Technology-Oriented Innovation in Construction: A Conceptual Mapping Framework

A. Suliman, J. Rankin, and A. Caskey

1 Introduction

When compared to other industries, such as the automobile industry, the inefficiencies of the construction industry are apparent. Many of these inefficiencies can be attributed to the current onsite methods of construction [2]. Off-site Construction (OSC) is an innovative construction process where a significant portion of the construction work is completed at offsite fabrication shops before delivery for installation on site. Fabrication shops provide a properly-equipped, controlled work environment, with safe working conditions [1]. In Canada, off-site construction practices such as prefabrication and modular construction, are growing in acceptance, due to improved project quality, reduced material waste, reduced construction time and overall greater efficiency.

Despite the many potential benefits of OSC innovations, propagation and acceptance is still limited [7]. OSC represents only a small portion of the construction industry in Canada, as it does around the globe. Research has found that there is a need for the development of a strategic roadmap to direct efforts in OSC research, education, and innovation.

This research takes a crucial first step in developing a strategic OSC roadmap by developing a framework for mapping and benchmarking innovation in off-site construction. Benchmarking provides a necessary means for comparison and measuring progress in addition to supporting planning and implementation towards a future/desired state [3]. This research includes the development of a conceptual

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model necessary to represent, simplify and clarify complex real word conditions. The research project under consideration includes both technology-oriented and process-oriented innovation types. However, the research discussed in this paper will be limited to technology-oriented innovation.

1.1 Literature Review

A review of the existing literature included the review of many road mapping studies and planning initiatives specific to the construction industry. These included but were not limited to FIATECH [4], Seaden et al. [13], Rezgui and Zarli [11], and Kazi et al. [9]. The conducted review revealed the existence of good examples of roadmap models and frameworks. However, a model that is dedicated to or capable of accurately addressing and directing innovation in OSC was not found. In addition to that, the existing models tend to identify the future trends and desired state without assessing the current state or indicating the present level of construction innovation. A comprehensive review of the previous work is beyond the scope of this paper, but a brief review of the most relevant project is included below.

Froese [5] developed a strategic roadmap intended to direct efforts for research and development (R&D) in regards the construction innovation in the Canadian context. The roadmap presents three perspectives that convey three largely orthogonal issues associated with the R&D process: the application areas, the technology areas, and the innovation areas. These three perspectives have root in the conceptual framework introduced in Froese and Rankin [6]. It represents the most recent framework that developed and applied a roadmap to construction innovation within the Canadian context. In their paper, they introduced a multi-dimensional framework intended for modelling construction innovation and supporting a more comprehensive and richer understanding of the innovation process. Their framework outlines two sets of dimensions, the first set consists of three areas as follow:

1. **The Application Areas**. This dimension classifies the field of activity within the construction industry to which the innovation is targeted. The application areas are categorized into three classes: (1) *Management processes* (e.g., construction and project management), (2) *Project lifecycle processes* (e.g., design, procurement, production, maintenance, etc.), and (3) *Supporting processes* are considered to provide underlying foundation for all activities (e.g., collaboration, sustainability, and workforce, etc.).
2. **The Technology Areas**. This dimension categorizes technologies straightforwardly as being either *computational* or *non-computational.*
3. **The Innovation Areas**. This dimension explicitly models the various lifecycle stages that move innovations from a new idea to a new standard practice in five phases. These phases are data collection, technology development, conceptual development, production development, and application.

The first set represents the primary dimensions that are clearly defined, hence; they were used to develop roadmaps of construction innovation. The second set consisted of (1) *Organization*, (2) *Innovation objectives/drivers*, and (3) *Time*. This set of dimensions was not as well defined and thus was omitted from their framework.

This framework proposes a sound conceptualization of the current state of innovation but at a more conceptual level of detail and does not include elements of a specific benchmarking tool. For example, the subcategories of the application areas are only vaguely defined, relatively ambiguous, and incompatible classifications for some recent technology (e.g., Cyber Physical Systems do not fit this taxonomy as these systems relate to non-computational mechanisms that are controlled or monitored by digital computational technology). Furthermore, the framework does not provide subclass processes and/or granularity levels. Additionally, these subclass processes and levels are expected to vary between academic research, across different construction domains, and change along technology evolutions without defined boundaries. Thus, the research described in this paper attempts to build on their work to mitigate its limitations and accommodate the measuring complexity of innovation and potential technology and application advancements.

