


Article

Sustainable BIM-Based Construction Engineering Education Curriculum for Practice-Oriented Training

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Abstract: The latest IT technology integration movements, such as building information modeling (BIM), have engendered changes in the technology and participatory organizations in the construction industry, which have resulted in process innovations and productivity gains. BIM lays the foundation for using a variety of new information that is not applicable to traditional construction methods. Construction companies are applying such information to various analyses, simulations, and learning and education projects to stimulate innovation. In Korea, however, since BIM was introduced in 2008, it has been used in various ways across diverse fields, but its contribution remains minimal. This is due to the inadequate competence level of BIM managers, who emerge from a system incapable of adequately educating BIM managers. In other words, the curriculum has not been able to impart the BIM skills necessary to accommodate the requirements of the industry. Only the most basic BIM modeling course is offered, and even such a course is dependent on external instructors. This creates a gap with the existing construction engineering educational curriculum. This study proposes a BIM-based construction engineering educational curriculum that has not been attempted before to overcome these limitations and generate a BIM workforce to cater to the industry.

Keywords: BIM-based construction engineering education curriculum; Tyler model; systematic course development approach

1. Introductions

In the construction industry, a number of organizations collaborate and carry out projects, right from the initial structure to the final product. During this process, a variety of factors, such as the environment, organization, technology, and resources, often contribute to reducing the efficiency of collaboration and communication [1,2]. The reasons for the deteriorating efficiency of construction projects are because of limitations arising from 2D (Dimension)-based drawings, paper drawings, and collaborative methods based on unstructured information [3–6].

Building information modeling (BIM) began in the 1990s as an object-oriented building product model (OBPM) that could define and represent the shape, function, and properties of building systems and component models. It was initiated to supplement the limitations of computer-aided drafting (CAD) [7,8]. Countries that had been carrying out construction projects by conventional methods, such as 2D CAD, paper documents, and Excel sheets, quickly implemented BIM to automate their processes. In particular, in the case of Korea, BIM has become a technique that is very commonly applied in construction, rather than it being applied for a few representative projects only [7–10].

The reason for BIM being extensively implemented is that it not only offers basic functions, such as conflict, interface, and collision detection, but also can be utilized for a variety of other purposes, including visualization, fabrication or shop drawings, code reviews, energy simulations, design validation, option analysis (value engineering), forensic analysis, facilities management, cost estimation, construction sequencing, and constructability reviews [7,9–19]. In addition, BIM introduces more values and improves collaboration within the construction supply chain. These advantages are also closely linked to the concepts of lean construction, green principles, and integrated project delivery [7,20–22].

Despite its advantages, the construction industry in Korea is facing difficulties pertaining to maximizing the utilization of BIM. The biggest hurdle is finding an experienced and skilled workforce [16,23–26].

In particular, it is difficult to transform the construction industry from its conventional work-intensive and labor-oriented culture to an IT-based knowledge industry. This is because there is only a small percentage of the workforce equipped with the ability to implement BIM and reap its benefits [27,28]. There have been many research studies that have applied the BIM and ICT (Information and Communications Technologies) technologies in the construction industry [29–31]. However, various causes, such as the culture, workforce, and system of the organization, act as a serious impediment to BIM application [32–35]. In particular, construction companies are reluctant to adopt a wide range of high-tech digital technologies due to their complexity, high risk, and conservatism. However, major IT vendors, BIM companies, and some universities are confident that education can accelerate the introduction of high-tech technologies, such as BIM [26,35].

In this regard, construction engineering educational programs, established in order to cultivate BIM talents that can change the future of the construction industry and companies, as well as BIM technology, should play a key role. The program should not be limited to basic techniques and theoretical education [10]. In order to apply new smart technologies such as BIM to education, such education models as project-based learning, constructivist pedagogy, efficient learning, and Bloom's taxonomy must be utilized, which can enhance the educational performance of students. In particular, by offering nD education in areas such as scheduling (4D), cost (5D), and energy (6D), students' extensive understanding of BIM and problem-solving skills can be improved [36]. In addition, education that considers convergence with construction engineering theories, expansion of creativity, and learning ability rather than simple software utilization or technical training is effective in teaching the ability to carry out real projects and collaboration capabilities [37]. There are five BIM educational models used to accelerate these achievements: action learning (AL), constructivist learning (CL), selective learning (RL), autonomous learning (AuL), and cooperative learning (CL). These BIM training models are intended for project-based learning, student ownership of learning, collaborative learning, and so on [38].

