

1 Implications of Construction 4.0 to the Workforce and Organizational Structures

2 Abstract

3 The counterpart of Industry 4.0 in the AEC/FM industry is known as Construction 4.0. Its essence is
4 the digitalization and automation of the AEC/FM industry. As robots and other technologies make
5 their way into the different phases of the lifecycle of construction projects, the concern about the
6 future of jobs and wages will increase. While the use of robotics has the potential to improve
7 productivity and safety, it should not necessarily reduce total employment in the construction sector
8 in the long run. It is expected that existing roles will evolve, and new roles will be created (e.g., in
9 addition to designers there would be a need for employees with digital skills). Focusing on the
10 construction phase of a robotically built concrete wall, the different roles were evaluated. From this
11 study, it was found that there will be a time in which conventional construction and robotic
12 technologies will coexist, leading to a higher job variability and new roles, both at the managerial and
13 operations/execution levels. Although this study is not meant to be an exact representation of how
14 the AEC/FM roles will change as a consequence of Construction 4.0, it opens the debate and research
15 in this area.

16 *Keywords: Construction 4.0; construction automation; digital fabrication (dfab); human-robot*
17 *interaction; industrialized construction; organizational structure; platform-based integration; project-*
18 *based integration; project delivery and contract strategies; robotic construction*

19 1. Introduction

20 The AEC/FM industry is known for being conservative and with an adversarial culture and inertia to
21 change, particularly with the adoption of new technologies (Anumba and Evbuomwan, 1997).
22 Moreover, other factors such as extreme fragmentation and lack of collaboration limit the
23 implementation of innovative construction processes and technologies. The fragmented structure of
24 the construction industry leads to the organization of large construction projects as decentralized,
25 modular clusters (Sheffer, 2011). Conventional construction organizations are highly based on the
26 interaction of the owner (or client) and the system integrators, which depending on the delivery
27 system used, are usually the leading designer and general contractor. This high involvement of the
28 owner in project decisions is translated into a Design-Bid-Build (DBB) project delivery system,
29 characterized by contractual relationships of the owner to all planners and contractors separately
30 (Ling et al., 2004). With the push from Construction 4.0 (i.e., the counterpart of Industry 4.0 in the
31 AEC/FM industry which promotes digitalization and automation), current construction organization
32 and roles need to be transformed in many aspects. A reduction of lead times and the improvement of
33 the quality and cost by integrating design and construction activities and by maximizing parallelism in
34 working practices are important aspects to take into consideration (Anumba and Evbuomwan, 1997).

35 To ensure competitiveness, it is vital that the construction industry adopts a new organization
36 involving collaboration and interaction between the different construction professionals.

37 The automation and digitalization of the AEC/FM industry, and in particular the construction sector,
38 through the adoption of digital fabrication (dfab) processes and new technologies, provides a potential
39 means to overcome these problems. It also helps the construction industry to realize the opportunities
40 that technology and automation bring to reduce wastage and duplication as well as to improve quality,
41 reduce time, and complete projects within budget. Related parties in the construction sector are
42 seeing how the potential benefits impact the bottom line as well as the company's reputation. Many
43 of the factors for Construction 4.0, typically attributed to the manufacturing sector, are critical for
44 success in such a competitive market with such narrow margins, and efforts are being made to align
45 the research efforts with the industry needs (Chen et al., 2018). Construction is distinguished from
46 manufacturing in that the bulk of the production tasks typically occurs in a field setting and is
47 undertaken in an uncontrolled environment (Saidi et al., 2008).

48 Moreover, buildings are complex systems that cannot be conceived as serial products, such as an
49 automobile for example (Gramazio et al., 2014). Each building is designed and constructed according
50 to specific conditions and stakeholder decisions, making automation harder to implement when
51 compared to other industries (e.g., manufacturing). Automation involves machines, tools, devices,
52 installations, and systems that are all platforms developed by humans to perform a given set of
53 activities without human involvement. Although there are many definitions for automation, mostly
54 depending on the sector in which it is used, there is no doubt that it is powerful. As Nof (2009) said,
55 automation "has a tremendous impact on civilization, on humanity, and it may carry risks." For this
56 study, the concept of automation is directly related to the use of robotic systems or robots to assist
57 construction workers or to perform construction tasks during onsite operations. Within that context,
58 the definition of a robot proposed by Matarić (2007) is used in this study, therefore, "*a robot is an*
59 *autonomous system which exists in the physical world, can sense its environment, and can act on it to*
60 *achieve some goals.*"

