Requirements and Qualifications of Emerging Construction 4.0 Job Categories

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Construction 4.0 is the application of Industry 4.0 concepts to construction industry. Changes toward construction 4.0 are already in place, including the use of more technology in the construction industry, which has long been seen as a technology laggard industry. This new reality will cause changes in companies, business models, and workforce development. Some new roles have been suggested by previous studies. However, there is a lack of studies to identify recent information from industry about those and other new positions. To address this gap, this paper utilizes a qualitative review of job postings for top 20 2023 ENR contractors. A total of 186 emerging construction 4.0 positions were selected for further analysis. Based on the findings, the researchers identified four major categories of construction 4.0 positions: 'virtual design and construction,' (VDC) with the most open positions, followed by 'design and construction integration management,' (DCIM) 'lean and industrialized construction' (LIC) and 'innovation management' (IM). VDC as well as DCIM positions are focused on project, mainly design phase, management. However, while VDC positions manage building information modeling, DCIM focus on a broader scope of information management. LIC positions focus on production and process improvement. And IM positions support innovation at the company level. Main responsibilities and qualifications for each category are presented in our results. The findings included here can help construction educators understand the nature of these emerging construction 4.0 roles and start a conversation about how this information can affect construction education.

Introduction

Construction has been traditionally seen as a laggard industry. However, recent changes in society and the economy, such as lack of labor, productivity issues, and the COVID-19 pandemic, have accelerated the industry's adoption of emerging technology. These emerging technologies focus especially on the digitization and the merging of cyber-physical systems, echoing changes brought by Industry 4.0 [1,2,3]. And this new phase of construction progress is sometimes called Construction 4.0. Examples of construction 4.0 processes and technologies include digital twins, 3D printing, mixed reality, and offsite construction. Examples of emerging technology use for construction can be seen in an ABC [4] report, and they represent the core business of several emerging construction technology (contech) companies [5].

Previous research has highlighted the importance of these changes to the architecture, engineering, and construction (AEC) industry [1,2,6]. Furthermore, researchers of Industry 4.0 have indicated the need for companies and workers to embrace lifelong learning as new job requirements emerge [7,8]. Yet, specifically to construction, the discussion about construction 4.0 job requirements remains open [6]. It is noted that new roles will emerge because of the use of technology and new processes, but few research explored what these current roles are and what they entail [1,9]. Furthermore, the increased use of technology in the construction industry may appeal to the younger generation and be used as a recruitment tool for the industry [10].

Therefore, we explore emerging roles in construction utilizing a review of publicly posted job openings to address this gap. A similar approach to evaluating skills and requirements in the architecture, engineering, and construction (AEC) industry was used recently by [11-13]. Of those, only [11] focused on emerging roles in the industry, exploring emerging Building Information Modeling (BIM)-related positions, their scope, and required skills.

In this pilot study, we will also conduct a review of publicly available job postings, but we will focus only on large companies because of their forefront position in adopting new technology. Moreover, in the present study, we analyze which non-traditional positions are being advertised, what they entail and what are the required educational background for them. We are particularly driven by the following research questions:

1) Which construction 4.0 positions are emerging in the workforce?
2) What are the responsibilities of these emerging construction 4.0 positions?

Our findings will assist construction engineering and management programs to prepare students for upcoming changes in the workforce. Our findings will also provide other researchers with an initial assessment of emerging positions and how these positions complement traditional construction roles to move the industry forward.

Background Literature

Construction 4.0 can be considered the application of Industry 4.0 concepts to the construction industry. Previous research indicates Construction 4.0 to be a transformative framework [2,14] encompassing changes during production (namely increasing industrial production), the application of cyber-physical systems, and the wider spread of digital technologies. Therefore, Construction 4.0 is not a single, but a system of emerging and connected technologies and processes.

Previous research has categorized these technologies and processes into five groups: artificial intelligence (AI)-assisted technologies, advanced manufacturing, smart tools, digital simulation and visualization, and data acquisition and detection [1]. Examples of technologies included in these groups are digital visual capture of drone images, use of augmented reality on jobsites, digital twins, blockchain, and the use of artificial intelligence systems for predictive analytics and Building Information Modeling (BIM). These technologies often work in tandem and span several phases of the planning, design, construction, and operations building life cycle [1].

Because of the pervasive nature of emerging technology, the construction industry might also incur transformations of its business models and production processes. This is because Construction 4.0 changes include increased interaction and connectivity among stakeholders and various project phases [1,3]. For example, to achieve a higher rate of offsite construction, previous research suggests that the architecture, engineering, and construction (AEC) industry may need to embrace a product-oriented approach, looking for improving standardization and process simplification [15].

Therefore, these changes in technology and processes will require a transition in the construction workforce into newly created positions, the restructuring of current roles, and will also likely eliminate certain existing positions [6,16]. While previous research has only started to consider

the role of robotics and automation in the construction industry, even fewer studies have explored the impact of predictive analytics using large language models (LLM), such as ChatGPT or BERT. Yet, the little existing research also points to the need for reskilling the existing workforce [17,18], albeit unclear on the broad implications beyond direct development and interaction of LLMs. Short- and long-term implications of the use of ChatGPT in all industries are still unclear [18]. However, due to its analytical nature, it might displace different positions than those affected by the use of robotics.