The curriculum of public and private educational institutions in Korea can be divided into two types according to direction and objectives: a curriculum that combines construction theory and BIM basic skills, and another curriculum that focuses on BIM skills and education while ignoring construction theory [7]. At present, the curriculum of construction-related departments in higher educational institutions such as universities in Korea contains BIM in almost all institutions. Nevertheless, BIM is either regarded as just one of many subjects or the extent of the curriculum is limited to BIM modeling as part of the capstone project. In most cases, the number of subjects a student takes in relation to BIM for the entire undergraduate period is only one or two. Hence, the extent of exposure is often limited to learning basic modeling skills. This is because many professors do not possess the capabilities required to teach BIM or even impart the skills necessary for basic modeling. In order to fill this gap, higher educational institutions rely on external instructors or affiliated professors who are BIM experts in the industry. However, the number of subjects or courses is still limited and is a far cry from driving integration in order to accommodate the needs of the industry. Therefore, in this educational environment in which only a few subjects related to BIM are added to the curriculum of existing

construction-related departments, it is not surprising that the students who take these courses are not able to grasp the BIM-related needs of the industry and implement BIM for real problems. Table 1 shows the BIM course examples of major institute of South Korea. Due to the limitations of having to teach many things within a short period of education, most curricula have a structure in which they cannot give deep and balanced lectures on BIM theory and practice.

Table 1. Building information modeling (BIM) curriculum cases in South Korea.

Institute	Curriculum	Course Description
University A	BIM-based construction information management	<ul style="list-style-type: none"> Comprehensive understanding about BIM concepts. BIM tool operation (authoring, analyzing, and managing). BIM application in real field is insufficiently considered and the curriculum is too short to learn the practical capabilities.
University B	BIM and IPD (Integrated Project Delivery)	<ul style="list-style-type: none"> Object-oriented modeling methodology based on IPD case projects. Lecture about IPD and project practice based on that. Field experience encouraging trainees to acquire practical knowledge to apply BIM in the field. Tools students handle are limited and cannot teach problem-solving strategies.
University C	Construction technologies	<ul style="list-style-type: none"> Lecture-centered education on BIM trends, utilization, and cases, BIM practice is conducted for only three of 16 weeks. 4D and 5D information management. Differentiated lectures on BIM-fused technological cases reflecting latest trends.
Institute A	BIM expert training course	<ul style="list-style-type: none"> Long-term BIM course for project information management. Industry experts join the course to help trainees acquire basic work skills in practical classes. There are few lectures on BIM theories and principles.
Institute B	BIM expert Training course	<ul style="list-style-type: none"> Systematic training coping with needs of the industry, such as BIM-based drawing, estimation, schedule management, coordination, and quality management for each stage, as well as IT implementation. BIM managers who are familiar with collaboration participate in class.
Institute C	Beginner course	<ul style="list-style-type: none"> Architectural design process using BIM authoring software. Case-based BIM modelling using site, building, and other objects.
	Manager course	<ul style="list-style-type: none"> Parametric concept for building and BIM data of the design phase. Documentation (2D drawings and quantity take-off). Engineering analysis based on BIM simulation software. Clash detection, 4D simulation, and constructability review.
	Expert course	<ul style="list-style-type: none"> Intended for testing the competency of entry-level workers in architectural engineering. BIM model review, collaboration, and documentation.

In order to properly address these problems, a completely novel educational curriculum should be designed and developed. This curriculum should integrate IT modelling software such as BIM with conventional construction-related subjects, and the students should also be selected in accordance with the new change. It would be ideal if companies could participate in the new curriculum so that the students could be transformed into a project-based, learning-type (PBL) workforce who would be able to perform the practical jobs required in the industry upon graduation [7,10,39].