1.2 Research Mission

The mission of this research was to develop a conceptual framework based on a maturity model for the analysis of technological innovation in OSC. OSC innovation is defined, in this research, as “new applications of new or existing technologies to achieve improvements in activities related to OSC including time, cost, quality, safety, certainty, and automation.” This work was conducted alongside the development of a similar maturity model for process/method innovation in OSC. The process/method model was beyond the scope of this paper and was therefore omitted.

This maturity model framework was intended to contribute to a larger road mapping study to support innovation in OSC within the Canadian context. Roadmapping as implied by the analogy to literal roadmaps, is a strategic visioning exercise intended to identify the current location/state, future location/state, and the path to get there. However, the most important part of roadmaps is the map itself which is the contribution of this study. The roadmap designed in this research is illustrated in Fig. 1. The figure outlines the roadmap in four components:

A. **Map (Framework)**: the framework that maps the applicable technologies.
B. **Current State (Benchmark)**: the reference that represents the maturity status at a specific time (i.e., the current time) with respect to a specific context (e.g., Canadian context).
C. **Future State (Matured State)**: the identified targets based on the measured maturity levels.
D. **The Road (Maturity Gaps)**: the maturity gaps identified based on levels of maturity models.

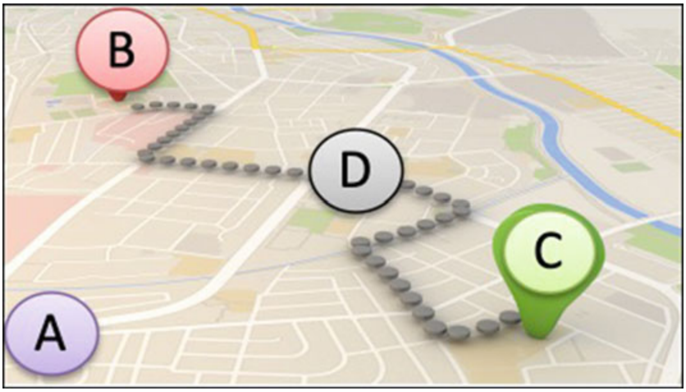

Fig. 1 The designed roadmap and its major components (Adopted from payment.com)

The maturity model framework developed in this research was modeled through technology-oriented conceptual frameworks as recommended by Deros [3]. This framework is intended to facilitate capturing the current state (benchmarking) and help in designing the roadmap for a desired future state. Where the scope of this research diverges from most other roadmapping initiatives, is that by itself, it is not intended to address future priorities or planning, but rather to provide a tool that can be useful for informed prioritization and planning. The development of the conceptual framework is described in the following section.

2 Developing the Technology Mapping Framework

To map the technology-oriented innovation in construction domain, the conceptual mapping model is divided into two facets, (1) Technology framework and (2) Maturity scales, as follows.

2.1 Technology Framework

From a geometrical conceptualization perspective, technology-oriented innovation is presented in a three-dimensional (3-D) space. The space includes technology, application, and innovation dimensions. As a 3-D space, the first two dimensions defined a kind of planimetric location, while the third defines the innovation level. This conceptual model is powerful in understanding and modelling the innovation process in construction. Similarly, a multi-dimensional framework can be modeled to map various aspects of technology-oriented innovation in OSC. In contrast to other multi dimensional frameworks, our model provides a distinction between

