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CONSTRUCTION 4.0 MATURITY TOOL WITH ONTOLOGY DEVELOPMENT METHODOLOGY FOR ORGANISATIONS

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Abstract

In recent years the construction industry innovations have become an attractive market for investors. Innovations bring significant efficiency to construction companies while impacting business processes. Digital transformation in the construction industry is evolving slowly, as several criteria must be met simultaneously in order to be able to embrace these technologies for construction companies. In our research, we investigated which are the main pillars of the Construction 4.0 maturity model for organisations. As a result of our research, we created a Construction 4.0 organisational maturity model and verified the model by ontology development methodology. This model can help construction firms accelerate their digital transformation journey.

Keywords: construction 4.0, digital transformation, maturity model, ontology, sustainability

1. Introduction

The value chain of the construction industry has undergone a digital transformation, resulting in the introduction of new technologies, methodologies, and concepts. This transformation has not only enhanced efficiency but also rendered the industry more sustainable, ultimately resulting in the creation of the Construction 4.0 ecosystem that refers to a cyber-physical ecosystem that incorporates various technologies, methodologies and processes aimed to create a human-centered sustainable construction industry.

The past two years have seen a growing number of construction companies taking substantial strides towards technological advancement as a result of the proliferation of digital technologies. Technological catch-up is further pushed by the recent availability of artificial intelligence to society. Yet the industry's adoption of technology-led business transformation has been comparatively sluggish due to management mindset [1], lack of IT knowledge, and limited process innovation that is necessary for the growing number of collaborating systems [2].

The slow pace of the Construction 4.0 transformation in the Construction Industry is attributed to insufficient education, unclear processes, and inadequately implemented technologies within the organisations. Providing strong external support can help companies navigate the digital transformation landscape and achieve optimal preparedness.

Based on the novelty of Construction 4.0 concept that has been emerged in the past three years no guiding framework has been introduced yet. Thus, the aim of this research is to improve a Construction 4.0 maturity model by building its ontology that guides construction industry organisations in order to assess and implement technologies.

2. Research methodology

Throughout this research, a combination of Design Science, Maturity model building and Ontology development were employed. The frame of the research was guided by Design Science Methodology which produces an artifact in the form of a model [3] that is widely used for maturity model building. Within the framework of maturity model building ontology development supports to logically clarify information's.

During the model building, we followed the six steps of the model building guideline proposed by de Bruin et al., 2005 as Figure 1 illustrates.

Figure 1 The Model Building Guideline

In the process of building the model, the initial step was to determine its scope. The primary objective of this model is to create an assessment tool for Construction 4.0 that enables construction companies to assess and enhance their business processes while supporting their digital transformation. The intended stakeholder for this model's development is academia.

The design phase was the second step in building the model. The main categories of the initial model and its subdomains were defined from literature review and the definition of Construction 4.0. The subdomains consist of industry-specific elements identified from our previous research. The primary driver for the application of the model will be internal requirements, and the respondents will be from the management level.

The populate phase is one of the most important parts of the model that defines what needs to be measured. It includes ontology building. Ontology is a "*formal and explicit specification of a shared (shared) conceptualization*" [5]. Ontology falls under the topic of knowledge representation within the field of artificial intelligence. It is one of the pillar of semantic technologies and knowledge-based decision support systems. The ontology development methodology provides a toolkit for mapping real-world objects, their characteristics and properties into a computer-interpretable form, thus enabling the development of artificial intelligence-based systems. However, ontologies not only encapsulate this conceptual model, but also describe more precisely the relationships between the elements of the model through axioms and rules, which by definition reflect the logic of the domain.

Figure 2 The Populate Phase - Ontology building steps

The populate phase was restructured with the ontology development approach (Figure 2). During our development process, prototypes and specific critical properties were formulated to determine the class membership. This was followed by a grammatically logical linking of the concepts, which was later combined into a complex set of ideas. The ontology thus constructed provides a description of the set of concepts of a domain. The ontology building includes seven steps: (1) defining scope and domain, (2) examining existing ontologies, (3) listing key terms, (4) defining classes and (5) class hierarchies, (6) defining properties of classes and (7) providing examples [6]. These steps can be done in a unified system using the Protégé software with the OWL2 Web Ontology Language, which has been developed by the University of Stanford for ontology machine processing. It includes the ontology built so far, which mainly helps to categorise the innovations.

