

Article



Assessment of BIM Competencies and Correlation Analysis between Competencies and Career Characteristics of FAB Construction Project Participants

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Abstract: Currently, BIM implementation in domestic FAB construction projects is in such an early stage that they are benchmarking the BIM implementation method applied in the conventional building sector. As such, in order to enhance the usability of BIM in FAB construction projects, it is necessary to have a correct understanding of FAB construction and to apply BIM in accordance with the characteristics of FAB. This requires defining critical BIM competencies needed by the participants of FAB construction projects in undertaking their tasks as well as identifying their current level of competency possessed. Accordingly, this study defined and presented BIM competencies that reflect the characteristics of FAB through the analysis of typical tasks related to FAB construction projects. For this, project participants from three FAB construction project sites in Korea (where BIM was implemented) were recruited, and a survey was conducted on their status of competency level. Moreover, a comparative analysis was conducted focusing on the correlations between their career characteristics ('Construction project experience', 'BIM-based construction project experience', 'FAB construction project experience', 'BIM-based FAB construction project experience' and 'Overall project experiences') and their current level of BIM competencies. As a result, high correlations were found between BIM competencies and BIM-based FAB construction project experience for the owner group, whereas competency items related to BIM-based construction project experience showed high correlations for the designer group.

Keywords: fabrication facility (FAB); construction project; BIM; competency; competency assessment

1. Introduction

1.1. Background and Purpose of the Study

Fabrication facility (FAB) is a manufacturing facility composed of numerous sophisticated equipment [1]. Parallel to the advancement of manufacturing technology, the FAB industry sector, represented by the manufacture of semiconductors and display panels, is undergoing a change by overhauling the conventional production method of simply delivering new products. Instead, it started to employ a new way to produce new products by predicting the market demand in advance, or to design new production lines that can help match with the tailor-made products requested by the client in a short span of time. In view of such characteristics of the industry that the timely production of the required products is of high priority, the FAB is usually constructed by implementing fast-track construction thus that the proposed production schedule can be met [2].



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As defined by Isikdag et al. [3], Building Information Modeling (BIM) entails the process of creating, sharing, exchanging, and managing project information as a single repository of data throughout the whole building lifecycle effectively and efficiently. This single repository database function of BIM enables not only easy access and sharing of information by all project stakeholders [4] but also allows immediate analysis of the benefits of various cost-time options since the time and cost dimensions can be added to the model [5]. Considering these benefits, the active implementation of BIM in FAB construction projects was initiated by project owners reflecting his/her needs for fast-track construction to ensure meeting the time schedule of production lines operation as well as for securing a 3D model of high consistency, which can ensure the efficient operation and maintenance after the construction completion. However, BIM implementation in domestic FAB construction projects is in such an early stage that they are benchmarking the BIM implementation method applied in the conventional building sector. It is noteworthy that the project owners are recruiting personnel with BIM experience from outside in order to adopt and implement BIM in FAB construction projects. As such, in order to enhance the usability of BIM in FAB construction projects, it is necessary for the workforce recruited from outside to have a correct understanding of FAB construction and to be able to command BIM properly in accordance with the characteristics of FAB. In addition, the existing participants of FAB construction projects need to acquire and possess new competencies, which are required for commanding BIM properly in FAB construction projects. Whether for the recruited workforce from outside or for the existing FAB construction participants, having a clear understanding of required BIM competencies for FAB projects and equipping them with such accordingly will only guarantee the benefits of BIM implementation.

Accordingly, this study aims to assess and present BIM competencies needed for the successful implementation of BIM in FAB construction projects and for enhancing the usability thereof. In addition, this study will identify the current BIM competency status as well as the correlation between career characteristics and BIM competencies of project participants engaged in FAB construction projects where BIM was implemented. Although there are previous studies on identifying BIM competencies, such as Uhm et al. [6], which identified 43 competencies for the eight BIM job types (e.g., BIM project manager, director, BIM manager, etc.), this study furthers the body of knowledge on BIM competencies by specifically identifying the needed BIM competencies for FAB construction projects. As such, it can be expected that the findings of this study be used as a base for the development of customized BIM educational programs, thus as to enhance the competencies of project participants of BIM-based FAB construction projects in the future.

The overarching aim of this study is to assess specific competencies needed for the successful implementation of BIM in FAB construction projects and to enhance usability. The specific objectives associated with this aim are:

- Objective 1: to identify the current BIM competency status in the construction industry in Korea
- Objective 2: to evaluate the correlation between career characteristics and BIM competencies of project participants engaged in FAB construction projects where BIM was implemented
- Objective 3: to justify the need for customized BIM educational programs thus as to enhance the competencies of project participants of BIM-based FAB construction projects in the future

1.2. Scope and Method of Research

The competencies referred to in this study are the knowledge or skills needed for utilizing BIM in FAB construction projects. First, this study presents BIM competencies required for FAB construction projects through the analysis of typical work involved in FAB construction projects, and, for that purpose, a survey was conducted targeting the participants of three FAB construction projects (Paju, Tangjeong of Asan, and Cheongju), where BIM was being implemented.

Considering that BIM in FAB construction projects was initially implemented to meet the needs of project owners and that the experience level of project participants on FAB construction was unequal since many of them were recruited from outside for their experience of prior BIM knowledge, the entire survey respondents were categorized into two groups, which are the owner group and the designer group when the comparative analysis of their competency status was conducted. Further, the comparative analysis was performed using SPSS Statistics[®] of IBM[®] to analyze the correlation between the career characteristics and the subdivided specific competencies.

Taking both qualitative and quantitative research approaches, this study was conducted based on the following steps:

Qualitative research approach:

- 1. Analyzed the characteristics of BIM-based FAB construction projects, including the characteristics of FAB construction projects, cases of BIM implementations, reasons for the BIM implementation, involved tasks, etc. (expert interview)
- 2. Analyzed BIM-related competencies and performance standards specified by the National Competency Standards (NCS)
- Defined and finalized BIM-FAB competencies based on adopting and modifying the competencies presented by the NCS to reflect the characteristics of FAB construction projects or by adding new competency items

Quantitative research approach:

- 1. Conducted survey on BIM-FAB competencies by soliciting survey participants from domestic FAB construction projects, which implemented and utilized BIM
- 2. Analyzed survey results to understand the current status of BIM competencies and the FAB construction project participants' awareness of required competencies

2. Background

2.1. FAB Construction Project and BIM

FAB is an abbreviation for 'fabrication' or 'fabrication facility', which means the production facility for manufacturing semiconductors or display panels. FAB belongs to a high-tech industry supported by advanced facilities and sophisticated technologies, as shown in Figure 1, which involve the use of high-risk chemicals, the cleanroom construction with a controlled air environment, etc. Some noticeable characteristics of this industry are that it needs a qualified professional workforce possessing expertise for various work types and that there are numerous laws and regulations pertaining to this industry. In addition, since the semiconductor and display panel production come with diverse product groups, it is important to respond quickly to the market demand, which is not easy to predict in advance. As such, product type, production quantity, and operation start date for new production lines, etc., are typically determined depending on the market demand or the customers' order, which in turn dictates the design plan and construction duration [1–27].