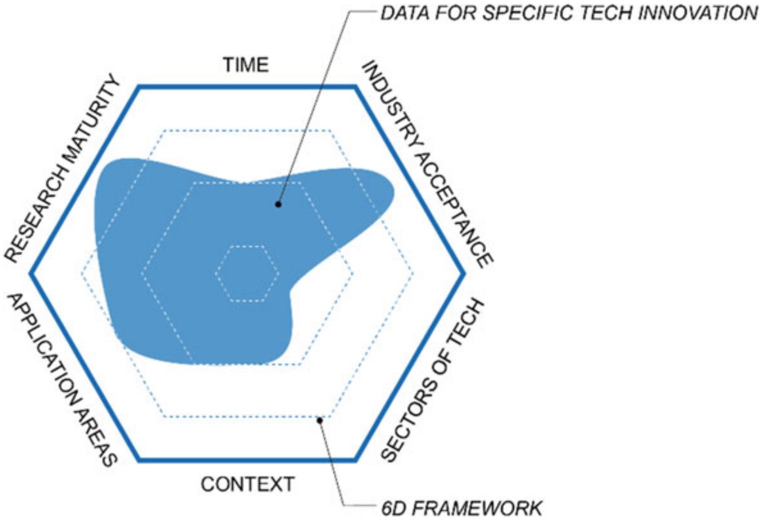

Fig. 2 The six-facets/dimensions of the technology mapping model

research maturity and industry acceptance to add additional accuracy and clarity in modelling and understanding the maturity of innovation at a given time. This resulting four-dimensional mapping model represents a snapshot in time within a certain scope/context. By adding two additional dimensions, time, and context, it becomes a six-dimensional model capable of capturing a more complete realization of the state of innovation. The time dimension allows for the identification of trends over time while, the context dimension defines specific boundaries to the captured trends. For example, the context dimension could account for the scope of the framework application or scalability based on the location and management/government levels (e.g., maturity may vary in Canada vs. Europe vs. Asia at the organization, municipality, or provincial levels). The proposed model is illustrated in Fig. 2.

The dimensions of the model in Fig. 2 are (1) technology areas, (2) application areas, (3) time, and (4) context. These four dimensions define the technology framework. In contrast, the innovation dimension is modeled in terms of maturity scales. This maturity is considered in two dimensions: (5) research maturity (academia) and (6) industry acceptance (practice). The acceptance level is selected to represent a scale of which the innovation can become a common practice. Although there is a similarity in the dimension names and purposes of the model of Froese and Rankin [6], the applied classification and aggregation approaches are different. It should also be noted that within the dimensions of Technology and Application Areas, the proposed model features are further sub-categorized. The first four dimensions are described in the following paragraphs:

Technology Area Dimension—this dimension has been sub categorized into five technological areas. This classification was inspired by the three-theme classification of technology proposed under the umbrella of the Fourth Industrial Revolution or

Industry 4.0 (4IR) which includes Industrial Production, Cyber-Physical Systems, and Digital and Computing Technologies [12]. Building on the 4IR technology themes this model categorizes OSC innovation into five areas:

(1) Digital computational technologies,
(2) Smart technologies,
(3) Cyber-physical technologies,
(4) Industry production technologies, and
(5) Supporting technologies.

The 4IR classification system describes digital technologies as those that live in the cyber environment, while industry production technologies are those that operate in the physical environment. Cyber physical technologies are viewed as those technologies that operate across both realms. In the proposed modified classification, a smart technologies classification is used to categorize the digital technologies that can develop self-decisions and/or take actions. Similarly, the supporting technologies classification is included to accommodate any existing or future technologies that do not neatly fit within any other category. Table 1 demonstrates how established and emerging OSC technologies fit within the described categories.

Application Area Dimension—this dimension has also been subcategorized into five levels that are within three project phases. This classification was inspired by the 4-P's management concept in software engineering [8]. The "**5-P's model**" identifies technological innovation implemented in OSC at five levels: *Project, Process, People, Physical resources,* and *Product*. Furthermore, the expected benefits from applying the different technologies are as follows, (i) increased certainty in planning processes; (ii) increased efficiency in the execution processes; and (iii) increased effectiveness (ease and accuracy of the monitoring processes). Therefore, as inspired by Newtown Square [10], the application areas of the technology groups are identified as the three management process groups (planning, execution, and monitoring) of construction across the different levels of the 5-P's model.

Table 1 The five technology areas of the technology dimension

Computational technologies	Smart technologies	Cyber physical technologies	Industry production technologies	Supporting technologies
• Building information modeling (BIM) • Simulation • 4D simulation • Integrated geospatial BIM (GEOBIM)	• Artificial intelligence • Internet of things • Big data • Block chain/smart contracts • Cloud/fog computing	• Mixed, immersive, augmented or virtual reality (MR/AR/VR) • Identification/localization (RFID/GPS) • Sensors • Computer vision • Laser scanning • Ground penetrating radar (GPR)	• 3D printing/additive manufacturing (AM) • Robotics	• Information and communication technologies (ICT) • Symantec wed • UAVs/GAVs • Mobile devices