3. The research – Building the formal model of the maturity tool

3.1. Scope

The impact of digitalisation in industrial manufacturing, Industry 4.0, has already led to the emergence of many of the technologies. Three years after the announcement of Industry 4.0, researchers found that organisations need strategic guidance and a holistic approach to integrate Industry 4.0 [7] to enable companies to effectively transform their business processes by considering risks and recognizing opportunities. A readiness assessment is “the systemic analysis of an organisation’s ability to cope with and undertake a transformational process or change is defined as measuring or assessing readiness” [8]. Our long-term purpose is to develop a software to support technology implementation with giving advice.

3.2. Design phase: The Maturity Model

In 2019 defined five main dimensions: Manufacturing and Organisation, People Capability, Technology Driven Process, Digital support and Business Organisation strategy to evaluate SME’s readiness for Industry 4.0 [9]. In a subsequent study, 18 maturity models were examined using nine criteria to enhance a comprehensive digital readiness model that can be applied to various contexts [10]. This research defined five main process dimensions: strategic governance, information and technology, digital process transformation and workforce management. At this stage of the research, we still accept that readiness and capability are equivalent and use them as synonyms, but later on we will emphasize the distinction between them.

The aim of this research was to create a tool for construction organisation to measure the organisational aspect of Construction 4.0. Thus, the first phase of this model building was to create the categories of Construction 4.0 within the organisation. Categories refer to the highest level of the model that defines the main Construction 4.0 aspects.

Six categories were identified as the initial point of the model from the literature review: Technology Management and Business Applications [9], Culture and People Management [9], [11]–[14], Collaboration and Communication [11], [14], Technology for Automation[9], [11], [14]–[16], Innovation [11], [14] and Change Management and Processes[9], [12], [14]–[16].

Technology Management and Business Applications refer to the process of planning, organizing, and controlling the use of technology within an organization to achieve its strategic goals and objectives. It involves the IT management of technology-related resources, including hardware, software, data, networks, and people and Cybersecurity.

Culture and People Management category pertain to overseeing the organizational framework, administering knowledge, and facilitating ongoing progress by means of digital leadership and persistent enhancement of skills among personnel within the organization.

Collaboration and Communication refer to the collaboration, communication and cooperation within the physical and digital environment of the organisation as well as throughout its supply chain.

The technology for Automation category includes the use of industry-specific automated devices, information modelling techniques, sensing systems and data infrastructure, AI and Machine learning and Human-machine interface to streamline and improve the efficiency of construction projects.

The **Innovation** category evaluates the corporate culture, leadership approach, and feasibility of innovation to foster the creation and implementation of novel concepts, products, services, technologies, or procedures that generate value, instigate beneficial transformations for the organization, and set it apart in the construction sector.

The **Change management and Process** category refers to the degree of alignment between organizational and digital processes that enable the company to promptly and efficiently address customer requirements, as well as to integrate or introduce new processes. This category also incorporates the organisational capability of change management.

These six lenses were selected to investigate the company maturity for technology adaptation. The literature review discovered that several common areas are in the maturity models meaning change management, people and culture, collaboration and so on [11]. Their main discrepancies are how these areas are emphasized, connected with each other and measured in these models. Our ultimate goal is to create a software that provides guidance for technology implementation, which necessitates the establishment of a rule-based system, hence we want to build an ontology-based system. The main advantage of the ontology development is to describe not just each category including its levels, but their relationships precisely for computer programs.

3.3. Populate phase: Ontology development

The Change Management and Process category was designated to illustrate how the ontology was built and serves what purposes. The ontology development put great emphasis on semantics of the concepts namely definitions, attributes, relations, axioms of classes [6]. The Change Management and Process category definition highlights

- specific processes such as organisational, digital processes, process integration and transformation. They share the common characteristics namely each process has set of tasks, use resources and are target oriented. In this sense, they are connected to the Process class as subclasses.
- the connection with change management whose importance was identified in many papers by [11]. The also stated that open and flexible organisational culture, leadership to conduct changes and shared learning among peers play pivotal role in enhancing change management. The characteristics of these concepts differ so they belong to other classes, but connected to the Change Management class through other relations (see Fig x). The light blue circles are related to the 'Change Management and Process category' view of the Maturity Model, the yellow ones are to the 'Information modelling techniques (BIM / Digital Twin)' below the 'Technology for automation'.