As for the FAB construction project, the extreme complexity and diversity of manufacturing equipment or facilities as a whole, added by the cleanroom codes compliance, complex schedule management, and budget control requirements, make the FAB project more challenging than other projects, such as residential and commercial buildings. With the implementation of BIM in FAB construction projects, a significant amount of time and resources, such as labor force, could be saved, especially during the pre-construction phases. This is because of the numerous benefits BIM presents, such as drawing generation function, rapid prototyping, interferences checking (i.e., clash detection), regulation or code compliancy verification, etc., mostly can be conducted automatically. Previous studies have proven that although implementation of BIM at the design stage will increase initial expenses, the benefits of BIM will outweigh the expenses, which will be paid off during the construction stage. In other words, exerting a bit more effort at the design phase



with the implementation of BIM will lead to a greater benefit in terms of overall project performance [8].

Figure 1. BIM-based FAB project drawing relationship diagram (adapted from [9-11]).

2.2. Examples of Applying BIM in FAB Construction Projects

The semiconductor companies with a global market, such as Intel and TSMC, as shown in Figure 2, have been applying BIM to their FAB construction projects. Intel has introduced BIM to minimize the downtime of production lines when replacing internal production facilities of existing semiconductor plants. It has increased the ratio of pre-production work by means of prefabrication and has eventually reduced the time and cost for installing the facility by setting up the proofs of concept (POCs) based on the 3D models of high consistency [10]. TSMC, a Taiwanese semiconductor company, has introduced and utilized BIM early from the construction stage, envisaging in advance integrated management during the operation management stage. As a result, the operation management platform based on Crystal 5D has been established thus as to flexibly cope with the change of the production lines by building the related libraries [12,13].



Figure 2. Case study: BIM-based FAB construction projects (adapted from [14,15]).

SK Hynix, a world-class memory semiconductor chipmaker and supplier, had built three FAB plants in South Korea: M14 and M16 at Icheon, M15 at Cheongju. The latest M16 was completed in 2021, occupying a total area of 57,000 m² with an investment of 3.5 trillion Korean Won. In order to address the limitations of 2D modeling programs based on floor plans and problems associated with a large number of piping, ductwork, and cable tray components installation at accurate locations, these three projects had adopted BIM from the design stage. Implementation of BIM in these FAB construction projects demonstrated that BIM could help in determining optimal conditions for the distance between cleanrooms and electrical rooms, as well as in checking the placement of cables connected to each piece of equipment in the cleanrooms [16,17].

Furthermore, Exyte, as a construction engineering company, is widely known for its expertise in planning and designing high-tech production plants. In 2019, Exyte introduced their smart FAB concept where the digital twin acts as the core element and consists of BIM along with real-time data from the facility monitoring and control system. With the implementation of this concept, more enhanced quality and safety standards were achieved, at the same time, optimizing the system's sustainability and increasing energy efficiency throughout the FAB's life cycle [18,19].

2.3. Data Integration of BIM and GIS

The construction of BIM shape/attribute information modeling based on the existing blueprint consists of 3D BIM data modeling incorporating facility maintenance data and 2D architectural plan. If the Geographic Information System (GIS) information is added to this BIM information, the 3D BIM data will be augmented with accurate locational information. Based on this adjustment, GIS and BIM information can be stored into a master database, which can be used for precise maintenance and repair work during the facility management (FM) phase, even for the complex FAB facility. Moreover, any data generated during this process can be archived and stored in the data library for future use, thus creating a virtuous circle of data usage. In order to build the aforementioned system, data should be managed in accordance with the FM system. Finally, data mapping system-based various data, such as locational information, spatial information, attribute information, equipment/facility information, historical track record information, etc., are managed in terms of object and space, thus building the database system, which in turn is saved as an integrated database constantly being used for facility maintenance work. Figure 3 graphically shows BIM and GIS-based working system configuration that can be applied to FM work for FAB facility.



Figure 3. BIM and GIS-based working system configuration diagram.

3. Research Design and Methods

3.1. FAB-BIM Competencies

Successful project management and execution can be guaranteed by the seamless performance of detailed tasks undertaken by the project participants, which means that the project participants must have the competencies necessary to perform their assigned tasks. In this sense, this study defined the required BIM competencies through the analysis of BIM-related work in FAB construction projects.

As the government mandates implementing BIM in projects exceeding 40 million dollars, the necessity and importance of utilizing BIM are well-recognized at the national level. In this regard, the NCS suggested needed competencies to carry out BIM-related tasks successfully. These BIM competencies presented by the NCS were analyzed in defining BIM competencies for this study. Figure 4 below shows the flow of defining and assessing BIM competencies for FAB implemented in this study.



Figure 4. FAB-BIM competency through analysis of work in FAB construction projects.

3.2. Prior Studies on BIM Competencies

As summarized in Table 1, BIM competencies are defined in different ways depending on the target individual whose competency is being measured as well as the tasks being undertaken [20]. For example, under the assumption that measurement of individual member's competency reflects the competency levels of the entire organization, Succar et al. [21] developed a competency evaluation model that can be applied to the entire organizational members by defining competencies using common measures, such as management, operation, support, research, etc. By targeting specific task performers, such as BIM managers, Chung and Kim [22] analyzed specific tasks performed and defined BIM competencies particularly required to undertake such tasks. As such, in order to apprehend the BIM competency level of those involved in domestic FAB construction projects, it is necessary to understand tasks typically involved with FAB construction projects and to define BIM competencies that reflect those tasks relevant to FAB projects.