2.2 Maturity-Based Scales

The maturity dimensions of the model include both **Research Maturity**, and **Industry Acceptance** dimensions which could be viewed as factors that push and pull innovation towards overall maturity. In terms of innovation within OSC, academic research could be seen to represents the innovation push, while industry adoption could be viewed as the pull. To measure the maturity of these two dimensions it is necessary to quantify innovation based on a scale. Froese and Rankin [6] proposed a five-level scale of innovation as data collection, technology development, conceptual development, production development, and application. For the purpose of this framework, Froese and Rankin's innovation scale is limited in application as it is not precise in its delineation of the phases of innovation nor dose it differentiate between research and practice maturity. These shortfalls are addressed in the alternative framework presented in Table 2 which is intended to provide a more accurate representation of innovation maturity.

Using this model, a measure of research maturity could be measured by sampling a representative set of on-going construction research in technologies (i.e., research projects at Canadian universities or as a common proxy, journal or conference papers published in relevant Canadian research fora).

Table 2 Maturity models for the academic research and industry acceptance

Maturity level	Research maturity (a representative sample of relevant papers/R&D projects)	Industry acceptance (level of use in the last "xx" projects)
1	**Basic research** (exploring/understanding): research intended to understand novel technologies and explore their application opportunities in construction domains	**Limited** ($X \leq 20\%$)
2	**Applied research** (innovative applications): research considered when the new technologies are being innovatively applied in construction applications	**Promising** (21–40%)
3	**Evaluation research** (performance assessment): research intended to review and assess previous studies in terms of the success, failure, costs, and benefits of the technologies applied in novel construction applications	**Adapted** (41–60%)
4	**Prototype development** (commercialization/transferability): research that includes a development of a prototype of modified or new technology that demonstrate transferability and commercialization possibility	**Implemented** (61–80%)
5	**Adoption research** (study of industry acceptance): the research intended identify the barriers and restrictions of a technology from being transferred/adopted in the industrial practices	**Accepted** ($X > 80\%$)

The industry acceptance levels proposed in our study was made adopted to simplify implementation and quantification. It is essentially a five-level scale based on the percentages of implementing a specific technology in a certain number of past projects within a specific context. The industry acceptance of a specific technology in construction can be measured by surveying a representative sample of OSC organizations. For example, in the last 100 OSC construction projects, 30 projects were implemented using Building Information Modeling (BIM technology) within the Canadian context. This measure would indicate that the level of BIM-adoption within OSC projects in Canada is 30%.

Appendix is a graphical representation of the technology mapping framework developed. As indicated earlier, the technology-oriented innovation includes two aspects (research maturity and industry acceptance). Each cell in the framework has upper and lower rows where the upper row is for the measured research maturity and the lower row is to document the measured industry acceptance. Each row has five space where each one is dedicated for a maturity level in a sequence from left to right. Hence, the value in each space indicates the number of collected responses (either from industry projects or academic papers) that satisfy the specific maturity level indicated by its location. For example, we may have 20 research papers about an "X" technology applied to project cost estimation. Six papers are of research maturity 1, four papers are of research maturity 2, eight papers are of research maturity 4, and two paper of the last maturity level. Based on this example, the upper row of the cell would be filled out as follows [**6|4|0|8|2**]. If the industry acceptance of the same technology was found to be of different levels, the same principles are applied. The received responses are documented in the lower row of the same cell; as an example of 20 responses, [**5|7|3|2|3**] where five responses were considered level 1 maturity, and so on.

3 Framework Use Demonstration

As explained above, the mapping framework for technological innovation in OSC was developed to measure two simultaneous states of innovation maturity: the research maturity, and industry acceptance of specific technologies.

In the typical case, the necessary information required to measure the **research maturity** could be collected by various means including a literature review and/or survey. A review of literature that highlight publications of completed and on-going research projects related to OSC technologies could serve as an appropriate indicator of the maturity. The relevant literature and/or research projects would need to be selected to define a specific time and context. For example, the current status (time dimension) of the Canadian context (context dimension). Since these types of publications are typically assigned to university-based researchers, with specific publication times and geographic context they provide a reliable accessible database to draw information from. Similarly, a survey circulated to academics, and research professionals within a certain time and context could serve to provide sufficient indication of research maturity regarding technological innovation.