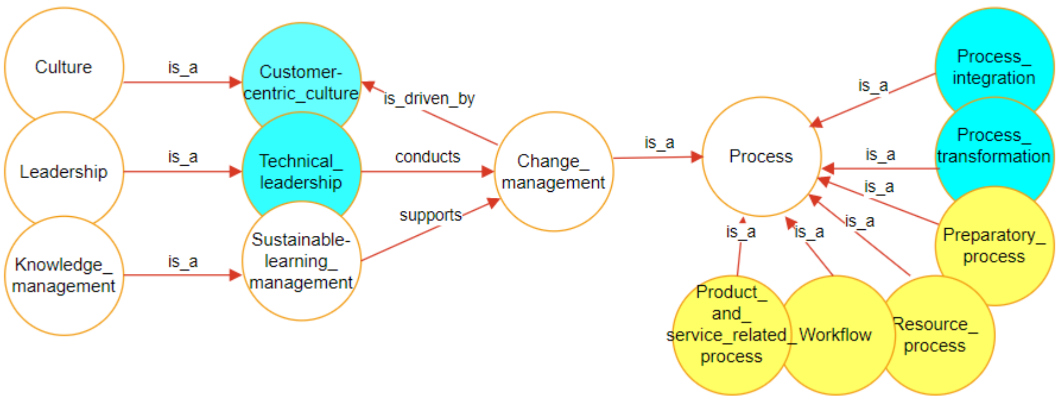

Figure 3 The Change Management and Process category

This model helps to design the questionnaire for detecting the company readiness for a given technology. It is worth noting that the measurement of customer-centric culture can differ in different countries due to the cultural aspects. Technical leadership is an ability so it can be measured by an ability test. Every process has input/output documents, so the existence of each process type can be detected by the specific documents. The model also presents that customer-centric culture is a driving factor of change management. The 'Culture and People Management' and the 'Process category' are connected via this link. If a change management is fully supported by a company with leadership and learning, but it is not customer-oriented, the technology implementation won't be complete. This is only an illustration how our rule-based computer program could give advice in a future in the respect of technology implementation. Once fully developed, the system can serve as a valuable tool not just for research and development, but also for industry to asses its Construction 4.0 capability and maturity.

3.3 Test phase: Case study of Kész Group

During the first test we verified the ontology thought a case study with KÉSZ Group from the construction of the Hungarian National Athletic Stadium where large volume metrology, BIM, DfMA, computer-controlled cable tension and parametric design was applied. During the test phase we explained each subcategory and its relation within the Change Management and Processes class.

Technical leadership was controlled by the company during the project and further consultancy company was involved. The combined use of these technologies required a **direct** guideline without which the company would not have been able to apply these technologies.

While assessing the **Process transformation**, it was determined that **proactive** change was required due to the implementation of a collaborative software system. The case study indicated that the processes and ecosystem used had already been implemented in a previous project, and thus, were deemed a proactive action.

The case study revealed that the innovations used to implement the complex project were generated by customer demand at the tender stage. The use of the innovations had to be defined by the company at the tender stage and was therefore assessed the **Customer-centric culture** as **proactive** behaviour.

Process integration has become an additional element of our model, as demonstrated in the case study. Some of the processes required by the technologies had to be **proactively** integrated or re-engineered into the company's existing processes.

4. Discussion and conclusion

The digital transformation of the Construction industry is a long journey in a complex environment, therefore, the key to achieving successful digitalization is to adopt a long-term strategy [17]. The purpose of research is to provide a guideline for creating this business strategy, and therefore contribute to the work of the research community.

The case study conducted during the model's testing phase revealed that the impact of technologies in each category manifests in construction companies through indirect, direct, or proactive activities. These findings will assist us in developing additional metrics for the maturity model.

We plan to continue our research by validating the entire model through qualitative and quantitative data. Additionally, we aim to establish measurable metrics, which can be used to develop a tool for market participants.

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