Moreover, it is clear through the increased use of information technologies that roles related to this discipline will start to be part of the building process. For example, the centrality of Building Information Modeling (BIM) and the need to manage the information process generated by the models has pushed for creating Virtual Design and Construction (VDC) roles in the industry. And while VDC positions seem to have originated in the use of BIM, previous research indicates that the scope of work for this type of professional might increase with time [19]. Another role that has emerged to manage the increased information flow from BIM is an Information Manager (IM). Previous research defines the IM requirements as similar to those of VDC professionals, mainly managers [20], and it is unclear whether they are comparable positions.

Additionally, the approximation of the construction to the manufacturing industry, due to the 4.0 transformation, raises the importance of supply chain management, information technology and potentially the use of lean methodologies in the design and construction processes [6,21]. Previous research in the Nordic context identified roles that emerge in more collaborative construction processes, including design managers, BIM-managers, coordination managers, collaboration managers, and construction managers [22]. And specific to Construction 4.0, [6] explored emerging roles for the collaborative delivery of a multi-story research building in Europe, including “digital fabrication (dfab) managers, dfab coordinators, and dfab programmers.” Moreover, due to the integrative nature of digital technologies, it is likely that we will see more collaboration early on in the design and building process between contractors and designers. This is especially true for offsite and industrialized construction, in which premises of design for manufacturing and assembly (DfMA) and early contractor involvement are desirable for improvement of the design process [23].

As mentioned previously, it is likely that Construction 4.0 transformation will change the skills required of construction employees and create new roles. Previous research has been recently conducted to identify which skills and abilities will be demanded from construction 4.0 professionals due to ongoing technological transformations, including the ones by [1,6,24-26]. Their findings highlight a mix of soft, personal, interpersonal and technical skills. In terms of personal and interpersonal skills, previous research emphasizes the rising importance of communication, problem-solving, decision-making, critical thinking, collaboration, and leadership. For technical skills, researchers indicate knowledge about programming/coding, digital literacy, BIM, data analysis and data management and automation processes to be heightened as Construction 4.0 emerges [1,25-29,]. And, while a few researchers have explored matching skills and emerging technologies (for examples, see [1,27]), a gap remains to identify emerging Construction 4.0 roles and their required skillset.

Methodology

This paper uses a systematic review approach, with a focus on the review of publicly available construction job postings of the top 20 companies of the 2023 Top 400 Contractors list from Engineering News Record (ENR). The choice to focus on large companies was because those companies usually have the resources and work breadth to justify the creation of dedicated construction 4.0 positions and technologies [30]. Of course, this limits the ability of our study to evaluate new positions created by smaller contech start-ups, which should be considered when interpreting the results.

The list of the top 20 Contractors by ENR is publicly available in ENR [31]. Following, one of the authors manually reviewed all open positions for the top 20 companies in each company's website to create a spreadsheet with title and company for all available positions, except for trade and craft positions. This resulted in a total of 6,872 positions. Additionally, we note that some websites included separate lists for craft/trade, entry-level, and experienced positions and it is uncertain if there is overlap between those lists, especially between entry-level and experienced positions, given that trade and craft labor were already excluded.

Following, descriptions for the positions identified as construction 4.0-related were downloaded for further analysis. This review was based on a comparison between title of positions, previous literature and construction 4.0 principles and technologies. Non-technical positions (such as human resources analysists, administrative assistants and accountants) were excluded from the analysis. This also includes positions that may be aligned with industry 4.0, but are not construction specific, such as information technology (IT) specialists. Furthermore, some of the analyzed companies also performed design and/or engineering services. Positions associated exclusively with design and engineering services were excluded from the analysis as they are out of the scope of this paper. We note that some positions evaluated seemed to fall in the interface of design and construction, such as design management and pre-construction positions, and although some might argue that those are not construction-related positions or they are not as construction 4.0 positions as others, such as virtual design and construction (VDC) positions, the authors chose to keep those positions in the analysis to further evaluate how these two align with construction 4.0 principles. This resulted in 366 positions that were then revised to exclude any duplicates. A second review for scope of position was also performed, eliminating a series of engineering related positions, such as intelligent transportation systems, document & data specialist, and cyber security engineer. Furthermore, upon closer inspection at the project descriptions, the researchers decided to exclude preconstruction-related positions from the analysis, given that most of them did not align with construction 4.0 transformations. Figure 1 depicts the inclusion and exclusion criteria and steps for the data selection.

The resulting 186 files were uploaded to NVivo for qualitative analysis. All positions were then coded for basic or minimum educational requirements, location, and experience requirements. Following, to answer the first research question, the positions' given titles were coded nvivo. A second pass was performed, grouping the positions into major categories of emerging construction 4.0 roles, with the assistance of their descriptions.