The necessary information required to measure the **industry acceptance** could also be collected by various means, but research suggests an industry survey is most appropriate. In an ideal scenario, the information could be captured from a centralized database of recently completed projects within a certain context or region. However, such databases tend to be incomplete and rarely include specifics of the technologies implemented during the project. In lieu of a centralized database, a survey administered to a sample of construction companies would serve as a reasonable indication of industry acceptance of certain technological innovation in OSC. The survey should collect responses indicating the frequency of using/applying those technologies in the last "X" number of OSC projects.

Table 3 demonstrates, with an example, how the framework described in the previous section could be used to interpret the maturity based on the collection of the

Table 3 Technology-oriented innovation assessment in both academia and industry

Aspect	Example description	Assessment outcome	
		Framework	Maturity scale
Academia R&D project	This research explored the application of virtual reality headsets for on site BIM model verification by developing a VR headset prototype capable of showing workers the exact intended location and features of building elements	This research applies immersive visualization technology (that is part of cyber-physical technologies) to help improve the process and accuracy of construction. Therefore, this project is mapped under the process planning and virtual reality technology	**Level 4—applied** This project attempts to apply the virtual reality in prototype development. Hence, it is an applied research. The maturity is of level 4
Industry construction project	A construction organization was contacted for a survey participation. The question was as follows: *In the last 10 OSC projects, how many times the visualization (virtual reality) technology has been used to enhance product design process?* The response was 2 OSC project	The question measures the frequency of using the virtual reality technology to enhance the product design. Therefore, the response should be mapped under product planning and virtual reality technology	**Acceptance level is limited (level 1 ≤ 20%)** The survey responder indicated that the virtual reality technology was used for less than or equal to 20% in the last 10 OSC projects. Hence, the industry acceptance on that technology is limited and it was applied in one project

types of data described above. The example is intended to facilitate the understanding of the implementation of the developed map. It is designed to cover the technology frameworks and maturity models. The hypothetical assessment outcome presented in Table 3 is documented in the relevant framework cell provided in Appendix. The white cell in the framework is the one that has entries based on the hypothetical assessment result. While the values inside the cell correspond to the number of the surveyed projects, and the location of these numbers indicates the maturity level out of the five levels of the developed maturity scales.

4 Conclusions

This research was initiated to pave the road towards building a strategic roadmap of innovation in OSC. This paper presented the conceptual framework for measuring maturity within OSC technological innovation. It introduced a conceptual design for a maturity-based innovation road mapping. This roadmap consists of four components: map (framework), maturity models (scales), benchmark (current state), and maturity gaps (road to future state). The first two components were the focus of the study to date.

This model drew from previous works including Froese and Rankin [6] and the classification of the fourth industrial revolution (4IR) among other works. The presented framework model is intended to serve as a tool for benchmarking and recording advancements in various forms of technological innovation in OSC. The model allows for maturity to be recorded over time and between various contexts.

The applicability of this model was described through a proposed implementation approach with an explanatory example. Based on that, the developed framework has high potential to create a solid foundation towards developing a strategic technology-oriented innovation roadmap to inform efforts in OSC research and adoption in the construction industry.

Next steps in this research are exploring data collection through more extensive surveying of industry professionals and researchers. It will also explore more extensive means of data collection such as the development of an online building database specific to OSC.

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Appendix

The context		Planning processes				
Technology-oriented innovation framework		P1	P2	P3	P4	P5
Technology areas (construction industry)	Available technologies	Project level time/cost estimation	Process virtual construction/site planning	People safety planning and training	Physical resources and logistics planning	Product or facility virtual design (eng.)
1. Computational technologies	BIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Simulat	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	4D Vis	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	GBIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
2. Smart technologies	BChain	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	AI	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	IoT	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	BigData	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	CComp	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
3. Cyber-physical technologies	AR/VR	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	**0|0|0|1|0** **1|0|0|0|0**

(continued)

(continued)

The context		Planning processes				
Technology-oriented innovation framework		P1	P2	P3	P4	P5
Technology areas (construction industry)	Available technologies	Project level time/cost estimation	Process virtual construction/site planning	People safety planning and training	Physical resources and logistics planning	Product or facility virtual design (eng.)
	Sensors	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	IDloc	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	CVison	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Laser	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	GPR	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
4. Industry production	AM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Robotics	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
5 Supporting technology	CT/IT	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Sweb	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	UAVs	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0

