. 2012. Strategizing information systems-enabled organizational transformation: A transdisciplinary review and new directions. J Strateg Inf Syst. 21(2):103–124.

Blanco JL, Mullin A, Pandya K, Sridhar M. 2017. The new age of engineering and construction technology. New York (NY): McKinsey & Company-Capital Projects & Infrastructure.

Bowden S, Dorr A, Thorpe A, Anumba CJ. 2004. Mapping site processes for the introduction of mobile IT. Proceedings of ECPPM eWork and eBusiness in Architecture, Engineering and Construction, 491–8.

Brahma SS. 2009. Assessment of construct validity in management research: A structured guideline. J Manage Res. 9(2):59–71.

Bryde D, Broquetas M, Volm JM. 2013. The project benefits of building information modelling (BIM). Int J Proj Manage. 31(7):971–980.

Carolis A, Macchi M, Negri E, Terzi S. 2017. A maturity model for assessing the digital readiness of manufacturing companies. In IFIP International Conference on Advances in Production Management Systems, 13–20.

Chanias S, Hess T. 2016. How digital are we? Maturity models for the assessment of a company's status in the digital transformation. Management Report, Munich School of Management, Institute for Information Systems and New Media 2016(2):1–4.

Eadie R, Perera S, Heaney G. 2012. Capturing maturity of ICT applications in construction processes. J Fin Manage Prop Constr. 17(2):176–194.

Fosse R, Ballard G, Fischer M. 2017. Virtual design and construction: Aligning BIM and lean in practice. Conference of the International Group for Lean Construction.

García de Soto B, Agustí-Juan I, Joss S, Hunhevicz J. 2019. Implications of Construction 4.0 to the workforce and organizational structures. Int J Constr Manage. 18:1–3.

Gobble MM. 2018. Digital strategy and digital transformation. Res-Technol Manage. 61(5):66–71.

Hall DM, Whyte JK, Lessing J. 2020. Mirror-breaking strategies to enable digital manufacturing in Silicon Valley construction firms: a comparative case study. Constr Manage Econ. 38(4):322–339.
Hatch MJ, Cunliffe AL. 2013. Organization theory: modern, symbolic, and postmodern perspectives. 3rd ed. Oxford University Press, New York.
Hosseini MR, Banihashemi S, Chileshe N, Namzadi MO, Udaeja C, Rameezdeen R, McCuen T. 2016. BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model. Constr Econ Build. 16(3):71–86.
Illingworth JR. 2000. Construction methods and planning. 2nd ed. London: E. & F.N. Spon.
Ivert LK, Jonsson P. 2014. When should advanced planning and scheduling systems be used in sales and operations planning? Int J Oper Prod Manage. 34(10):1338–1362.
Johnson RM, Babu RI. 2020. Time and cost overruns in the UAE construction industry: a critical analysis. Int J Constr Manage. 20(5):402–411.
Kassem M, Succar B, Dawood N. 2013. A proposed approach to comparing the BIM maturity of countries. In 30th Int Conference on Applications of IT in the AEC Industry.
Koskela L. 2020. Theory of lean construction. In: Koskela L, Kagioglou M, Tzortzopoulos P, editors. Lean construction: Core concepts and new frontiers. Boca Raton (FL): CRC Press; p. 2–13.
Lin CH, Hwang SL, Wang EM. 2007. A reappraisal on advanced planning and scheduling systems. Ind Manage Data Syst. 107(8):1212–1226.
Mäki T, Kerosuo H. 2015. Site managers' daily work and the uses of building information modelling in construction site management. Constr Manage Econ. 33(3):163–175.
Mayring P. 2014. Qualitative content analysis: theoretical foundation, basic procedures and software solution. Social Science Open Access Repository, Klagenfurt.
McAuley J, Duberley J, Johnson P. 2007. Organization theory: Challenges and perspectives. London: Pearson Education.
Meng X, Sun M, Jones M. 2011. Maturity model for supply chain relationships in construction. J Manage Eng. 27(2):97–105.
Meredith J. 1993. Theory building through conceptual methods. Int J Oper Prod Manag. 13(5):3–11.
Mettler T. 2011. Maturity assessment models: a design science research approach. Int. J. Soc. Syst. Sci. 3(1/2):81–98.
Mohamed SF. 2006. Improving construction site management practices through knowledge management [dissertation]. Loughborough: Loughborough University.
Mullaly M. 2014. If maturity is the answer, then exactly what was the question? Int J Manag Proj Bus. 7(2):169–185.
Oesterreich TD, Teuteberg F. 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. Comput Ind. 83:121–139.
Paulk MC, Curtis B, Chrissis MB, Weber CV. 1993. Capability maturity model, version 1.1. IEEE Softw. 10(4):18–27.
Rachinger M, Rauter R, Müller C, Vorraber W, Schirgi E. 2018. Digitalization and its influence on business model innovation. J Manuf Technol Manage. 30(8):1143–1160.
Remane G, Hanelt A, Wiesboeck F, Kolbe L. 2017. Digital maturity in traditional industries–an exploratory analysis. In Proceedings of the 25th European Conference on Information Systems (ECIS).
Rolstadås A, Schiefloe PM. 2017. Modelling project complexity. Int J Manag Proj Bus. 10(2):314–395.
Rolstadås A, Tommelein I, Schiefloe PM, Ballard G. 2014. Understanding project success through analysis of project management approach. Int J Manag Proj Bus. 7(4):638–660.
Sacks R, Koskela L, Dave BA, Owen R. 2010. Interaction of lean and building information modelling in construction. J Constr Eng Manage. 136(9): 968–980.
Saleh Y, Alshawi M. 2005. An alternative model for measuring the success of IS projects: the GPIS model. J Enterp Inf Manag. 18(1):47–63.
Santos RC, Martinho JL. 2019. An Industry 4.0 maturity model proposal. J Manuf Technol Manag. 31(5):1023–1043.
Scott WR. 2003. Organizations: rational, natural, and open systems. 5. ed. Upper Saddle River, N.J.: Prentice Hall.
Sezer AA, Bröchner J. 2019. Site managers' ICT tools for monitoring resources in refurbishment. Eng Constr Archit Manag. 27(1):109–127.
Succar B. 2010. The five components of BIM performance measurement. In CIB World Congress 2010.
Ustundag A, Cevikcan E. 2018. Industry 4.0: managing the digital transformation. Cham: Springer.
Valdez-de-Leon O. 2016. A digital maturity model for telecommunications service providers. Technol Innov Manag Rev. 6(8):19–32.
Vrijhoef R, Koskela L. 2000. The four roles of supply chain management in construction. Eur J Purch Supply Manag. 6(3–4):169–178.
Wernicke B, Lidelöw H, Simu K. 2019. Flow dimensions at Swedish Construction Contractors. Lean Constr J. 2019:24–46.
Whyte J. 2019. How digital information transforms project delivery models. Proj Manag J. 50(2):177–194.
Willis CJ, Rankin JH. 2012. The construction industry macro maturity model (CIM3): theoretical underpinnings. Int J Product Perform Manag. 61(4): 382–402.