Once the emerging role categories were established, the positions were coded for their responsibilities and qualifications. Word clouds were then generated of those codes to assist with a second round of coding performed by the researchers, and the second round was performed under each category individually. After the second round of coding, the researchers identified the top responsibilities and requirements for each job posting category. Similarly to educational

requirements, only basic qualifications or qualifications with no mention to level (such as basic, minimum or preferred) were included in the analysis.

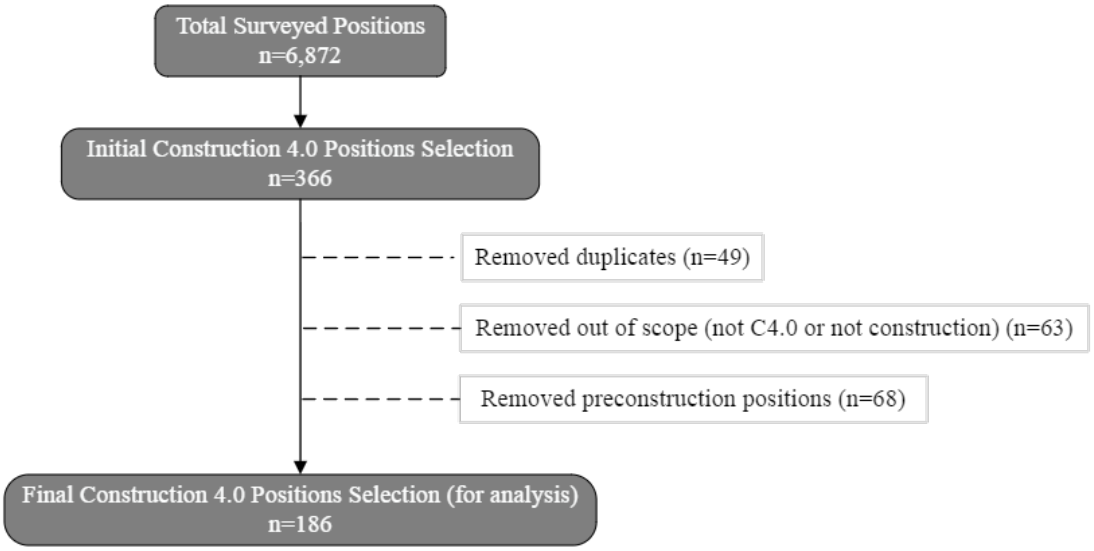

Figure 1. Data collection criteria

Results

Seventeen of the twenty companies evaluated advertised positions of interest for the present studies, ranging from a minimum of 1 position to a maximum of 25 positions. Table 1 summarizes the findings per company. The authors note that we are limited by the publicly available job postings included on their websites at the time of the search. We also note that some positions within the same company had very similar descriptions, albeit different locations and requisition numbers.

Table 1. Number of positions analyzed per Top 20 ENR Contractor company

Company Name	Number of Positions	Company Name	Number of Positions
Turner	14	Hensel Phelps	6
Bechtel	22	Gilbane	1
Mastec	0	PCL	0
Kiewit	17	AECOM	21
STO	0	Walsh	2
DPR	12	JE Dunn	16
Whiting Turner	25	Arco	5
Fluor	19	HITT	2
Clark	3	McCarthy	9
Skanska	1	Clayco	11
Total 186			

Job locations are spread out across the continental United States. Utilizing the US Census divisions, Figure 2 displays the distribution of postings per region and states. The South Atlantic region is the one with the most evaluated job postings (n=50). The states with the most open positions are Virginia (n=19), Texas (n=19) and California (n=14). We note that 18 positions indicated that multiple locations were available for the same requisition.