61 Even though the construction industry is one of the oldest and it represents a significant part of a
62 country's GDP, it is also one of the most unfamiliar regarding the R&D fields for the automation
63 community (Balaguer and Abderrahim, 2008). However, the research of robotic systems applied to
64 the AEC/FM industry is not new and has been around since the 80s. In 1984, Warszawski presented
65 one of the first critiques about the use of robots in the building sector at the first International
66 Symposium on Automation and Robotics in Construction (ISARC) held in Pittsburgh, trying to examine
67 robot requirements, implementation and economic feasibility of their application (Warszawski, 1984a,
68 Warszawski, 1984b, Warszawski, 1990). Paulson (1985) also provided one of the first reviews of
69 robotics and automation in construction. Exploratory studies were conducted in the fields of civil
70 engineering (Skibniewski, 1988; Haas et al., 1995), infrastructure (Herbsman and Ellis, 1998; Kobayashi
71 et al., 1988; Skibniewski and Hendrickson, 1990), digital design and production (Bock, 2008), surveying
72 (Vähä et al., 2013), prefabrication (Benjaoran and Dawood, 2006; Hu, 2005) and assembly (Chu et al.,
73 2013). In addition, researchers started investigating the feasibility of robotic applications in various
74 architecture and construction activities (Boles et al., 1995; Everett and Slocum, 1994; Warszawski and
75 Rosenfeld, 1994) and also for freeform construction (Lim et al., 2012; Buswell et al., 2007).
76 Combination of construction automation with robotics has also been investigated (Morales et al.,
77 1999; Balaguer and Abderrahim, 2008). However, early attempts in robotic construction did not
78 succeed mostly because of the lack of computation power, and partly because of the highly specialized
79 character of the robots developed and used (Balaguer et al., 1999).

80 Fast forward over 30 years since robots were investigated for automation of construction,
81 maintenance, and inspections, the use of robotic systems, mainly those used onsite, is very limited
82 and for the most part, used as a prototype or for research purposes. Examples include the Semi-
83 Automated Mason (SAM100, n.d.), the Tybot rebar-tying robot (Sweet, 2018), the In situ Fabricator
84 (Gifftthaler et al., 2017), or the HRP-5P humanoid bot (Cowin, 2018; Cisneros et al., 2018). They are
85 becoming technically and economically possible, and it is expected that they will gradually be used in
86 the industry as cost-effective solutions are found. Another driving force pushing contractors to give a
87 more serious look at robotics and automation is the shortage of skilled construction workers. The

88 aging working population coupled with the lack of new generation joining the construction workforce
89 are giving construction companies a hard time finding qualified labor (Harris, 2018). According to a
90 survey by Autodesk and the Associated General Contractors of America (AGC), 70% percent of
91 construction firms are having difficulties finding qualified craft workers to hire during growing
92 construction demand (AGC, 2017). This lack of interest is not new. Something similar happened in the
93 1980s in Japan, where construction demand was booming. However, construction jobs were not
94 attractive to young Japanese generations which triggered a substantial investment and research into
95 construction robotics. After a significant amount of resources invested in the development of highly
96 customized automation systems and robots, the technical excellence was never matched by economic
97 success, causing the abandonment of the robotic pursuit in construction (Bechthold, 2010).

98 The aim of this study is to present an overview of the different roles that were identified during the
99 evaluation of an ongoing project in Switzerland in which robots are used for digital fabrication on-site
100 (case study presented in Section 3). Particular attention was given to the changing roles during the
101 construction execution phase. Given the research and prototype nature of the case study, the
102 observations from this study should only be considered as exploratory and not as a generalization for
103 the construction industry. Although the findings and opinions are objective for the case study
104 investigated, extrapolation or generalization to other cases should be done with caution. However,
105 this type of studies can be useful to evaluate trends and changes in the roles of other projects and
106 eventually forge new directions in the construction sector. The rest of this paper is organized as
107 follows. Section 2 presents an overview of the current situation highlighting impacts of automation
108 (specially as it relates to the use of robots) to the existing roles. Section 3 introduces the case study
109 and presents objective information related to the existing roles in particular as it relates to their
110 evolution and the identification of new ones, in relation to the observations from the case study.
111 During that section particular attention is given to the planning and execution phases of the project
112 investigated. In addition, Section 3 provided an outlook of the evolution of the organizational
113 structures to accommodate both digital fabrication, and the evolution or existing roles and creation
114 of new ones. Section 4 provides a conclusion and suggest future research directions.

115 **2. Current situation**

116 *2.1 Uncertain impacts on labor and workforce*

117 As robots and other technologies take over tasks previously performed by construction workers, there
118 will be a change in the current roles, from laborers to designers. This transformation in the
119 construction sector will be accompanied by the concern about the future of jobs and an increase in
120 wages. Recent debates about the future of jobs have mainly focused on whether or not they are at
121 risk of automation (Berriman, 2017; Frey and Osborne, 2017; Arntz et al., 2016; Acemoglu and
122 Restrepo, 2017). According to Berriman (2017), 41% of construction jobs in Germany are at high risk
123 of automation by 2030, 35% in the US, 26% in Japan and 24% in the UK. Studies for other industries
124 have also investigated the effect of robots and automation to the social dimension. Frey and Osborne
125 (2017) estimated that around 47% of total US employment has a high risk of computerization by the
126 2030s, while the estimations by Arntz et al. (2016) were quite a bit lower, only 10%. The findings in
127 Berriman (2017) are somewhere in between, estimating that 35% of US jobs are in danger of being
128 lost to the robots. Most studies have minimized the potential effects of automation on job creation,
129 and have tended to ignore other relevant trends, including globalization, population aging,
130 urbanization, and the rise of the green economy (Bakhshi et al., 2017).