Study Purpose	Competency Items	Study Contents
BIM competencies defined to develop BIM educational model [6]	Checking BIM data, checking BIM requirements, defining BIM operation process, BIM-based collaboration, conforming modeling standards	Defined BIM competencies through analyzing BIM-related governmental publications and BIM-related job posting
BIM uses defined to present guidance in establishing BIM work plan as well as to be used as a reference in establishing BIM work plan [23]	Fabricating, exploring, and analyzing BIM model, applying analytical software, knowledge on building construction and operation, understanding of building owners' requirements	Analyzed BIM uses and derived BIM resources and competencies required for each use
BIM competencies of the individual member of the organization measured thus as to identify BIM competencies of the entire organization [21]	Managerial, administration, functional, operation, technical, implementation, supportive, research, and development	Defined general BIM competency measures regardless of the expertise or specific tasks, developed online BIM competency evaluation tool
BIM competencies identified as a reference for developing training and educational material for BIM managers of domestic construction projects [22]	Identifying BIM implementation purpose, understanding BIM project delivery contracts, analyzing BIM risk, managing process of the combined model, establishing BIM usage extent	Defined specific tasks and required BIM competencies for BIM managers through literature reviews and expert surveys
BIM competencies analyzed thus as to reinforce the competitiveness of domestic building design [24]	BIM administrative strategy, BIM organizational culture, BIM infrastructure, and BIM quality assurance dividing into managerial area and technical area	Conducted BIM competency evaluation of domestic architectural design firms, analyzed the current state of BIM competency level of design firm contingent to BIM adaptation

Table 1. Prior studies on defining BIM competencies.

3.3. Analysis of Work of FAB Construction Projects

Currently, in Korea, FAB construction projects implement BIM in different phases in which BIM is heavily being used during the design phase. In this sense, this study derived the required competencies through the analysis of typical work involved in the design. Among the FAB construction projects in Korea, the 9 field experts of the construction project sites where BIM was implemented were interviewed thus as to analyze their typical tasks involved with FAB construction projects [25]. These field experts were solicited by first identifying ongoing or recently completed FAB construction projects, which implemented BIM during the planning, design, and construction phases. Then the personnel in charge of the projects were contacted for their assistance in identifying field experts for the interview. Through this process, 9 experts were identified, and phone interviews were conducted at the agreed date and time. Each interview session lasted less than 30 min when the prepared set of questions, such as their responsible tasks, the extent of BIM usage, etc., were asked.

The interview results show that 4 major tasks were typically performed; 'BIM integrated model building', 'design review', 'project management', and 'licensing'. In particular, the 'design review' and 'licensing' tasks in FAB construction projects were further subdivided compared to general construction projects due to their specialized work types and high complexity. Specifically, the 'design review' work was subdivided into the review of building structure, equipment layout, and utility (UT) matrix, whereas the work related to 'licensing' included acquiring the construction permit and cleanroom (CR) certification. Moreover, it is noteworthy that the owner's requirements (OR), such as 'presenting the specification of the production equipment' and 'specifying the production operation start date' largely influence the design plan (equipment layout, piping design) and the design duration (design duration matching with the finalized start date of production operation) [26].

3.4. BIM Competencies of Domestic Construction Projects

Among the BIM competencies specified by government agencies, the competencies defined by the National Competency Standards (NCS) was adopted for this study since the NCS established detailed competencies needed for performing the BIM-related tasks successfully [27].

The BIM-related capability measures include 'Design using BIM' and 'Establish BIM implementation and utilization plan'. According to the NCS, 'Design using BIM' (capability measure) consists of 4 capability measure elements; 'Preparing for BIM', 'Managing BIM application', 'Creating BIM', and 'Utilizing BIM', while 'Establish BIM implementation and utilization plan' (capability measure) also consist of 4 capability measure elements; 'Establishing BIM implementation plan for planning phase', 'Establishing BIM implementation plan for operation planse'. After collating the subdivided competency items of 'Knowledge', 'Skills', and 'Attitude' presented for each capability measure element of 'Design using BIM' and 'Establish BIM implementation and utilization plan', they were organized by excluding the redundant items [28,29].

3.5. FAB-BIM Competencies

The NCS classified the competencies into 3 levels, 'Knowledge', 'Skills', and 'Attitude'. However, in the case of 'Attitude' competency as a qualitative indicator, it may present different results depending on the respondents' criteria, and as such, it is difficult to evaluate it as a quantitative indicator. Therefore, in this study, the items involving knowledge or skills among competency items of 'Attitude' were reflected in the competencies of 'Knowledge' domain and 'Skills' domain. For example, 'Attitude to understand the optimal BIM program for different design phase work' was shifted to 'Major functions of BIM software' (Knowledge), while 'Attitude to collaborate and share data derived through analysis' being changed to competency groups of 'BIM-based reports and documents extraction' (Skills) and 'BIM-based data sharing' (Skills).

The competencies in this study were defined as BIM-FAB competencies redefined from the BIM competencies presented by the NCS (Knowledge, Skills, and Attitudes) to match with the characteristics of the FAB through FAB's work analysis. As can be seen in Table 2, the above FAB-BIM competencies needed for carrying out the tasks of FAB construction projects were further subdivided and grouped in hierarchical fashion into the 'Specific Competency' (level 3- minor classification), 'Competency Group' (level 2- middle classification), and 'Competency Domain' (level 1- major classification).

The competency of the 'Knowledge' domain was composed of 13 specific competencies. The specific competencies were grouped into 4 competency groups, which were 'BIM-related knowledge', 'Understanding FAB', 'Construction related knowledge', and 'Standards evaluation'. For this study, the competencies of 'Principles of CR (cleanroom)', 'Utility characteristics', 'Process and Instrument Diagram (P&ID)', and 'CR certification criteria' were added to reflect the characteristics of FAB.

The competency of the 'Skills' domain was composed of 19 specific competencies. The specific competencies were grouped into 5 competency groups, which were 'Generate BIM data', 'BIM-based project management', 'BIM-based analysis and review', 'BIM-based reports and documents extraction', and "BIM-based data sharing'. For this study, the competencies of 'Equipment layout review', 'UT (Utility) matrix review', 'CR airflow review', and 'Approval for construction (AFC) drawings extraction' were added to reflect the characteristics of FAB.

	Competency (Level 1)	Code	Competency Group (Level 2)	Code	Specific Competency (Level 3)
				K11	Major functions of BIM software
	Competency (Level 1) Cod K1 K1 K2 K2 Knowledge K3 K4 S1 Skills S3 Skills S3 Skills S3	K1	BIM-related knowledge	K12	Object and BIM library classification system
				K13	Level of Detail (LOD) definition
				K14	Attribute value definition
				K21	Principles of CR (cleanroom) *
		K2	Understanding FAB	K22	Utility characteristics *
Κ	Knowledge			K23	Process and Instrument Diagram *
				K31	Schedule management
		K3	Construction-related	K32	Supply management
			into vicage	K33	Cost management
				K41	CR certification criteria *
		K4	Standards evaluation	K42	Construction licensing standard
				K43	BIM data quality evaluation
				S11	BIM modeling
		S1	Generate BIM data	S12	BIM library
				S13	Attribute value input
		S2		S21	4D scheduling
			BIM-based project	S22	5D quantity takeoff
	_			S23	Cost planning and review
	_			S31	Design review
				S32	Equipment layout review *
S	Skills	62	BIM-based	S33	UT matrix review *
0	5Kiii5	55	analysis and review	S34	CR airflow review *
				S35	Clash detection
				S36	Interference review
	_			S41	Construction licensing documents and drawings
			BIM-based reports and documents extraction	S42	Approval for construction (AFC) drawings extraction *
				S43	Bill of material and quantity
				S44	Export the report
	_			S51	Update BIM data
		S5	BIM-based data sharing	S52	Interoperability of BIM data
			_	S53	Security of BIM data
			*	CEAD	

 Table 2. FAB-BIM competencies.