This study aims to develop a BIM-based construction engineering curriculum for practice-oriented training, in which the various academic and industrial needs are accommodated, enabling students to become leaders of the new age of the construction industry. For the development of the curriculum, the systematic course development methodology is applied to present educational

objectives, composition of educational topics, composition of educational contents, and evaluation criteria. Furthermore, the developed construction IT curriculum is instituted in a Korean university and the detailed analysis results are presented in this paper.

2. Methodology

Unlike previous research studies that have added subjects related to BIM to an existing construction engineering educational program, this study aims to develop the entire curriculum of a department from scratch, including goals and objectives of the education, learning topics, composition of learning subjects, and transformation of evaluation methods. Two major curriculum models can be used to develop a curriculum that meets these objectives: (1) the product model and (2) process model [40]. The product model is a model that emphasizes plans and intentions, and the process model is a model that focuses on the effects of activities and education [41]. The product model and process model have opposite characteristics in terms of educational purpose, intent, and tools, as follows:

1. Product model: behavioral objectives model, interested in products of curriculum (e.g., Tyler and Bloom model)
2. Process model: focus on teacher activities and roles, student activities, emphasis on means rather than ends (e.g., Stenhouse)

Unlike the process model, which relies on an experiential approach, the Tyler model is a representative example of the product model that is widely used in the development of science and technology curricula [40]. Since the objective of proposing a curriculum in this study is to create a new construction engineering educational program incorporating IT (Information Technology), the Tyler model is applied in this study. The study follows the 3 steps of the Tyler model: (1) curriculum preparation, (2) curriculum development, and (3) curriculum improvement [42,43]. In addition, it is verified that the developed curriculum is pedagogically and technically appropriate by implementing the curriculum in a newly established university in Korea. Figure 1 illustrates the methodology showing the objectives and procedures of this study.

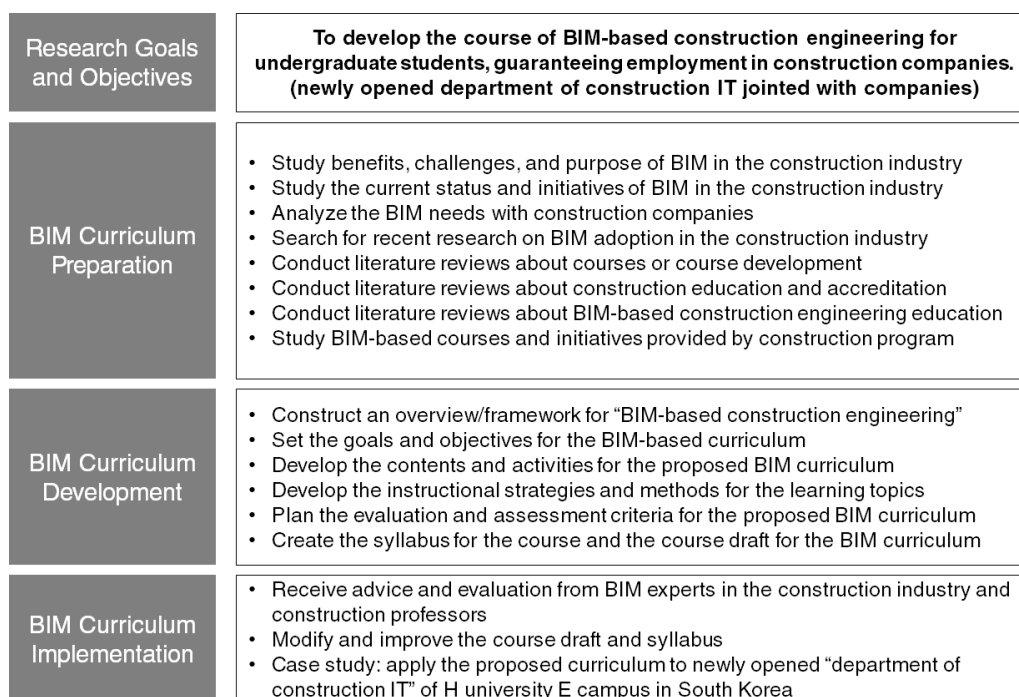


Figure 1. Research procedures.