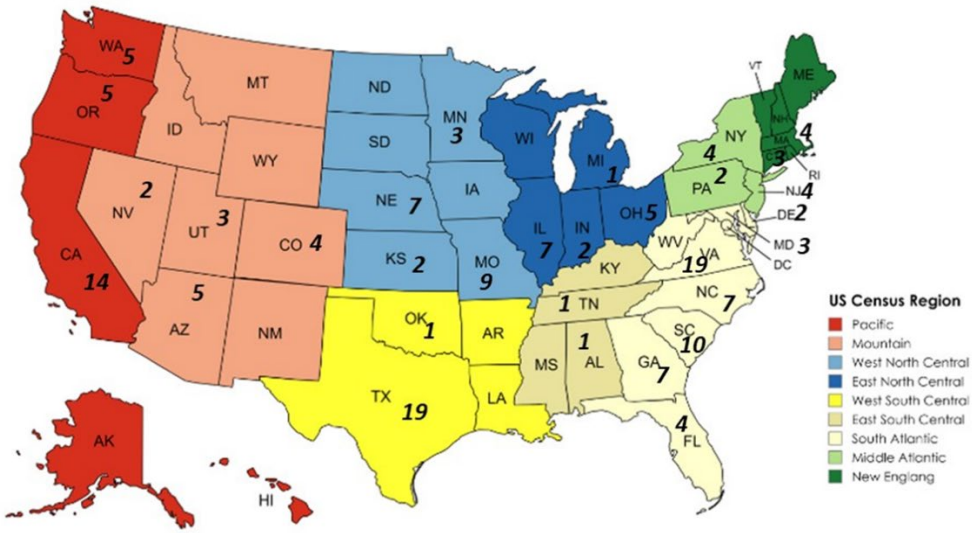

Figure 2 – Distribution of positions per US census region and state

Most of the positions analyzed were for experienced applicants (n=142), followed by internships (n=21) and entry level (n=16). Information about experience level was not available for six positions. Data was compromised for one opening, meaning that the pdf generated was cut out on the information about experience and education requirements.

We note that most positions had a basic and a preferred set of requirements. The following information related to field and level of education is based on what was included in either the basic or the only requirements available for the job postings. Nineteen positions did not include any mention of education level or field. In terms of education level, most positions required either a bachelor's degree or a combination of education and experience (n=80), followed by positions that did require a bachelor's degree (n=48). Table 2 includes more information about the education level of the positions surveyed.

Table 2 – Educational level requirements of the surveyed positions (n=167)

Education level	**Number of positions**
Bachelor's degree or combination of education and/or experience	80
Bachelor's degree	48
Associate or bachelor's degree preferred	15
Ongoing bachelor's degree	6
Associate's degree	5
Associate's degree or experience	4
Others combined	9

Field of education was not clearly indicated in 51 of the 167 positions that included some education information. Of the positions surveyed, construction-related (n=67), engineering (n=60), and architecture (n=59) degrees were demanded in most positions. We note that several positions indicated more than one option of field of education. Table 3 includes the areas in demand in the positions surveyed. Traditional architecture, engineering and construction degrees seem to still be the main demanded background, however computer-related backgrounds seem to be also in demand for a few positions (n=8).

Table 3 – Field of education of the surveyed positions (n=116)

Field Education	**Number of positions**
Construction-related	67
Engineering (non-specific)	60
Architecture	59
Civil and/or structural engineering	24
Business-related	20
Economics	13
Computer science-related	8
CAD or drafting	7
Other engineering	7
Supply Chain-related	5
Interior Design	3
Analytics or statistics	2
Others	9

Answering research question 1, the researchers analyzed the positions titles, descriptions, responsibilities and education to group into larger Construction 4.0 positions themes. Initially, six groups were created, but after a second round of analysis, including the creation of word clouds for job posting responsibilities and qualifications, three groups related to technology management, automation, and data analytics were merged into one, resulting in four categories. One position, 'sustainability specialist,' was not able to be included in any of the created categories. However, we note that within the list of surveyed positions there were two additional positions related to sustainability ('carbon analytics and simulation lead' and 'waste to value manager') that were classified under other categories. The four categories created include 'virtual design and construction' (VDC) (n=96), with the most construction 4.0 positions analyzed, followed by 'design and construction integration management' (DCIM) (n=40), then 'lean and industrialized construction' (LIC) (n=29) and 'innovation management' (IM) (n=20). Table 4 includes examples of names of positions within these four categories.

Following, the researchers analyzed coded excerpts and word clouds for job postings in each of the categories included in table 4 to determine common themes for job duties and requirements, as well as qualifications. The next paragraphs present the findings for each major category, answering research question 2.

Table 4 – Construction 4.0 job postings categories and examples of positions

Category	Virtual Design and Construction	Design and Construction Integration Management	Lean and Industrialized Construction	Innovation Management
Examples of job posting titles	BIM or VDC manager BIM or VDC engineer BIM or VDC specialist BIM modeler BIM coordinator Construction Technology Specialist	Design manager Project information manager Construction coordinator Design-build manager Construction information manager	Supply chain manager Quality/Six Sigma engineer Logistics engineer Lean manager Lean specialist	Data analyst AI-lead Machine Learning Engineer Technology manager Research & development associate Automation lead

Virtual Design and Construction (VDC) (n=96 postings)

Most of the construction 4.0 positions examined fall under this category. Positions here include the generation of a building model, that is drafting and modeling activities, as well as the management of information contained in the model in support of the design and construction process. In fact, model coordination (n=81), model development (n=41), and model management (n=35) were the most frequently found responsibilities across the different job postings in this category. Additional requirements included quality control (n=31) either of the model of on-site installation, and stakeholder management (n=30). Other responsibilities that were worth of note are training (n=25), as well as researching new technology (n=20) which seems aligned with the emerging nature of these positions and the technology they employ. Figures 3 includes the top codes found for the duties and responsibilities of VDC positions.