* Competency reflecting the characteristics of FAB.

4. Formulation of Questionnaire and Analysis of Career Characteristics of Respondents

4.1. Overview of the Study Administration

Among the project participants from three FAB construction project sites where BIM was adopted (Paju, Tangjeong of Asan, Cheongju), an on-site survey was conducted targeting three workgroups; owner, CM, and designer. Table 3 highlights the overview of the survey conducted.

Table 3. Overview of the survey conducted.

Categories	Contents		
Survey period	2018.05–2018.06		
Target	Participants of FAB Construction projects (adopting BIM)		
Purpose	Status of competency level		
Method	On-site survey using the questionnaire		
Require	120		
Responded	88		
Response rate (%)	73.33%		

Eventually, all survey respondents were classified into two groups according to the tasks they were undertaking, the owner group and the designer group, while the CM group was combined with the owner group since it had few numbers of samples available due to the project characteristics. After discarding 12 responses deemed unreliable, 18 question-naire responses (23.7%) from the owner group and 58 responses (76.3%) from the designer group were analyzed for this study, as summarized in Table 4 below.

Table 4. Distribution of survey respondents.

Distribution	Ν	%
Owner	18	23.7
Designer	58	76.3
Total	76	100

4.2. Formulation of the Survey Questionnaire

The assessment of FAB-BIM-specific competencies in FAB construction projects was carried out in order to identify the competency status of the participants partaking in FAB construction projects. In terms of specific competencies, the survey questionnaire was prepared to measure participants' current level of competencies using a five-point Likert scale. Considering the fact that BIM is in the early introduction stage in FAB construction projects, each Likert scale point was interpreted in such a way that 'very low' corresponded to 'no competency level', 'low' to 'beginner level', 'ordinary' to 'medium level', 'high' to 'advanced level', and 'very high' corresponded to 'expert level'.

In order to analyze the correlation between the subdivided career characteristics and the competencies, the respondents' practical experience was classified into 'Construction project experience', 'BIM-based construction project experience', 'FAB construction project experience', 'BIM-based FAB construction project experience', and 'Overall project experiences'.

4.3. Analysis of Career Characteristics of Respondents

As summarized in Table 5, the aggregated total work years of the owner group (N = 18) averaged 8.939 years. Among them, the construction project experience averaged 3.028 years, BIM-based construction project experience averaged 2.06 years, FAB construction project experience averaged 1.972 years, and BIM-based FAB construction project experience averaged 1.883 years. The standard deviation and variance values in Table 5 show that respondents representing the owner group possessed the most work

	Working Experience								
	Total	Construction	BIM-Based Construction	FAB	BIM-Based FAB Construction				
Avg	8.939	3.028	2.06	1.972	1.883				
median	7.750	1.000	0.00	0.000	1.500				
StDev	6.1167	4.9303	3.334	4.0091	1.3053				
Var	37.414	24.308	11.114	16.073	1.704				
Min	0.9	0	0	0	0.5				
Max	22.0	16.5	10	14.0	5.0				

experience in general construction projects and the least experience in FAB construction projects using BIM.

Table 5. Descriptive statistics: the owner group (N = 18).

(Unit: year).

The aggregated total work years of the designer group (N = 58) averaged 7.855 years, among which construction work experience averaged 3.474 years, BIM-based construction project experience averaged 1.31 years, FAB construction project experience averaged 1.647 years, and BIM-based FAB construction work experience averaged 1.424 years. Similar to the respondents representing the owner group, the standard deviation and variance values in Table 6 show that respondents representing the designer group possessed the most work experience in general construction projects and the least experience in FAB construction projects using BIM. Descriptive statistics for the designer group are shown in Table 6.

			Working Experie	ence	
	Total	Construction	BIM-Based Construction	FAB	BIM-Based FAB Construction
Avg	7.855	3.474	1.31	1.647	1.424
median	7.000	2.000	0.00	0.000	1.000
StDev	5.4031	4.4093	2.422	3.7146	1.5431
Var	29.194	19.442	5.867	13.798	2.381
Min	0	0	0	0	0
Max	26.0	25.0	10.0	23.0	8.0
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Table 6. Descriptive statistics: the designer group (N = 58).

(Unit: year).

5. Findings—Analysis of the Current Competency Level of the Owner Group and the Designer Group

5.1. Analysis of Current Competency Level of 'Knowledge' Domain Competencies Conclusions

The current competency level with respect to the competency groups and the specific competencies in the 'Knowledge' domain was analyzed, as can be seen in Figure 5. As for the owner group, the respondents showed the highest level of competency in the competency group of 'Understanding FAB (3.46)', followed by 'BIM-related knowledge (3.36)', 'Construction related knowledge (2.87)', and 'Standards evaluation (2.69)'. Among the specific competencies within the 'Knowledge' domain, 'Principles of CR (3.78)' within the 'Understanding FAB' competency group was found to be the highest level of competency possessed by the respondents. Additionally, the competency level of 'Utility characteristics (3.39)' and 'Process and Instrument Diagram (3.22)' from the same competency group of 'Understanding FAB' were found to be higher compared to other competencies.



Figure 5. Current competency level of 'Knowledge' domain competencies.

As shown by the respondents of the designer group, the current competency level in 'BIM-related knowledge (3.32)' within the 'Knowledge' domain marked the highest level, followed by 'Understanding FAB (2.87)', 'Construction related knowledge (2.78)', and 'Standards evaluation (2.46)'. In comparison, the level of competency was lower than that of the owner group in general. Among the specific competencies within the 'Knowledge' domain, the current level of competency in terms of 'LOD definition (3.39)' and 'Major functions of BIM software (3.37)' were high, but the competency level for most other specific competencies was found to be low (2.5 and below).