3. Systematic Development of the BIM-Based Construction Engineering Education Curriculum to Develop Problem-Solving Talent

3.1. Preparation Stage of BIM Curriculum Development

Instead of adding a few BIM-related subjects to the existing curriculum of construction engineering departments in universities, a construction–IT convergence course for training BIM and construction IT talent is proposed. However, it must have a completely different curriculum for each semester. The new curriculum enables students to acquire a comprehensive understanding of construction engineering knowledge and theories, as well as a variety of BIM and construction IT methodologies. Accordingly, the curriculum should be developed through a systematic procedure to impart training of BIM principles, knowledge, and skills necessary for the construction industry. In the preparation stage, which is the first stage of curriculum development, the following aspects should be considered:

1. Goals, advantages, and obstacles in BIM implementation for the architecture, engineering, and construction (AEC) industry
2. Purpose of BIM education for the construction industry
3. Status, limitation, and problems of BIM education in existing construction programs
4. Difference of importance of BIM skills and knowledge between original construction tasks and BIM-based new tasks, as well as importance of new BIM-based construction engineering curriculum
5. The relationship between BIM and construction engineering tasks in companies
6. Areas of BIM implementation in the construction industry and in companies, as well as BIM knowledge and skills required for new employees
7. Other fields that converge with BIM, such as smart construction technologies
8. Importance of knowledge and theories of BIM-based construction engineering and management
9. Priority of BIM education in companies

According to the current status of BIM education in Korea, public and private institutions as well as universities are biased towards imparting theory-based BIM education. Especially in the case of universities, the curriculum only contains one or two BIM classes [7]. This is due to a variety of reasons, namely the closed culture of existing university education, the limitations of BIM knowledge and application among construction engineering professors, and the difficulty of introducing external instructors who have combined capabilities of theory and knowledge. In particular, when a typical full-time faculty conducts BIM classes, lectures only cover related theories or general content, resulting in inadequate information necessary for practical application on site. On the contrary, if an external lecturer presides over the lecture, they will primarily focus on BIM modeling or data management. Hence, the lectures will give more focus only to practical BIM skills and software. This shows that both cases are extremely unbalanced [10].

According to the results of a survey conducted in major construction companies in Korea, the companies have higher levels of expectations from BIM engineers from universities [7,10]. Seven of the top eight companies have a BIM team. BIM applications, such as design (drawing) quality management, 3D visualization-based communication, scheduling and sequence planning, constructability reviews, and interference management, are carried out by all eight companies, and six companies or more carry out site logistics and construction system design. As for the knowledge and skills expected of university graduates, the companies require a basic conceptual understanding of the importance of BIM implementation in the construction engineering, areas of BIM implementation in the construction process, and BIM-based quantity take-off and cost estimation. As for software requirements, it is imperative that the graduate should be familiar with a BIM checker and simulation tool, such as Navisworks or Revit. The construction companies listed spatial trade coordination, communication, design quality management, constructability review, 4D simulation, and shop drawing

as high priority applications of BIM and insisted that these aspects should be included in university education [10].

In summary, the current status of BIM shows that the existing BIM curriculum in university education does not meet the basic level of requirements. On a positive note, it is possible to develop a practical curriculum for cultivating human resources that meet the needs of the industry and academia. This curriculum should include: (1) general concepts and knowledge of BIM technology; (2) areas of implementation in the various construction processes (including visualization, communication, clash detection, and constructability review); (3) BIM-based construction engineering and management skills; (4) BIM project execution planning and BIM standards; (5) software compatibility; (6) expandability to other construction IT technologies.

3.2. Development Stage of BIM Curriculum Development: Overview

The curriculum development consists of five steps: (1) develop a basic framework that describes the curriculum's name, target, introduction, and characteristics; (2) set curriculum goals, objectives, and educational methods through various literature reviews on BIM implementation; (3) set learning topics and course schedules according to the goals and objectives using a systematic approach; (4) develop individual lectures and curricula for each learning topic and set lecture methods for each class; and (5) implement the developed curriculum and analysis of the implementation results. The curriculum framework involves setting the goals and objectives of the curriculum. In addition, the purpose of this study is to develop the entire curriculum by synchronizing optimal teaching methods with the duration for each learning topic.