131 Although some studies and projections are pessimistic about the impacts to labor (Frey and Osborne,
132 2017), others give a more optimistic view (Arntz et al., 2016; OECD, 2016), which is also shared by the
133 authors. The creation of new and specialized roles always happens when new technologies are
134 introduced, and it is expected that the same will occur in the construction sector. While Construction
135 4.0 will increase productivity (Castro-Lacouture, 2009; García de Soto et al., 2018a), it should not
136 necessarily reduce total employment in the long run. On the contrary, robots and automation will
137 create new jobs and provide new opportunities. According to the report by ManpowerGroup (2016),
138 about 65% of the jobs that people born from the mid-1990s to the early 2000s (known as Generation
139 Z) will perform, do not even exist yet. It is expected that existing roles will evolve, especially during
140 the transition phase (i.e., human-robot interaction), and new roles will be created. As indicated by
141 Gelbert et al. (2016), instead of drafters there would be a need for workers with more digital skills.

142 This will occur for different functions and services, including planning and execution. The exact impact
143 of the need of new roles, such as digital fabrication (dfab) Technicians to support robotic systems,
144 dfab Programmers to develop computer numerical control that can be implemented with industrial
145 robots, or dfab Managers and Coordinators, needs to be investigated in future research. In a report
146 from One of the main advantages of using robotics in construction has to do with the potential to
147 assist construction workers during the performance of repetitive or dangerous construction tasks in
148 an autonomous manner, or with little supervision from laborers. This has the potential to reduce
149 hazards exposition and increase safety for workers, while also increasing productivity and benefitting
150 the whole construction industry (Bernold, 1987). In addition, quality is expected to improve as robots
151 would be able to increase accuracy and precision during production (Tilley, 2017).

152 When comparing to traditional construction project phases, digital fabrication brings a significant
153 change, particularly during the planning and construction phases. Digital fabrication introduces
154 sophisticated human-robot collaboration based on robot sensory inputs. This builds a common base
155 for exchange and collaboration among participants of different skillsets and machines. Many
156 publications are about robots taking our jobs (Fagan, 2017), or how machine learning, artificial
157 intelligence, and automation, with the potential of outperforming humans, will eventually cause
158 manual jobs to disappear (Welsh, 2016; Waters, 2017). The reality is far from those views, and current
159 robotic systems and artificial intelligence are limited in their abilities to replace humans due to their
160 inability to understand the complexity of our most basic real environment (Moniz and Krings, 2016).
161 Despite the unquestionable advancements in those areas, robots will not replace humans but will help
162 them to make some tasks more efficient.

163 *2.2 Traditional roles and responsibilities*

164 The number of stakeholders in construction projects varies significantly, but in general, their number
165 is considerable, and their interactions are complex (Cleland, 1986). The most basic parties can be
166 grouped into the owner (or client, project sponsor), the designer/engineer, the contractor,
167 financial/legal/marketing institutions, and the general public/user. These main parties have different
168 important roles involved. For purposes of this study, we will focus on the designer/engineer and the

169 contractor during the design and execution phases as indicated in Table 1. The different terminology
 170 used and key responsibilities are according to the service model from the Swiss Society of Engineers
 171 and Architects (SIA, 2001). Slight variations regarding their name and responsibilities might be
 172 observed in different countries.

173 *Table 1. Main roles and their key responsibilities*

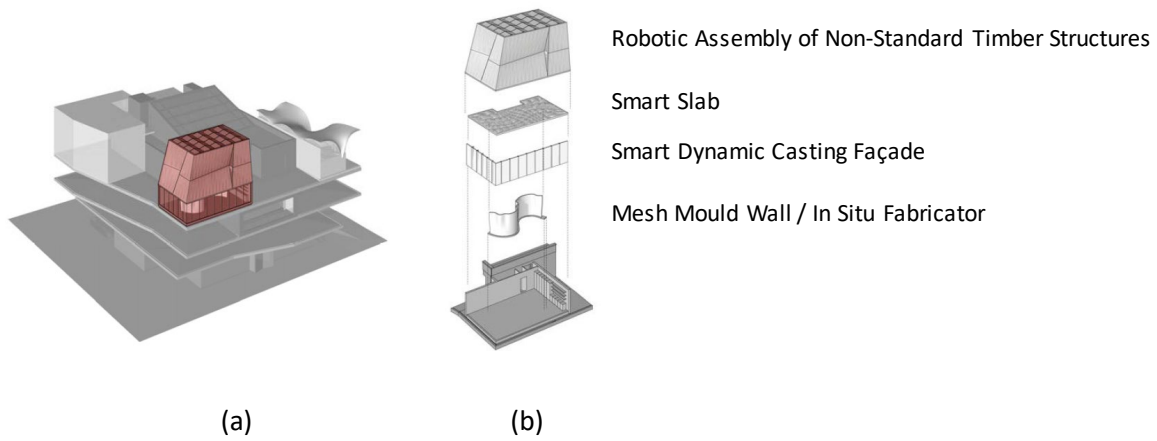
	Role	Main task
Planning/design	Leading designer/planner (project manager)	To coordinate the design/planning team
	Designer/engineer	To design a particular part of the project and often does the specialist site management for the part planned/designed
	CAD drafters	To prepare detailed technical plans or drawings
Construction	Construction manager	To coordinate the planning and execution of work on-site as a representative of the owner
	Site supervisor	To manage the contractor's team by assisting with the monitoring of onsite operations. Typically under the supervision of the construction manager
	Worker	To do the manual execution of the planned work, in most cases with the support of machines and tools