5.2. Analysis of Current Competency Level of 'Skills' Domain Competencies

The current competency level of the competency groups and the specific competencies in the 'Skills' domain competency was also analyzed, as can be found in Figure 6. With respect to the owner group, the respondents showed the highest level of competency in the competency group of 'Generate BIM data (3.61)' followed by 'BIM-based data sharing (3.13)', 'BIM-based reports and documents extraction (3.11)', 'BIM-based analysis and review (2.71)', and 'BIM-based project management (2.48)' in that order. The 'BIM modeling (4.5)' competency marked the highest among the specific competency items in the 'Skills' domain, with the competency level of the 'CR airflow review (1.67)' marking the lowest.



Figure 6. Current competency level of 'Skills' domain competencies.

In the case of responses by the designer group, the current competency level in 'Generate BIM data (3.66)' within the 'Skills' domain marked the highest level, followed by 'BIM-based data sharing (3.12)', 'BIM-based analysis and review (2.91)', 'BIM-based project management' (2.72), and 'BIM-based reports and documents extraction (2.70)'. Among the specific competencies within the 'Skills' domain, the competency level of 'BIM modeling (3.75)' and 'Attribute value input (3.74)' recorded comparably higher while the competency level of 'CR airflow review (1.75)' recording the lowest.

6. Findings—Analysis of Correlation between Career Characteristics and Competency Level

FAB construction projects started to implement BIM by educating BIM to existing FAB construction participants or by recruiting people who had prior work experience in BIM-based construction projects. This brought a workforce with diverse career characteristics working together in FAB construction projects. In view of such aspect, this section aimed to conduct correlation analysis between the career characteristics (experiences in 'Construction project', 'BIM-based construction project', 'FAB construction project', 'BIM-based FAB construction project', and 'Overall project experiences') and the current possession level of 32 specific competencies (13 'Knowledge' domain-specific competencies and 19 'Skills' domain competencies). This correlation analysis between the career characteristics and the specific competencies was conducted using SPSS Statistics[®] (Ver. IBM SPSS Statistics 25) of IBM[®].

The Pearson correlation coefficient (r) derived from the analysis was a coefficient indicating the degree of correlation between two items and has a value between -1 and 1. Correlation coefficient greater than zero (r > 0) indicated a positive correlation, a negative correlation at r < 0, and no correlation exists when r = 0. The larger the absolute value of the correlation coefficient (r), the stronger the correlation. Generally, it can be interpreted that there is a significant correlation when the absolute value of correlation coefficient (r) is 0.3 or more, a clear correlation when r is 0.5 or more, and a strong correlation when r is 0.7 or more.

6.1. Analysis of Correlation between Career Characteristics and Competency Level in 'Knowledge' Domain

6.1.1. Analysis of the Owner Group

Table 7 shows the correlation between the career characteristics and the 'Knowledge' domain-specific competencies of the owner group. Among the five career characteristics, 'Overall project experiences' and 'BIM-based FAB construction project experience' were found to have significant correlations with most specific competency items.

Among the specific competencies within the 'Knowledge' domain, 'Schedule management', and 'Supply management' showed a strong correlation with 'Overall project experiences' while 'Cost management', 'Construction licensing standard', and 'CR certification criteria' showed a clear correlation with the said career characteristic of 'Overall project experiences'. Therefore, it can be interpreted that 'Overall project experiences' generally correlated with specific competency items pertaining to the competency group of 'Construction related knowledge' and 'Standards evaluation'.

Specific competencies that showed clear correlations with the 'BIM-based FAB construction project experience' were 'Object and BIM library classification system', 'Attribute value definition', 'Major functions of BIM software', 'LOD definition', and 'BIM data quality evaluation'. There appeared a correlation mainly with specific competencies belonging to the 'BIM-related knowledge' competency group. In the case of 'BIM-based FAB construction project experience' career characteristic, it can be interpreted that the competency has been acquired through training and education, considering the short career span of 0.5 to 5 years and that the BIM-related education has recently been provided.

Specific competency that showed a clear correlation with the 'BIM-based construction project experience' was 'BIM data quality evaluation', whereas the 'principles of CR' competency showed a negative correlation with the same career characteristics. This can

be interpreted that the said competency typical to the FAB project (i.e., understanding of CR principles) diminishes as one engages more on general construction projects instead of FAB projects.

Table 7. Anal	vsis of correlation betwee	n 'Knowledge	' domain com	petencies and	career ch	aracteristics of	the owner s	group.
							(, ,

		Total	Construction Project Experience	BIM-Based Construction Project Experience	FAB Construction Project Experience	BIM-Based FAB Construction Project Experience
K11. Major function of BIM	Pearson's r	0.202	0.090	0.459	-0.372	0.577 *
software	<i>p</i> -value	0.420	0.722	0.055	0.129	0.012
K12. Object and BIM Library	Pearson's r	0.184	0.076	0.420	-0.382	0.679 **
classification system	<i>p</i> -value	0.464	0.766	0.082	0.117	0.002
K13 LOD definition	Pearson's r	0.314	0.022	0.345	-0.003	0.517 *
KIS. LOD demitton	<i>p</i> -value	0.204	0.931	0.161	0.991	0.028
K14. Attribute value	Pearson's r	0.048	-0.114	0.346	-0.266	0.591 **
definition	<i>p</i> -value	0.849	0.651	0.159	0.286	0.010
K21 Principles of CR	Pearson's r	0.184	0.193	-0.496 *	0.414	0.129
R21. 1 miciples of CR	<i>p</i> -value	0.466	0.444	0.037	0.088	0.610
K22 Litility characteristics	Pearson's r	-0.149	-0.276	-0.153	0.116	0.383
R22. Ounty characteristics	<i>p</i> -value	0.555	0.267	0.543	0.648	0.117
K23. Process and Instrument	Pearson's r	0.246	0.078	0.030	0.181	0.228
Diagram	<i>p</i> -value	0.325	0.760	0.907	0.471	0.363
K31 Schedule management	Pearson's r	0.743 **	0.424	0.363	0.273	0.114
Kon benedule management	<i>p</i> -value	0.000	0.080	0.139	0.273	0.652
K32 Supply management	Pearson's r	0.706 **	0.428	0.385	0.174	0.174
K32. Supply management	<i>p</i> -value	0.001	0.077	0.115	0.489	0.489
K33 Cost management	Pearson's r	0.686 **	0.441	0.376	0.176	0.048
Root. Cost management	<i>p</i> -value	0.002	0.067	0.124	0.484	0.849
V41 CD contribution aritoria	Pearson's r	0.529 *	0.249	-0.136	0.527 *	0.265
K41. CK certification criteria	<i>p</i> -value	0.024	0.319	0.592	0.025	0.288
K42. Construction licensing	Pearson's r	0.668 **	0.398	0.264	0.254	0.174
standard	<i>p</i> -value	0.002	0.102	0.290	0.310	0.489
K42. BIM data quality	Pearson's r	0.328	0.127	0.609 **	-0.322	0.492 *
evaluation	<i>p</i> -value	0.184	0.617	0.007	0.192	0.038

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

6.1.2. Analysis of the Designer Group

Table 8 shows the correlation between the career characteristics and the 'Knowledge' domain-specific competencies of the designer group. Among the career characteristics, 'Overall project experiences', and 'BIM-based construction project experience' were found to have correlations with most specific competency items within the 'Knowledge' domain. Correlation is significant at the 0.01 level (2-tailed).