The name of the BIM curriculum is "BIM converged construction engineering curriculum", and the target of this curriculum are the students in the department of professional BIM training. These students are guaranteed jobs upon admission to the department through a contract established with a construction company.

One of the characteristics of the curriculum is that there is an agreement with a construction company for hiring upon graduation. Additionally, it is an industry-academia collaborative curriculum jointly operated by the university and the company. Unlike the conventional construction engineering departments in South Korea, this is the first curriculum in which BIM and conventional construction engineering subjects are integrated to cultivate a BIM workforce. Both the knowledge and the skills necessary for BIM are taught in depth from the first year until graduation, and the PBL-type classes for various problems in connection with a company will be held to train the workforce. Furthermore, to develop a curriculum that can produce BIM professionals tailored to the construction industry, this should reflect the needs of the company in terms of individual lectures coupled with a variety of methods, such as PBL and industry-linked methods, and practice lectures, so that the new curriculum can be clearly differentiated from the existing BIM curricula.

Based on these characteristics, the basic framework of the curriculum is presented, as shown in Figure 2. Students participating in the curriculum achieve a balanced understanding of basic BIM and construction IT knowledge and skills, as well as construction engineering and construction management theory and knowledge. In addition, emphasis has been put on the joint activities proposed by the companies to enhance the labor skillset in the construction industry. Through the balanced distribution of these 3 types of classes, theoretical knowledge and practical task capabilities can both be developed and enhanced. In order to facilitate early hiring of students, the structure of the curriculum is designed so that full-time education can be conducted for the 1st year students, and hiring and part-time education can be conducted for the 2nd and 3rd year students.

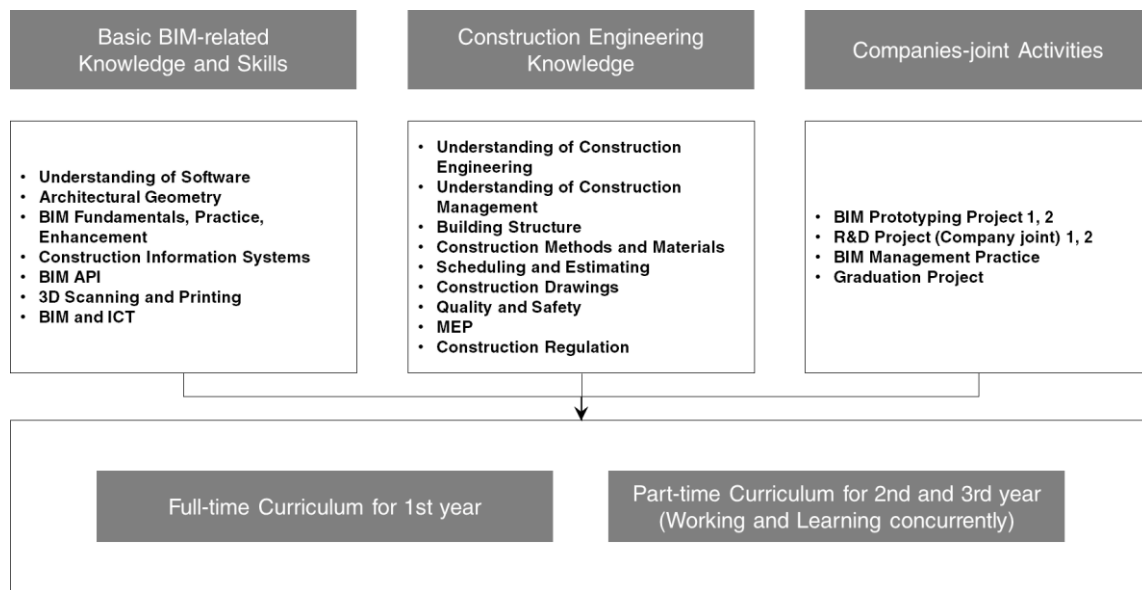


Figure 2. Framework of the BIM-based construction engineering curriculum. API = application programming interface; ICT = information and communications technologies; MEP = mechanical, electrical, and plumbing; R&D = research and development.