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175 **3. Case study**

176 The investigation of the different processes and interaction among the project participants was done
 177 from February to July 2017. The authors used the planning and execution of some elements from the
 178 NEST (Next Evolution in Sustainable Building Technologies) building, a research and innovation
 179 building being built at the Swiss Federal Laboratories for Materials Science and Technology (Empa by
 180 its German acronym) in Dübendorf, Switzerland. The observations made are only an excerpt of the
 181 ongoing processes of the NEST building. The NEST building is the backbone of several units aimed to
 182 test and advance technologies, materials, and systems under real conditions. One of those units is the
 183 DFAB HOUSE, a project lead by Empa in collaboration with the NCCR Digital Fabrication, ETH Zurich,
 184 and industrial partners. The unit consists of a three-story building (Figure 1).

185 Having several floors was done on purpose to show that dfab is possible for multi-story buildings. The
 186 DFAB HOUSE consists of four sub-projects, each carried out by a research team. The sub-projects are
 187 the Mesh Mould Wall, the Smart Slab, the Smart Dynamic Casting, and the Spatial Timber Assemblies.
 188 The different projects are summarized in Table 2.



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Figure 1. (a) Empa's NEST building; (b) Different components of the DFAB HOUSE (source: NCCR Digital Fabrication, 2017).

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The organization of the DFAB HOUSE project is rather complex since the two big entities EMPA and

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NCCR, as well as all other consultants and contractors, have to be integrated. The complicated

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organizational form is a direct consequence of the different research projects, involving many parties

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and decision makers. However, given the research nature of the project, there is a collaborative

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interaction among all the stakeholders not common in most public construction projects. The project

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delivery approach used was a combination between the Design-Build and Integrated Project Delivery

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System (IPD) (AIA, 2017). The project schedule was done using lean principles, in particular, the use of

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the Last Planner System. In addition, frequent meetings were also conducted among the different

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teams to ensure proper coordination. Although those meetings did not strictly follow the scrum

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concept (Streule et al., 2016), mostly because many of the artifacts were not considered, they followed

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a similar structure. As a coordination tool for the architect, the project manager, the designers, and

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the research teams, several systems (e.g., Favro, Trimble) were used. The shared online platform was

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accepted and used by all participants.

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Table 2. Different projects for the DFAB HOUSE and general description

Project	General description
Mesh Mould Wall	To produce freeform loadbearing walls that can contain building services, with a steel mesh, assembled robotically on site with the In situ Fabricator
Smart Slab Team	To investigate the potential of additive manufacturing (3D printing) for the prefabrication of large-scale lightweight integrative building components
Smart Dynamic Casting Team	To automatically produce structures with variable geometry using the slip-forming technology
Spatial Timber Assemblies	To prefabricate a timber module robotically and assemble the elements on site

206 *3.1 Evolution of existing roles and creation of new ones*

207 The evaluation of the traditional roles observed during the planning and execution during the five
208 months of interaction with the different participants at the DFAB HOUSE is summarized below. Only
209 the roles related to the case study are addressed. There might be a number of additional roles which
210 would be affected or would be created but are not considered in this study; therefore, the roles
211 identified here should be used for illustration purposes only and not meant for generalization to the
212 construction industry adopting automation and new technologies.

213 *3.1.1 Planning phase*

214 During the planning phase, most of the traditional roles are still applicable, but with some
215 modifications regarding their primary tasks. For example, the project manager maintains most tasks
216 as they are now, but as the projects become more automated or influenced by new technology, the
217 coordination among the different project participants will be shifted towards new roles (e.g., dfab
218 Manager). The role of engineers and designers during this phase will also remain very similar. Main
219 changes were related to the implementation of the new working platform (e.g., using BIM) and using
220 new software applications (in this study referred as dfab-software), such as the specialized plug-ins
221 developed for the DFAB HOUSE. Similarly, CAD drafters would not change significantly; only they will
222 need to adapt to the new parametric software used to represent the different elements specified by
223 the engineers/designers. Their involvement is likely to be reduced as the automation of the project
224 increases, but their involvement will not disappear completely. Finally, new roles would be required.
225 For example, dfab Managers, dfab Coordinators, or dfab Programmers.