In terms of qualifications and based on the coding generated, knowledge about BIM processes and tools was the most frequent requirement (n=68), followed by general computer requirements (n=63), technical knowledge (n=62), and effective communication skills (n=56). Other interesting requirements include experience laser scanning (n=16), knowledge about lean techniques (n=16), experience with data analytics (n=13), and visual programming (n=12). Several positions mentioned specific software required, however the researchers have not explored the data at that level and future studies could evaluate the most frequently required BIM-related software. It seems VDC positions require a balance between technical design and construction knowledge, BIM-related knowledge and effective management of the information flow utilizing effective communication and generic computer tools available (such as word processing, spreadsheets, and presentation tools). Figure 3 includes the top codes found for the qualifications of VDC positions.

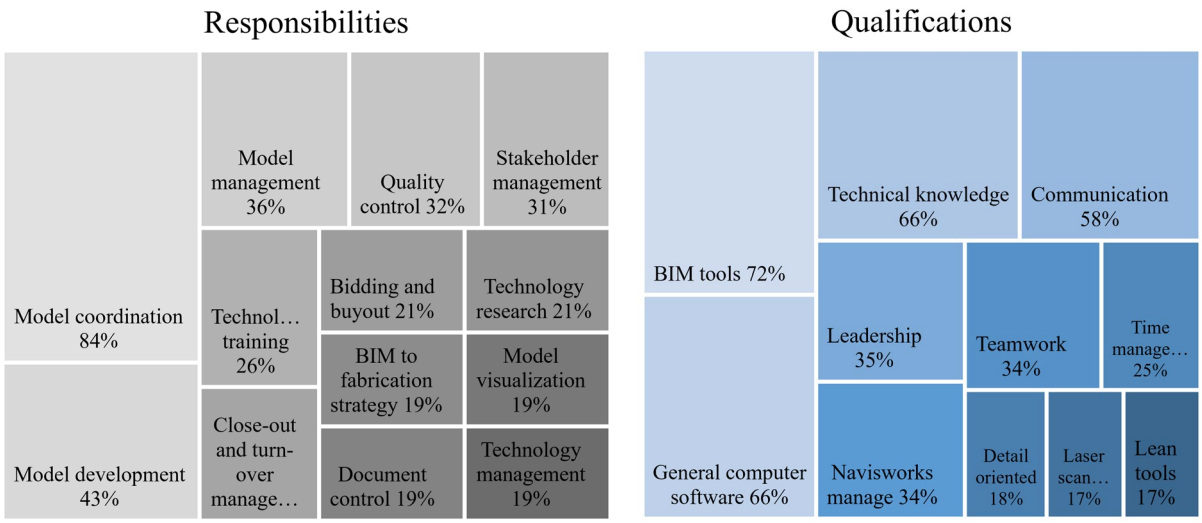

Figure 3 – Most frequent codes for VDC responsibilities and qualifications (n=96)

Design and Construction Integration Management (DCIM) (n=40 postings)

DCIM positions comprise the second most numerous category in the analyzed set. These positions seem to act as integrators between programming, design and construction, managing the flow of information through different stakeholders in the design and build process. Design appears as prominent in the postings' responsibilities. Understanding the scope of these positions, it is understandable that design coordination (n=34) and stakeholder management (n=20) are the most frequent responsibility for these types of employees. Interestingly, additional duties include performing risk analysis and management during design (n=16), participating in developing and presenting proposals for new projects (n=14), and training (n=14) indicate the wide breadth of responsibilities of these roles. Figure 4 includes the top responsibilities and qualifications coded for these positions.

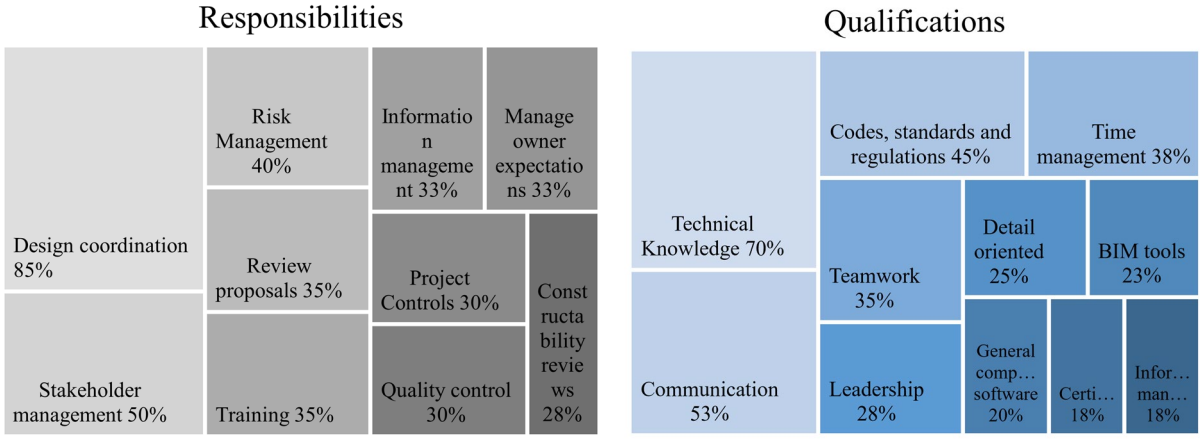

Figure 4 – Most frequent codes for DCIM responsibilities and qualifications (n=40)