3.3. Development Stage of BIM Curriculum Development: Setting the Learning Goals

Learning goals should make students industry-ready and employable. Setting learning goals is an important step in the systematic curriculum development process because goals provide milestones for the students, as well as invariably represent the knowledge, skills, and behavioral standards set by the curriculum [44]. The first step in setting learning goals was to study and review existing BIM-related courses, which the author analyzed in a previous study [7]. When setting the learning goals for the “BIM converged construction engineering curriculum,” the knowledge the students will acquire should be scalable for implementation in an actual project. Therefore, the curriculum considers the industry status, significance, and expectations of a new BIM course. Based on pedagogical factors of Bloom’s taxonomy, such as cognitive (mental skills, knowledge-based), affective (growth in areas of feeling or attitude, emotion-based), and psychomotor (manual or physical skills, action-based), the curriculum was categorized according to learning goals and objectives [45]. We developed the curriculum’s learning goals and objectives through a thorough literature review and by conducting analysis on the purpose of conventional BIM courses (Table 2).

Table 2. Learning goals and objectives for BIM-based construction engineering curriculum.

Learning Goals	No.	Learning Objectives	Type
Understand the BIM knowledge (concept and theories)	1	- Understand the general concept and theories of BIM	Cognitive
	2	- Trends and state-of-the-art BIM technologies applied in the industry	Cognitive
	3	- Understand the theories of computer-based modeling, such as AutoCAD, Revit, and Navisworks	Cognitive
Understand and implement BIM in construction processes	4	- BIM implementation methodologies and strategies	Cognitive
	5	- Identify the BIM implementation areas in the construction process	Cognitive
		<i>BIM-based design (architecture, structure, MEP, etc.)</i>	
		<i>Design quality control using clash detection between disciplines</i>	
		<i>BIM-based quantity take-off and cost estimation</i>	
		<i>Documentation for design phase</i>	
		<i>Scheduling and sequence planning</i>	
		<i>Constructability review using construction BIM model and 4D simulation</i>	
		<i>Visualization and communication</i>	
		<i>Spatial trade coordination</i>	
	<i>BIM-based field layout management and construction management</i>		
	<i>Building safety and quality management using BIM and as-built model</i>		
	<i>Documentation for construction phase</i>		
Become familiar with BIM software	6	- Distinguish importance and stakeholders' roles in BIM application	Cognitive
	7	- Acquire basic BIM modeling and authoring skills using Autodesk Revit	Psychomotor
Expand the BIM skills into BIM-related software and construction engineering	8	- Understand how BIM model is used for simulation, visualization, scheduling, estimation, and analysis	Cognitive and Psychomotor
	9	- Practice usable parametric BIM skills for "freeform and NURBS (Non-uniform rational B-spline)"	Psychomotor
	10	- Understand and study the diversity of BIM skills using 3D scanning, 3D Printing, and API	Psychomotor
	11	- Study the theories related to construction engineering and management	Cognitive
	12	- Link up BIM skills with construction engineering and CM (Construction Management) knowledge	Affective
	13	- Master BIM-based construction engineering and CM using BIM software	Psychomotor
	Become practical BIM professional for industry	14	- Practice real BIM skills that can be applied in the industry using joint-company projects, R&D projects, and prototyping
15		- Enhance creativity by planning virtual projects	Affective
16		- Understand and expand the future construction IT trends and BIM converged technologies	Cognitive

3.4. Development Stage of BIM Curriculum Development: Choosing Learning Topics

Learning topics should be in line with individual goals defined in the earlier stages and should be based on the learner's activities. In addition, the learning topics should be established based on the knowledge and skills that will be acquired through the curriculum, taking into account the values and behavioral codes set by the construction industry [44]. The curriculum of the newly established BIM specialist training department consists of five learning topics and 19 subtopics, as shown in Table 3. In addition, these learning topics and subtopics are set according to the learning goals and objectives highlighted earlier (Table 2). The main point in this process is to consider all the learning topics and reorder them so that the students can learn them sequentially and effortlessly for a period of three years. Thus, by incorporating all these considerations, we set up a learning schedule.

Table 3. Selection of learning topics for the BIM-based construction engineering curriculum.