226 The dfab Manager is a new role. This role arises once dfab becomes more preponderant in a project
227 (similar to BIM managers in BIM-based projects). Some of the key tasks of the dfab Manager include:

- 228 • Writing and enforcing the dfab report (a report defining the scope of dfab) in cooperation with
229 the project manager, the owner, and the involved designers.
- 230 • Defining the dfab goals.
- 231 • Defining the tasks, competencies, and liabilities concerning dfab for the different project
232 participants.

233 • Defining the standards for the BIM models, model use, and model exchange during planning,
234 execution and operation (at least the model handover to the owner).

235 • Defining the standards of dfab on the construction site. This includes soft- and hardware standards
236 and interface and communication protocols used.

237 The dfab Manager is a highly experienced the field of dfab and knows the constraints of automated
238 construction systems in general, and what are the elements to implement during the planning phase
239 in order to have an efficient execution. She or he advises the owner regarding which level of
240 automation might be optimal for the project. Since the whole set up of the project is done at the
241 beginning of the project, the dfab Manager is also required then, or at the latest when the planner is
242 hired. Once the set-up is done, the dfab Manager service for the project is done, and she or he might
243 only be called for further strategic question arising during the planning process. The BIM manager
244 could be brought into the project either as an advisor to the owner or (specialist) consultant.

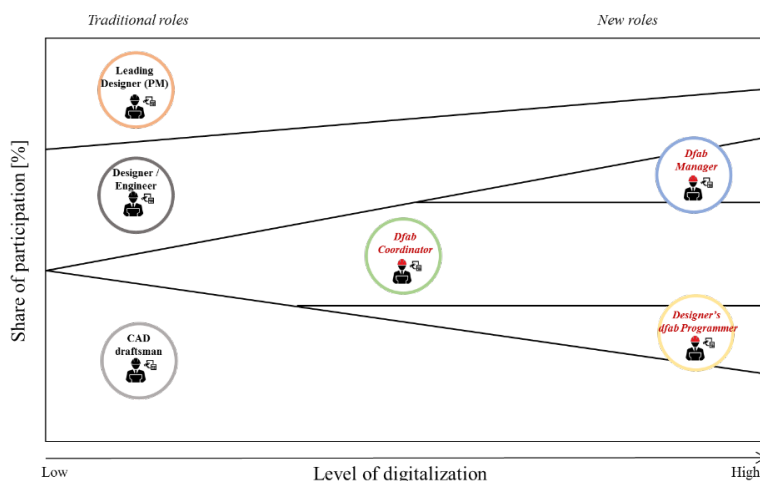
245 The role of the dfab Coordinator arises as soon as the model coordination was introduced in a
246 standardized way. Her or his level of expertise in the field of dfab is not as deep as that of the dfab
247 Manager. Since the planning of automated construction is suggested to be added to the BIM software,
248 the main tasks of the dfab Coordinator include:

- 249 • Determining the coordination and methods required.
- 250 • Checking and validating of partial models (clash-detection), including the automated construction
251 planning on site.
- 252 • Determining the necessary corrections, together with the project manager and the involved
253 planners.

254 The dfab Coordinator is required in the project as soon as the BIM platform is set up. Her or his
255 mandate would typically be included in the mandate for the project manager, meaning the planning
256 office must have the necessary dfab knowledge and people. This is usually during the preliminary
257 project or the construction project. Her or his role only ends once the models are delivered to the
258 owner during the project closeout.

259 The role of the designer's dfab Programmer is related to software design, which could be adapted
 260 from project to project. Similar to today's drafters, that are specialized in one or two CAD-software
 261 programs, dfab programmers should be specialized in one dfab-software. However, to avoid
 262 interoperability issues, it would be crucial that all specified software from the different planners and
 263 contractors would be compatible with this BIM software. The main tasks of the dfab Programmer
 264 would include coordination of the dfab-software (including fixing compatibility issues between
 265 participants and installation of plug-ins) and organization of the data storage and backup. The dfab
 266 Programmer is in charge of everything related to software, preparing it so that the planners can work
 267 at their level of understanding of informatics. The dfab Programmer is mainly required in the planning
 268 process, as soon as the BIM platform is set-up, which is done in the preliminary project. It could be
 269 thinkable that the organization that is managing the project also brings in the programmer since their
 270 work is related. She or he stays available for the construction manager during the execution.

271 The utilization of these roles, or their participation share, changes depending on the amount of
 272 automation or technology (i.e., the level of digitalization) used in a project. A qualitative
 273 representation of this participation based on the level of digitalization is shown in Figure 2. Only the
 274 roles being discussed are considered (other roles might be applicable) and the variation shown is a
 275 qualitative assessment from the author's observation of the case study. As depicted in Figure 2, the
 276 dfab Manager and the dfab Programmer only appear at an increased level of digitalization, since at
 277 low levels the tasks lay within the competences and knowledge of the current roles.