		Total	Construction Project Experience	BIM-Based Construction Project Experience	FAB Construction Project Experience	BIM-Based FAB Construction Project Experience
K11. Major function of BIM	Pearson's r	0.001	-0.170	0.449 **	-0.205	0.283 *
software	<i>p</i> -value	0.993	0.209	0.001	0.129	0.035
K12. Object and BIM	Pearson's r	0.066	-0.063	0.394 **	-0.247	0.400 **
Library classification system	<i>p</i> -value	0.628	0.643	0.003	0.066	0.002
K12 LOD definition	Pearson's r	0.314 *	0.066	0.410 **	-0.039	0.370 **
K15. LOD definition –	<i>p</i> -value	0.018	0.631	0.002	0.777	0.005
K14. Attribute value	Pearson's r	0.184	-0.063	0.386 **	-0.068	0.392 **
definition	<i>p</i> -value	0.173	0.647	0.003	0.619	0.003
K21 Principles of CR	Pearson's r	0.183	-0.198	0.091	0.354 **	0.219
K21. Principles of CK -	<i>p</i> -value	0.176	0.143	0.505	0.007	0.105
K22 Utility characteristics	Pearson's r	0.051	-0.091	-0.083	0.102	0.329 *
K22. Utility characteristics	<i>p</i> -value	0.709	0.506	0.543	0.453	0.013
K23. Process and	Pearson's r	0.147	0.113	-0.093	0.080	0.145
Instrument Diagram	<i>p</i> -value	0.279	0.406	0.493	0.556	0.286
K31 Schedule management	Pearson's r	0.344 **	0.057	0.262	0.191	0.173
Kon Schedule management -	<i>p</i> -value	0.009	0.678	0.051	0.159	0.203
K32 Supply management	Pearson's r	0.500 **	0.170	0.266 *	0.231	0.295 *
102. Supply management –	<i>p</i> -value	0.000	0.211	0.048	0.087	0.027
K33 Cost management	Pearson's r	0.533 **	0.162	0.275 *	0.263	0.342 **
	<i>p</i> -value	0.000	0.233	0.040	0.050	0.010
KA1 CP contification criteria	Pearson's r	0.280 *	-0.119	0.170	0.428 **	0.025
K41. CK tertification chiefia –	<i>p</i> -value	0.036	0.382	0.211	0.001	0.856
K42. Construction licensing	Pearson's r	0.350 **	059	0.299 *	0.376 **	0.021
standard	<i>p</i> -value	0.008	0.664	0.025	0.004	0.876
K42. BIM data quality	Pearson's r	0.281 *	-0.001	0.560 **	-0.112	0.385 **
evaluation	<i>p</i> -value	0.036	0.996	0.000	0.412	0.003

Table 8. Analysis of correlation between 'Knowledge' domain competencies and career characteristics of the designer group.

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

As was the case of the owner group, a clear correlation was found within the designer group between the 'Overall project experiences' career characteristic and certain competencies, such as 'Supply management' and 'Cost management', pertaining to the 'Construction related knowledge' competency group. In addition, significant correlations were found between the same career characteristic ('Overall project experiences') and certain specific competencies, such as 'Construction licensing standard', 'Schedule management', and 'LOD definition'.

The specific competency item that showed a clear correlation with the 'BIM-based construction project experience' career characteristic proved to be 'BIM data quality evaluation'. In addition, 'Major functions of BIM software', 'LOD definition', 'Object and BIM library classification system', and 'Attribute value definition' competencies showed significant correlations with the said career characteristic.

Specific competency items that showed significant correlations with the 'FAB-based construction project experience' career characteristic were 'CR certification criteria', 'Construction licensing standard', and 'Principles of CR'. In particular, a correlation was found between the 'FAB-based construction project experience' career characteristic and specific competency items related to the cleanroom, which is a characteristic space of FAB.

The specific competency showing the strongest correlation with the 'BIM-based FAB construction project experience' was 'Object and BIM library classification system'. In addition, there were significant correlations between the 'BIM-based FAB construction project experience' and 'Attribute value definition', 'LOD definition', 'BIM data quality evaluation', 'Cost management', and 'Utility characteristics' competencies. Similar to the owner group, it can be interpreted that the designer group acquired specific competencies through BIM education, considering that correlations were found among specific competency items within 'BIM-related knowledge' competency group.

6.2. Analysis of Correlation between Career Characteristics and Competency Level in 'Skills' Domain

6.2.1. Analysis of the Owner Group

Table 9 shows the correlation between the career characteristics and the 'Skills' domainspecific competencies of the owner group. Among the five career characteristics, mainly the 'BIM-based construction project experience' and the 'BIM-based FAB construction project experience' were found to have significant correlations with most specific competency items.

Table 9. Analysis of correlation between 'Skills' domain competencies and career characteristics of the owner group.

		Total	Construction Project Experience	BIM-Based Construction Project Experience	FAB Construction Project Experience	BIM-Based FAB Construction Project Experience
S11 BIM modeling	Pearson's r	-0.086	0.024	-0.043	-0.101	-0.077
511. Divi modeling	<i>p</i> -value	0.733	0.924	0.866	0.691	0.763
S12 BIM library	Pearson's r	0.295	0.192	0.429	-0.330	0.575 *
512. Dhvi norary	<i>p</i> -value	0.235	0.445	0.076	0.181	0.013
S13 Attribute value input	Pearson's r	0.326	0.175	0.463	-0.275	0.528 *
515. Attribute value input	<i>p</i> -value	0.187	0.487	0.053	0.269	0.024
S21_4D scheduling	Pearson's r	0.276	0.069	0.582 *	-0.247	0.301
521. 4D scheduling	<i>p</i> -value	0.268	0.785	0.011	0.323	0.224
S22 5D quantity takeoff	Pearson's r	0.325	0.102	0.648 **	-0.291	0.373
522. 5D quantity takeon	<i>p</i> -value	0.189	0.687	0.004	0.242	0.127
S23. Cost planning and	Pearson's r	0.311	0.120	0.584 *	-0.248	0.275
review	<i>p</i> -value	0.209	0.637	0.011	0.321	0.269
621 Decian review	Pearson's r	0.441	0.203	0.530 *	-0.098	0.250
551. Design review	<i>p</i> -value	0.067	0.420	0.024	0.698	0.317
S32. Equipment lay-out	Pearson's r	0.200	0.024	0.477 *	-0.239	0.361
review	<i>p</i> -value	0.427	0.925	0.045	0.339	0.141
C22 LIT matrix noview	Pearson's r	0.373	0.377	0.239	-0.259	0.511 *
555. UT matrix review	<i>p</i> -value	0.127	0.123	0.340	0.299	0.030
624 CD simflexy merricry	Pearson's r	0.354	0.322	0.242	-0.176	0.367
534. CK airnow review	<i>p</i> -value	0.149	0.193	0.332	0.484	0.134
\$25 Clash datastics	Pearson's r	0.367	0.154	0.445	-0.175	0.540 *
555. Clash delection	<i>p</i> -value	0.134	0.541	0.065	0.487	0.021
C26 Interference re	Pearson's r	0.386	0.194	0.455	-0.207	0.549 *
556. Interference review	<i>p</i> -value	0.114	0.440	0.058	0.409	0.018