In terms of qualifications, these positions emphasize technical knowledge (n=28), followed by several interpersonal skills such as written and/or oral communication (n=21), time management (n=15), teamwork (n=14), and leadership (n=11). Despite design not being included as a coded

theme in the qualifications, we note that it was indicated in the word clouds generated during analysis for qualifications of DCIM positions, suggesting that design-related knowledge or appreciation might be important for these roles. Knowledge and management of codes, regulations, and industry standards are also required in several of the revised positions (n=18). Moreover, we note that proportionally fewer job postings, that is 22.5%, in this category mention Building Information Modeling processes or specific tools required, when compared to 71.5% for the VDC category. The focus of DCIM positions seems to be on information and stakeholder management, integrating design and construction. The information generated through DCIM positions would then move to BIM and other data repositories and be managed by VDC positions.

Lean and Industrialized Construction (LIC) (n=29 postings)

Positions in this category relate mainly to either lean construction principles, such as continuous improvement and lean management, or to the management of bidding and buyout subcontractors and suppliers. Moreover, management of the bidding and buyout process was present in 19 job postings, while supply management (after bid process) was present in 12 of the 29. Project coordination (n=16) was also frequently mentioned to coordinate the buyout of the application of lean tools. We also note an emphasis on staff management, including coaching, mentoring, and training (n=15) and process development (n=11) and this is especially present in positions that are very aligned with lean management. The positions here seem to be more aligned with overall company management strategies or departments (such as procurement), acting in support of the design and, mainly, construction/production processes. Figure 5 includes the top codes for responsibilities and qualifications of LIC positions.

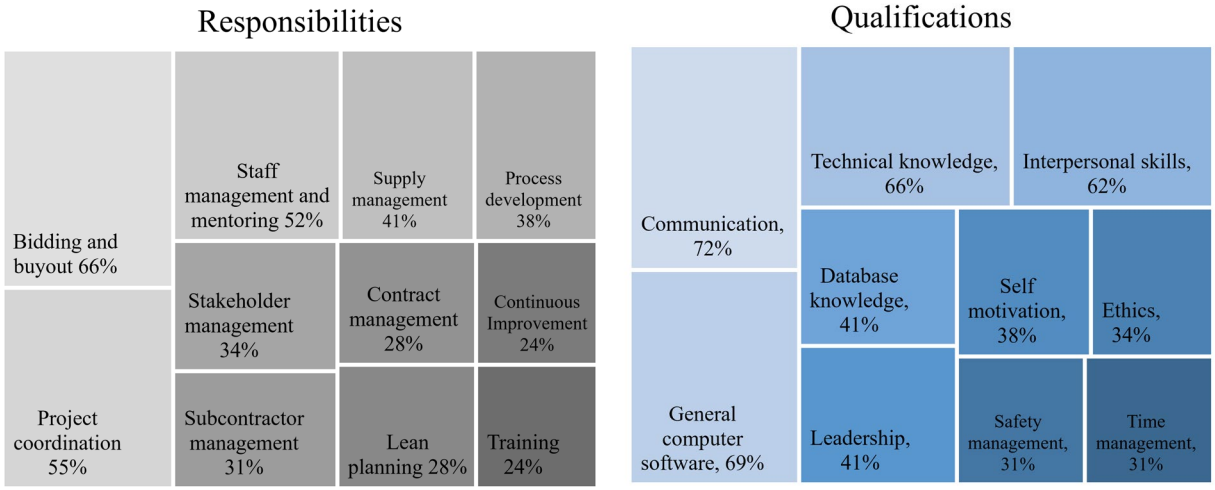

Figure 5 – Most frequent codes for LIC responsibilities and qualifications (n=29)

In terms of qualifications, given that these roles seem to interface with internal and external clients, communication (n=21) is the most demanded skill, followed closely by general computer skills (n=20) and interpersonal skills (n=18). Leadership is required for 12 positions and seem to be mostly aligned with those that focus clearly on lean and change management. About one third of the positions also highlighted the need for sound ethical principles (n=10) and database knowledge or management (n=12). Moreover, despite several positions being lean-focused, the

knowledge of lean tools is only required by four job postings, suggesting that employers understand they might need to train employees for these roles.

Innovation Management (IM) (n=20 postings)

Positions in this category mainly provide support for the digital integration of the design and construction process and utilize market and emerging technology research to manage the use of innovation in projects and companies. The focus on new technology becomes apparent in the most frequent codes for job responsibilities: technical support (n=13), providing training (n=9), digital integration (n=9), and automation services (n=9). Following, these positions are also involved in the management of technology adoption, being involved in project coordination (n=7), stakeholder management (n=7), managing innovation in their companies (n=7), and researching about new technology (n=6). These positions also perform data analysis (n=7) and management (n=6) as their primary role, or secondarily as part of evaluating the deployment of innovation and new technology. Figure 6 also includes the top responsibilities and qualifications for IM positions.