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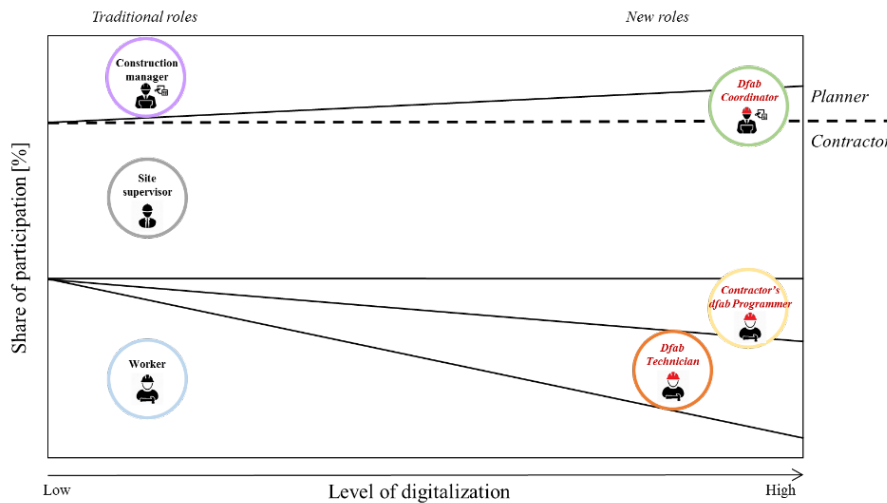
279 *Figure 2. Qualitative share of participation of each role vs. degree of digitalization during the planning phase (adapted from*
280 *García de Soto et al., 2018b)*

281 3.1.2 Execution phase

282 During the execution phase, most of the traditional roles are still applicable, but with some
283 modifications regarding their main tasks or level of involvement. For example, the construction
284 manager maintains most functions as they are now; however, there is a shift of their workload due to
285 the availability and reliability of information (e.g., fewer efforts to monitor and control schedule and
286 cost, but more efforts to coordinate with programmers). Similar to the construction manager, the site
287 supervisor's scope does not change a lot, but the workload shifts towards detail planning and
288 monitoring of the robotic systems from a control room. With regards to the construction worker, her
289 or his presence would be affected based on the amount of automation and digitalization used. One
290 can think of this as an evolution from construction worker to dfab Technician. This would be an
291 individual with experience in the execution of specific tasks, and that has been trained to operate or
292 provide support to one or a few automated systems, similar to operators of heavy machinery (e.g.,
293 cranes, excavators) in current projects. Some of their tasks would include setting up the machine on
294 site, supply the system with raw material. In essence, the dfab Technician does all standard functions
295 that are required to ensure the smooth development of the automated construction processes.

296 Another new role is the contractor's dfab Programmer. The scope defined for the designers' dfab
297 Programmer during the planning phase is also applicable to her or him, but only internally to the
298 contractor. However, for the internal task, there is a main difference: while the tasks of the designer's
299 programmer are about creating the framework for planning, the tasks for the contractor's
300 programmer consist of deducing the necessary codes for the robots from the BIM model. This also
301 includes the temporal planning (4D, in active interaction with the site supervisor and coherently to
302 the timeline defined by the planners). The whole planning can then be checked by the dfab
303 Coordinator, including the planning of all different contractors, showing the problematic points easily.
304 The dfab Programmer is involved in the process as soon as the contractor is involved. Her or his work
305 is then ongoing for detail-programming and adaption until the building is erected.

306 Similar to the planning phase, the participation share of the different roles would change depending
 307 on the level of digitalization of a project. A qualitative representation of their participation, based on
 308 the level of digitalization, is shown in Figure 3. Only the roles being discussed are considered (other
 309 roles might be applicable) and the variation shown is a qualitative assessment from the author's
 310 observation of the case study.



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 312 *Figure 3. Qualitative share of participation of each role vs. degree of digitalization during the execution phase (adapted from*
 313 *García de Soto et al., 2018b)*