		Total	Construction Project Experience	BIM-Based Construction Project Experience	FAB Construction Project Experience	BIM-Based FAB Construction Project Experience
S41. Construction	Pearson's r	0.369	0.248	0.474 *	-0.328	0.588 *
drawings	<i>p</i> -value	0.132	0.322	0.047	0.184	0.010
S42. AFC drawing	Pearson's r	0.349	0.275	0.391	-0.314	0.565 *
extraction	<i>p</i> -value	0.156	0.269	0.109	0.204	0.015
S43. Bill of material and	Pearson's r	0.378	0.234	0.461	-0.277	0.564 *
quantity	<i>p</i> -value	0.122	0.351	0.054	0.265	0.015
S44 Export the report	Pearson's r	0317	0.261	0.380	-0.345	0.588 *
544. Export the report	<i>p</i> -value	0.201	0.296	0.120	0.161	0.010
S51 Update BIM data	Pearson's r	0.287	0.183	0.507 *	-0.368	0.486 *
551. Optitie Dividual	<i>p</i> -value	0.249	0.468	0.032	0.134	0.041
S52. Interoperability of	Pearson's r	0.298	0.176	0.566 *	-0.387	0.477 *
BIM data	<i>p</i> -value	0.230	0.484	0.014	0.112	0.045
S53 Security of BIM data	Pearson's r	0.272	0.152	0.549 *	-0.402	0.532 *
555. Security of Divi data	<i>p</i> -value	0.276	0.547	0.018	0.098	0.023

Table 9. Cont.

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Specific competencies that showed the most significant correlation with the 'BIM-based construction project experience' were 'Cost planning and review', '4D scheduling', and 'Interoperability of BIM data'. In addition, there was a clear correlation between the career characteristic of 'BIM-based construction project experience' and '5D quantity takeoff' within the 'BIM-based project management' competency group. Additionally, 'Security of BIM data' and 'Update BIM data', which were the specific competencies belonging to the 'BIM-based data sharing' competency group, showed a clear correlation.

Specific competencies that showed very clear correlations with the 'BIM-based FAB construction project experience' were 'Construction licensing documents and drawings', 'Export the report', and 'BIM library'. Other specific competencies found to have clear correlations with the 'BIM-based FAB construction project experience' were 'Attribute value input' within the 'Generate BIM data' competency group, 'UT matrix review', 'Clash detection', and 'Interference review', which were included in the 'BIM-based analysis and review' competency group and 'AFC drawings extraction', which was the specific competency of the 'BIM-based reports and documents extraction' competency group. The abundance of BIM-based construction project experience can be interpreted as the designer group had more outside personnel recruited for their prior BIM knowledge who possessed more competency items having a correlation with 'Skills' domain than 'Knowledge' domain.

6.2.2. Analysis of the Designer Group

Table 10 presents the correlation between the career characteristics and the 'Skills' domain-specific competencies of the designer group. Similar to the results found from the owner group, most correlations were found between specific competencies within the 'Skills' domain and career characteristics of 'BIM-based construction project experience', and 'BIM-based FAB construction project experience'.

S52. Interoperability of BIM data

S53. Security of BIM data

p-value

Pearson's r

p-value

0.793

0.115

0.397

		Total	Construction Project Experience	BIM-Based Construction Project Experience	FAB Construction Project Experience	BIM-Based FAB Construction Project Experience
	Pearson's r	-0.090	-0.157	0.245	-0.173	0.173
SII. BIM modeling	<i>p</i> -value	0.509	0.248	0.069	0.201	0.201
C10 DD (11	Pearson's r	-0.039	-0.188	0.303 *	-0.115	0.210
S12. BIM library	<i>p</i> -value	0.773	0.165	0.023	0.397	0.120
	Pearson's r	-0.039	-0.220	0.487 **	-0.253	0.349 **
S13. Attribute value input	<i>p</i> -value	0.774	0.103	0.000	0.060	0.008
621 4D ashadulina	Pearson's r	0.154	-0.185	0.513 **	0.000	0.271 *
521. 4D scheduling	<i>p</i> -value	0.257	0.173	0.000	0.998	0.043
622 5D quantity takaoff	Pearson's r	0.220	0.078	0.497 **	-0.190	0.231
522. 5D quantity takeon	<i>p</i> -value	0.104	0.569	0.000	0.161	0.087
\$23 Cost planning and review	Pearson's r	0.280 *	0.083	0.535 **	-0.115	0.183
525. Cost planning and review	<i>p</i> -value	0.037	0.543	0.000	0.398	0.178
S31 Design review	Pearson's r	0.068	-0.218	0.502 **	-0.097	0.317 *
	<i>p</i> -value	0.621	0.106	0.000	0.477	0.017
S32. Equipment lay-out review	Pearson's r	-0.040	-0.157	0.404 **	-0.277 *	0.352 **
	<i>p</i> -value	0.772	0.249	0.002	0.039	0.008
	Pearson's r	-0.086	-0.068	0.341 *	-0.307 *	0.102
555. OT matrix review	<i>p</i> -value	0.529	0.620	0.010	0.021	0.456
S24 CD similary marries	Pearson's r	-0.063	-0.173	0.315 *	-0.142	0.127
554. CK airiiow review	<i>p</i> -value	0.644	0.202	0.018	0.297	0.350
625 Clash datastion	Pearson's r	0.142	-0.062	0.388 **	-0.087	0.283 *
555. Clash delection	<i>p</i> -value	0.297	0.650	0.003	0.522	0.035
626 Interference review	Pearson's r	0.121	0.005	0.464 **	-0.224	0.226
556. Interference review	<i>p</i> -value	0.375	0.973	0.000	0.097	0.093
S41. Construction licensing docs	Pearson's r	0.177	-0.022	0.388 *	-0.087	0.283 *
and drawings	<i>p</i> -value	0.219	0.878	0.000	0.208	0.073
S42 AEC drawing extraction	Pearson's r	-0.020	-0.082	0.291 *	-0.259	0.347 *
542. ATC drawing extraction	<i>p</i> -value	0.892	0.569	0.040	0.069	0.014
S43 Bill of material and quantity	Pearson's r	-0.059	-0.142	0.384 **	-0.310 *	0.362 **
515. Bill of material and qualitity	<i>p</i> -value	0.683	0.325	0.006	0.028	0.010
S44 Export the report	Pearson's r	-0.115	-0.167	0.318 *	-0.287 *	0.282 *
JH. Export the report	<i>p</i> -value	0.428	0.247	0.024	0.046	0.047
S51 Undate BIM data	Pearson's r	-0.099	-0.210	0.431 **	-0.287 *	0.277 *
oon opune biin una	<i>p</i> -value	0.469	0.121	0.001	0.032	0.039
	Pearson's r	0.036	-0.119	0.444 **	-0.224	0.318 *