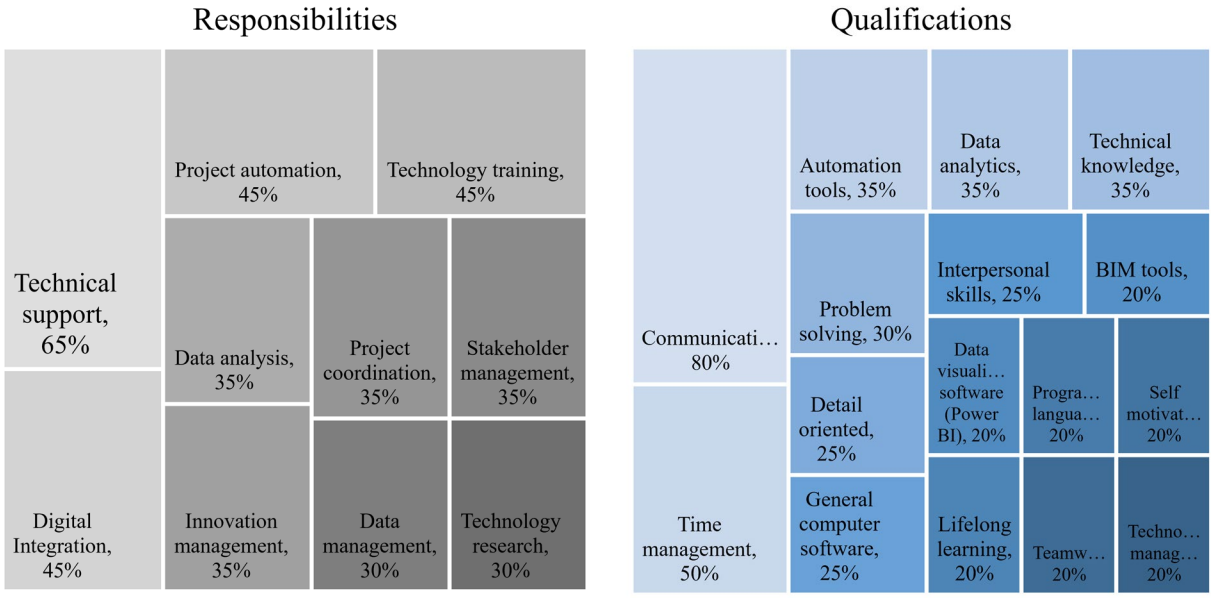

Figure 6 – Most frequent codes for IM responsibilities and qualifications (n=20)

Most of the positions under this category require strong communication skills (n=16), followed by time management skills (n=10), which can be justified by the fast-paced environment of technological innovation. Following, the most frequent requirements include technical knowledge (n=7), knowledge of automation tools and processes (n=7), and data analytics (n=7), followed by problem-solving (n=6). We also highlight that not many positions required programming knowledge (n=4) or specifically machine learning (n=3), which can suggest that not many qualified applicants with these skills may exist yet within the construction field.

Discussion

Our study revised 186 publicly available construction 4.0 job postings of the top 20 ENR 2023 contractors list. Our analysis indicates four main categories of construction 4.0 positions:

‘Virtual Design and Construction,’ ‘Design and Construction Integration Management,’ ‘Lean and Industrialized Construction,’ and ’Innovation Management.’ We then provide a brief description of these categories, including main job requirements and qualifications.

In our analysis, BIM- and VDC-related positions were grouped under one category, given that they share the model as central to their role. A few positions under the VDC category include responsibilities related to digital twinning and laser scanning, and these seem to relate back to moving the information generated in these processes back to a central model. Moreover, our findings appear to agree with survey research conducted by [29] in that this may be a role focused on supporting design coordination, including stakeholder management within the model and onsite or in-model quality control. Given that the VDC category seems to be related to positions that have been in industry for longer than other positions (such as BIM managers), we see that most positions already require specific knowledge about BIM processes and tools. Given the prominence of this position, we disagree with [32] analysis that BIM-related roles will be absorbed by the project manager role.

Our second created category, Design and Construction Integration Management (DCIM), also seems to be focused on design coordination. However, DCIM is different than VDC because the emphasis appears to be more on managing the information flow process from beginning to end, and not necessarily on BIM processes or tools. This can include managing coordination between design/engineering, construction, and owners. DCIM positions seem more aligned with the proposed information management positions proposed by [20], although in their work much of the information managed was aligned with BIM. The design manager position is also very aligned with this category. [33] discussed this emerging role, calling it construction design manager, from an English perspective. Responsibilities outlined by [33] include the integration of design and construction, coordinating and safeguarding design intent between the conflicting viewpoints and needs of the different stakeholders through the design and build process.