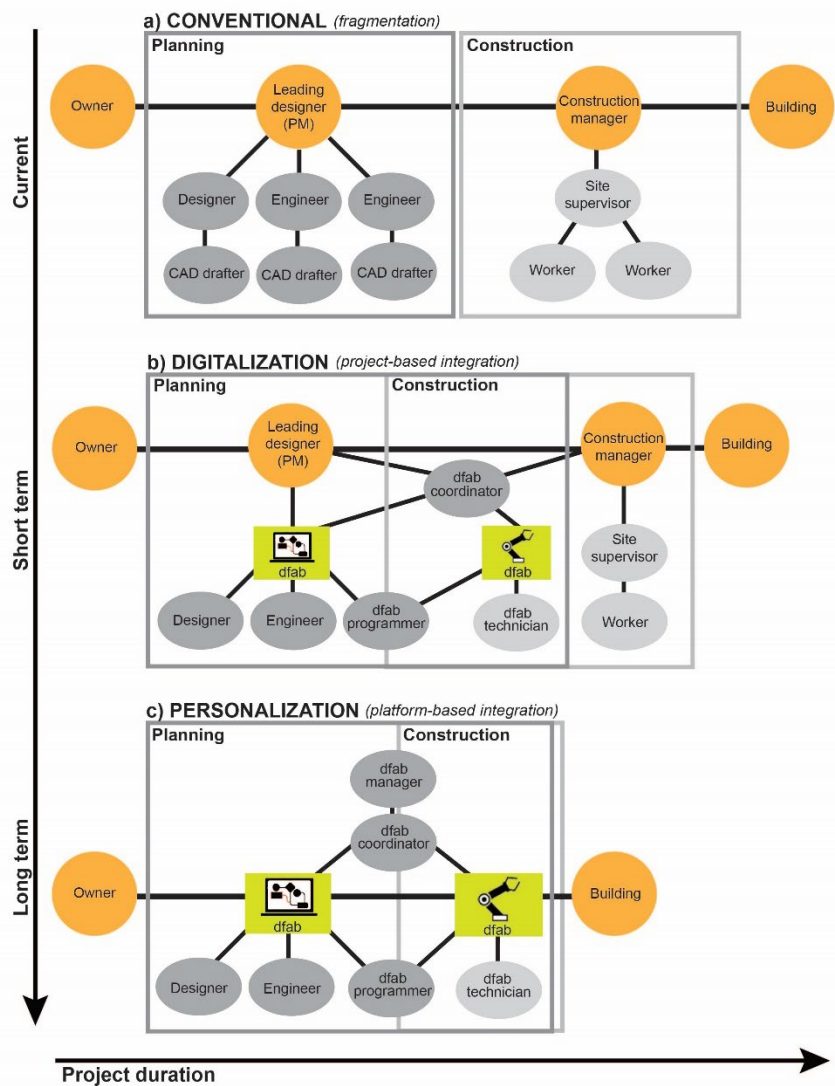
314 3.2 Evolution of the organizational structure

315 The transformation and development of the roles described in the previous section are based on the
 316 traditional organizational and delivery systems in place (i.e., the conventional design-bid-build would
 317 still work). A successful adoption of the elements required by Construction 4.0 will not only need a
 318 substantial change in the processes as we know them (similar to what has happened with the adoption
 319 of BIM and the push for early collaboration (Sacks et al., 2018)) but also in the way organizations and
 320 projects are structured. The implementation of digital information and automation technologies in
 321 construction moves forward the decision making to the early stages of the planning phase and includes
 322 execution decisions. Practitioners and researchers have emphasized that the full benefit of digitization
 323 cannot be achieved without restructuring organizational processes in construction (Whyte and
 324 Hartmann, 2017). Moving design decisions upstream implies an early involvement of the different
 325 stakeholders, which demands a collaborative and integrated organization of the team for improving
 326 construction project delivery (Lahdenperä, 2012). Integrated Project Delivery (IPD) systems facilitate

327 this early involvement and integration of versatile expertise, systems and business practices for the
328 best of the project. This project delivery method is distinguished by a contractual agreement between
329 a minimum of the owner, project manager and general contractor, where risk and reward are shared
330 (AIA, 2007). IPD allows the project organization to move from a decentralized modular cluster to a
331 collaborative modular cluster. However, this organizational structure is still project-based and has
332 limited integration, and it is only based on a contractual agreement. This limited organizational
333 integration usually implies low capital investments in new technologies for construction (Hall, 2018).

334 The construction organization observed in the case study is the consequence of a partial or short-term
335 implementation of digital fabrication technologies in construction. Specifically, the project delivery
336 system used is a combination between the Design-Build and Integrated Project Delivery System (IPD)
337 (AIA, 2007). This system allows a superposition between the planning and construction phases as well
338 as a fusion between the project manager, planners, and contractor through collaborative interaction,
339 particularly during the early phases of the project.

340 Based on this case study, Figure 4 illustrates the potential evolution of the construction organizational
341 structure derived from the adoption of Construction 4.0. There will be a transformation from the
342 current conventional fragmented organizations (Figure 4a) to project-based structures to adopt
343 digitalization during the transition phase (short term). In the “digitalization” scenario (Figure 4b),
344 digital platforms for project planning (e.g., BIM platform) and automated processes are starting to be
345 implemented in construction. However, the use of digital technologies, especially the use of a digital
346 platform to coordinate the design and construction of the project, is still limited. This restricts the
347 integration of the planning and construction phases, which derives into an organization that is still
348 highly conventional. Although it is expected that digitalization will result in shorter project durations,
349 the introduction of dfab adds complexity regarding collaboration between the new and the traditional
350 roles for the planning and construction phase, inducing a need for more and earlier collaboration
351 efforts. This is the situation with this case study, as it represents a first attempt to bridge the gap
352 between a traditional project and the new digital technologies with a focus on the use of on-site
353 robotics.