Table 10. Analysis of correlation between 'Skills' domain competencies and career characteristics of the designer group.

0.187**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

0.382

-0.179

To begin with, the specific competencies, which showed the clearest correlation with the 'BIM-based construction project experience' were 'Construction licensing documents and drawings' and 'Cost planning and review'. It was analyzed that the said career characteristic ('BIM-based construction project experience') was generally correlated to specific competencies pertaining to 'BIM-based project management', 'BIM-based analysis and

0.001

0.528 **

0.000

0.097

-0.128

0.346

0.017

0.407 *

0.002

review', and 'BIM-based data sharing' competency groups. Specifically, the correlation was found between the career characteristic of 'BIM-based construction project experience' and three specific competencies within the 'BIM-based project management' competency group, '4D scheduling', '5D quantity takeoff', and 'Cost planning and review'. With the same career characteristic, the strongest correlation found among the specific competencies within the 'BIM-based analysis and review' competency group was 'Design review', whereas significant correlations were observed between the career characteristic and certain specific competencies, such as 'Interference review' and 'Equipment layout review' competencies. Finally, 'Security of BIM data' among the specific competencies of the 'BIM-based data sharing' competency group showed a clear correlation, while 'Update BIM data' and 'Interoperability of BIM data' showed significant correlations.

A specific competency, which showed the strongest correlation with the 'BIM-based FAB construction project experience' was 'Security of BIM data'. In addition, significant correlations were found between the same career characteristic of 'BIM-based FAB construction project experience' and 'AFC drawings extraction' and 'Export the report', which were the specific competencies of 'BIM-based reports and documents extraction' competency group, 'Interoperability of BIM data', and 'Security of BIM data', which were the specific competencies of 'BIM-based data sharing' competency group.

7. Discussion

In order to implement and apply BIM to its full capacity, FAB construction projects started to educate BIM to existing FAB construction participants while recruiting people who had prior work experience in BIM-based construction projects. This resulted in the workforce with diverse career characteristics working together in FAB construction projects. With the purpose of providing base data for developing a customized BIM educational program, this study has analyzed the current level of competency status among FAB participants with different career backgrounds. In addition, a correlation analysis between their career characteristics and specific BIM competencies was conducted. For this, a survey was administered to the participants of three FAB construction projects where BIM was currently being implemented. The respondents of the survey were categorized into the owner group and the designer group.

Using SPSS Statistics[®] of IBM[®], correlations between the career characteristics and competencies within the 'Knowledge' and the 'Skills' domains were analyzed. As a result, significant correlations were found between the 'BIM-based FAB construction project experience' (one of the career characteristics) and specific competencies within the 'BIM-related knowledge' (one of the nine competency groups) from both owner and designer groups. In the case of 'BIM-based FAB construction project experience' career characteristic, considering the participants' short career span of 0.5 to 5 years, it can be interpreted that they mostly acquired relevant competencies through BIM training and education rather than prior practical experience.

For the owner group, strong correlations were found between the career characteristic of 'BIM-based FAB construction project experience' and 11 out of the total 19 specific competencies within the 'Skills' domain. On the other hand, correlations were found between the 'BIM-based construction project experience' and 17 specific competencies within the 'Skills' domain for the designer group. The strong correlations found in the owner group between the 'BIM-based FAB construction project experience' and large numbers of specific competencies can be attributed to the fact that a high ratio of existing participants engaged in FAB construction projects are recently being provided with BIMrelated training and education. However, compared to the owner group, the designer group had more outside personnel recruited for their prior BIM knowledge, which resulted in numbers of specific competencies significantly correlating with the career characteristic of 'BIM-based construction project experience'.

8. Conclusions

From this study, it can be inferred that the owner group should consider hiring more personnel having sufficient BIM-based FAB construction project experiences for their future FAB construction project, whereas it will be more effective for the designer group to supplement design staff having abundant BIM-based construction project experiences. Moreover, the design group should provide education and training on competency items that reflect the characteristics of FAB construction projects. Finally, it will be beneficial for both owner and designer groups to scrutinize competency items found to have low or negative correlations from this study and to find ways to strengthen those competency items for their personnel.

This study differs from the other existing studies on BIM competency in that it presented BIM competencies reflecting the characteristics of FAB based on the analysis of typical tasks related to FAB construction projects. Moreover, this study identified through the survey analysis that the current level of competency possessed by the participants varied depending on the work experiences accumulated and competencies required by the projects they were engaged in. It is expected that the findings of this study can be used as a reference for evaluating the work performance capability of FAB construction project participants while also being utilized for identifying specific competencies preferentially needed to be improved depending on the areas of major work experience. Finally, the presented results can be used as a base for developing customized BIM educational programs, thus as to enhance the competency level of future project participants in FAB construction.

Apart from considering the relative importance of BIM-FAB competency items suggested by the study in relation to the project experience, this study left the correlation analysis of competencies possessed by personnel with a different project role (e.g., BIM manager, BIM technician, BIM coordinator, BIM modeler, etc.) versus project characteristics and experiences as a future study. Moreover, the future study will consider refining competency items based on more concretized characteristics of FAB and BIM. Considering the limitations of this study, future work will provide a more in-depth analysis based on finding correlations between the expected goals of FAB projects implementing BIM and refined competency items as well as different competency groups. In addition, the future study will explore the benefits of integrating BIM and GIS in terms of creating a collaborative environment for complex projects, such as FAB construction.

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