Lean and Industrialized Construction (LIC) is the third category established in our paper. This category is very aligned with lean manufacturing, design and construction processes, as well as procurement. In fact, similar positions within this category can also be found in the manufacturing industry, such as supply chain manager, lean manager, or logistics engineer, indicating an approximation between construction and manufacturing industry as part of Construction 4.0. Moreover, this category seems to focus on the support of the production aspects of the construction, such as procurement and material delivery, but also on process improvement. Literature discussing the application of lean principles to construction exist since the early 2000 (for examples, see see [34] and [35]). Yet, there is a lack of studies related to how lean and manufacturing-related positions are being employed in the construction industry and very little record of their existence in order to provide a comparative analysis of our findings.

Finally, the Innovation Management (IM) category includes several positions whose role is to research, pilot and evaluate the use of new technology within their organizations. This seems to be a company-level position, rather than focused on specific projects. [36] have argued that beyond the research and development (R&D) of development tools, some of these positions also include the holistic evaluation of implementation. Within this category we also see some positions that are highly focused on the development of automated solutions, such as machine learning and data analytics. Few research has identified similar roles within the construction industry.

Conclusion

Based on our findings and discussion, we summarize how the analysis of 186 emerging roles fit within the Construction 4.0 design and build process. Four main job categories emerged from the analysis: Virtual Design and Construction (VDC), Design and Construction Integration Management (DCIM), Lean and Industrialized Construction (LIC) and Innovation Management (IM). VDC positions are more than twice as frequent as any other category analyzed individually, followed by DCIM, LIC and then IM as the least frequent.

Figure 7 provides a visual for how these roles interface. Of the four proposed categories, it seems that DCIM positions enter the design and build process earlier on than others. Given that some positions in this category include management of owner's expectations, DCIM positions act in the interface between owner, designers and construction. Following, VDC positions enter once programming phase is completed, but during design coordination and will be present throughout construction to assess constructability and quality control, as well as during closeout. Finally, the other two categories emerge as supporting roles. LIC positions may be present during design but are key during the planning and production stages of the building process. They focus on overseeing supply chain management, as well as the continuous improvement of operations. Finally, IM positions act at company level, but face outwards, connecting with the research community to identify how to utilize new technology in their businesses. They support higher management with data analytics on trends, changes, and pilot projects.

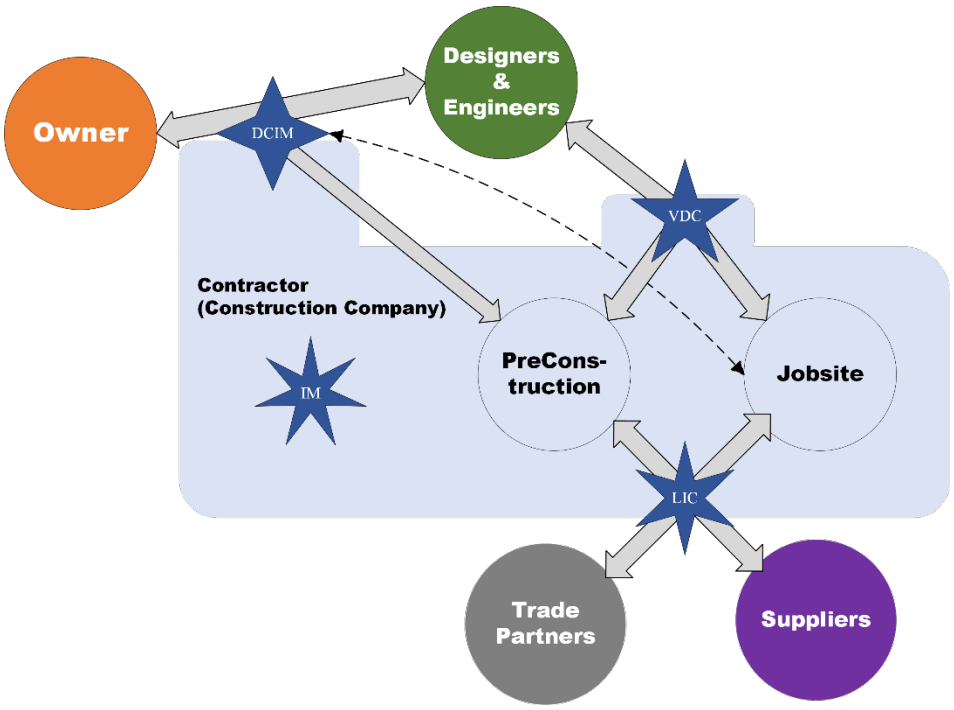

Figure 7 – Conceptual framework of construction 4.0 position categories

Undeniably, our research has limitations. In this case, we are limited to a snapshot in time (December 2023) and information publicly available from large contractors in the United States. Our coding procedure, because of its qualitative nature, may be biased to the coder's background and lived experience. Further studies could review larger amount of data utilizing the categories

established in the present paper as a starting point to a quantitative analysis to confirm or propose alterations on the current conclusions. The authors understand the evolving nature of the topic and provide the information here to start the discussion of how the emergence of these new roles can affect construction education of the future.

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