354 Figure 4. Simplified representation of the evolution of the construction organization derived from the implementation of
 355 digital fabrication (adapted from De Schutter et al., 2018)

356 The long-term implementation of digital fabrication technologies such as 3D printing or robotic
 357 assembly in construction, suggests an evolution of the construction organizational structure towards
 358 a platform-based model (Figure 4c). This results in a stream-lined process over the whole construction
 359 life-cycle from planning to construction, reducing project durations as well as some of the complexity
 360 in collaboration introduced through dfab (Figure 4b) that was applied to the conventional framework
 361 (Figure 4a). In this “personalization” scenario (Figure 4c), owners manage the construction process
 362 through a digital fabrication platform that allows the coordination of the planning and automated
 363 construction. Consequently, the owner becomes more than an informed participant, but an active
 364 responsibility-taker and administrator of the building process. This brings two important elements
 365 that need to be considered: knowledge and responsibility. For most aspects in planning, specialized
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366 knowledge is still necessary, which in some cases the owner does not have, so the role of an owner's
367 representative would still be necessary. The owner, however, can be more involved in the planning of
368 many "end-user-elements". This creates the need for a clear definition of the different responsibilities
369 shared between planners and owners.

370 Simultaneously, the role of the construction professionals evolves to a consultant, co-creator and
371 collaborator, making digital fabrication technologies accessible to owners. Specifically, construction
372 professionals plan the digital fabrication solutions contained in the online platform and assist the users
373 during project personalization. The digital fabrication platform coordinates software and hardware;
374 therefore, a big IT or automation company potentially manages it. As a result, these types of
375 companies may become large stakeholders in construction.

376 Studies from other economic fields also support this idea of personalization derived from the
377 implementation of digital technologies. For instance, in the healthcare sector, rising patient-driven
378 models are promoting the use of web-based tools, devices, and health social networking. Patients are
379 starting to manage their health with the collaboration of online communities and in consultative co-
380 care with medical professionals (Swan, 2009). Similarly, in the manufacturing sector, personalized
381 models are emerging due to the proliferation of 3D printers, which allow users to fabricate their own
382 objects (Chen et al., 2015).

383 **4. Conclusion and outlook**

384 There is no question that Construction 4.0 will have a profound impact on the AEC/FM industry, and
385 it will disrupt jobs; however, the exact consequences on the workforce are not yet known. When
386 looking at other industries, one can see that the creation of new and specialized roles always happens
387 when new technologies are introduced, and it is expected that the same will occur in the construction
388 sector. When comparing to traditional construction project phases, digital fabrication brings a
389 significant change, particularly in the planning and execution phases. As a result, it is expected that
390 current construction roles evolve, and new roles are created. There will always be tasks that will not
391 be fully automated. The construction workers will not disappear, but their number will be reduced as
392 the level of digitalization of a project increases. What is expected to occur is that the responsibilities

393 of the construction workers will shift from unsafe and hard conditions to safer and less labor intensive,
394 such as to monitor and control automated processes by transferring their know-how to the robotic
395 systems.

396 Nevertheless, it appears that Construction 4.0 will attract a new tech-savvy generation of workers to
397 the construction sector. It is expected that unpleasant aspects of construction work (e.g., working in
398 dangerous, dirty, and difficult conditions) will be automated, leading to an improvement in job
399 satisfaction for workers. Since it is anticipated that the use of robotic systems and onsite automation
400 will start with unsafe and unappealing tasks for workers, there should be a general acceptance from
401 policymaking institutions and labor organizations. In addition, since perceptions of the work being
402 physically too demanding will no longer be valid, there is also an opportunity to increase the share of
403 women working in the construction industry.

404 The organizations will also suffer modifications. There will be a movement from current fragmented
405 projects to project-based integrations (enable through digitalization), and eventually to a platform-
406 based integration (based on personalization) as a way to cope with the new roles and increased levels
407 of collaboration, coupled with the amplified involvement of the owners (enabled through the
408 platform). Although the transition (or short term) will be characterized by the adoption of
409 conventional structures trying to incorporate key elements from Construction 4.0, the long term view
410 suggests a clear departure from fragmented organizational structures towards platform-based
411 structures to support full integration between planning and construction.

412 The fact that the construction industry is getting ready for the fourth industrial revolution, with many
413 opportunities to innovate, is stimulating and can become attractive to new generations. Further
414 research is needed to evaluate the impacts of Construction 4.0 to the functional division, supply chain,
415 organizational structures and business models (with a particular emphasis on cybersecurity), as well
416 as the project deliveries and contract strategies of the AEC/FM industry, and to assess additional social
417 impacts, such as changes in education and training schemes.

418 It should be clear that this study is not meant to be an exact representation of how the AEC/FM roles
419 and organizational structures will change, but the authors hope that it will open the debate and serve
420 as propulsion for further research in this area.

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422 6. References

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