(continued)

(continued)

The context		Planning processes				
Technology-oriented innovation framework		P1	P2	P3	P4	P5
Technology areas (construction industry)	Available technologies	Project level time/cost estimation	Process virtual construction/site planning	People safety planning and training	Physical resources and logistics planning	Product or facility virtual design (eng.)
	Mobile	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
Total numbers (summation)						

The context		Execution/control processes				
Technology-oriented innovation framework		P1	P2	P3	P4	P5
Technology areas (construction industry)	Available technologies	Project level procurement/contractual relations/ripple effects predictions	Process/production automation	People collaboration, info. sharing, communication	Physical resources: enhancing material and automating equipment operation	Product or facility operation and maintenance
1. Computational technologies	BIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Simulat	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	4D Vis	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	GBIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
2. Smart technologies	BChain	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	AI	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	IoT	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	BigData	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	CComp	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
3. Cyber-physical technologies	AR/VR	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0
	Sensors	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0

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The context		Monitoring processes/future planning					Research on technology (evaluation/adaption)	Total numbers (summation)
Technology-oriented innovation framework		P1	P2	P3	P4	P5		
Technology areas (construction industry)	Available technologies	Project level work progress	Process monitoring: productivity measure	People safety monitoring	Physical resources tracking	Product quality assessment		
1. Computational technologies	BIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	Simulat	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	4D Vis	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	GBIM	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
2. smart technologies	BChain	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	AI	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	IoT	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	BigData	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
	CComp	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		
3. Cyber-physical technologies	AR/VR	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0	0|0|0|0|0 0|0|0|0|0		

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References

1. Alvanchi A, Azimi R, Lee S, AbouRizk SM, Zubick P (2012) Off-site construction planning using discrete event simulation. J Architectural Eng 18(2):114–122 (American Society of Civil Engineers). https://doi.org/10.1061/(ASCE)AE.1943-5568.0000055
2. Barbosa F, Woetzel J, Mischke J, Ribeirinho MJ, Sridhar M, Parsons M, Bertram N, Brown S (2017) Reinventing construction: a route to higher productivity. McKinsey Global Institute
3. Deros BM, Yusof SM, Salleh AM (2006) A benchmarking implementation framework for automotive manufacturing SMEs. Benchmarking Int J 13(4):396–430. Emerald Group Publishing Limited
4. FIATECH (2004) Capital projects technology roadmapping initiative [online]. Austin, Texas
5. Froese T (2009) Construction process technologies: a metaanalysis of Canadian research. Can J Civ Eng 36(3):480–491. https://doi.org/10.1139/L08-127
6. Froese T, Rankin JH (2009) Strategic roadmaps for construction innovation: assessing the state of research. Electron J Inf Technol Constr 14(August):400–411. https://doi.org/10.14288/1.0048556
7. Goulding JS, Pour Rahimian F, Arif M, Sharp MD (2015) New offsite production and business models in construction: priorities for the future research agenda. Architectural Eng Des Manag 11(3):163–184 (Taylor & Francis)
8. Jacobson I, Booch G, Rumbaugh J (1999) The Unified Software Development Process. Addison-Wesley Longman Publishing Co., Inc, USA
9. Kazi A, Hannus M, Zarli A (2007) Strategic roadmaps and implementation actions for ICT in construction. Availavble from http://cicvtt.fi/projects (September)
10. Newtown Square P (2017) A guide to the project management body of knowledge (PMBOK guide). Project Management Institute, Newtown Square, PA
11. Rezgui Y, Zarli A (2002) Roadcon—a European strategic roadmap towards knowledge-driven sustainable construction. In: Proceedings of the institution of civil engineers—civil engineering, vol 150, no 6, pp 24–26. https://doi.org/10.1680/cien.2002.150.6.24
12. Sawhney A (2018) Construction 4.0—innovation framework for the built environment. Available from https://www.linkedin.com/pulse/construction-40innovation-framework-built-environment-anil/.
13. Seaden G, Goulla M, Doutriaux J, Nash J (2001) Analysis of the survey on innovation, advanced technologies and practices in the construction and related industries, 1999