Learning Topics	Subtopic	Related Objectives	Learning Period (Year)
Background knowledge of BIM	- Definition and importance of BIM	1, 3, 6,	1
	- History of BIM and construction IT technology	2, 3, 8	1
	- Terminology and theories related to BIM	1, 3, 5	1
	- Issues and advantages of BIM adoption	1, 2, 3, 5, 6	1, 2, 3
BIM adoption in construction Industry	- Traditional process vs. BIM-based construction process	3, 4, 5, 6	1
	- Change of stakeholders' roles in application of BIM	5, 6	1
	- BIM-based collaboration	5, 6	2, 3
	- BIM application fields to improve productivity	5, 8, 11, 12, 13	2, 3
	- BIM-based project execution plan	4, 5, 11, 12, 13	2, 3
BIM software operating skills	- Authoring skills for architecture, structure, and MEP	3, 5, 7, 11, 12, 13	1, 2
	- Management skills using simulation and visualization	3, 5, 8, 11, 12, 13	1, 2, 3
	- BIM special skills for free-form structure and buildings	9, 11, 12, 13	2
Smart construction and IT technologies	- Programming capability to make new BIM API	5, 6, 8, 10	2
	- 3D scanning and printing for BIM applications	5, 6, 7, 10	3
	- Knowledge and trends of BIM and ICT technologies	10, 14, 15, 16	3
Practical construction engineering and management capability	- Basic knowledge of construction engineering and CM	11, 12, 13	1, 2, 3
	- Construction engineering skills using various BIM tools	11, 12, 13, 14	3
	- Basic CM capability to understand the real industry	13, 14, 15	1, 2, 3
	- Schedule, cost, quality, etc.	14, 15, 16	2, 3
	- Converge BIM skills into CM fields	14, 15, 16	2, 3

3.5. Development Stage of BIM Curriculum Development: Organizing Learning Topics

Based on the learning topics and schedule, the subjects of the BIM curriculum were organized. This study considered the issues in the subjects under this framework.

- The curriculum should be aimed at cultivating the capabilities necessary for employability in a construction company, which can be quantitatively evaluated by the company. Upon completion of the curriculum, the students should be equipped to such a level that they can immediately work on actual tasks within a company.
- The newly-established department has a three-year course. After one year of full-time study, two years of contract employment and part-time study are mandatory so that the subjects reflect the student's capabilities.
- It should reflect the current trends in Korea's construction industry and the BIM response strategies of construction companies.
- Learning topics and contents should be directly related to goals and objectives, and subjects should be organized to reflect theories and practices.
- Subjects based on learning topics should be organized according to the three-year course procedure, making it easy for students to understand and develop their competence levels.

- Construct curriculum contents that reflect all the learning goals, objectives, and topics, which are established during the development stage (Sections 3.3–3.5). Since the final purpose of this research was to apply the proposed curriculum directly to the newly opened departments, several brainstorm meetings and discussions were held to organize the curriculum contents with school officials and industry experts. The curriculum table was completed in consideration of the subjects students must take in each semester, difficulty level of each grade, and appropriateness of the curriculum arrangement. The curriculum of major institutes such as Associated General Contractors of America (AGC) and American Society of Civil Engineers (ASCE) were also studied. Subject syllabuses of universities in Korea, education contents of private organizations, papers on BIM technology research and education, and cases of BIM implementation in construction companies were considered. By selecting subjects appropriate for the three-year course, the students participating in the curriculum could acquire in-depth knowledge of the BIM technology and gain substantial construction engineering and construction management understanding. In addition, to maximize achievement of the learning objectives for each subject, the subject operation method (in other words, the lecture method) was selected and presented [44].

Table 4 shows the semester-wise subject schedule created by the systematic course development procedure. The three years of the curriculum comprise a total of 36 subjects. Essentially, each year's education objectives are set differently. The first stage of the course focuses on acquiring basic construction engineering theories, BIM fundamentals, and skills for employment after completion. Since second- and third-year students are working in the field and participate in the curriculum in the form of part-time education, the curriculum for them is mainly administered on weekends and via on-line teaching. In addition, advanced theories and skills for BIM and construction management are studied in the form of project-based learning and joint company learning in order to deepen basic knowledge and skills learned through the first grade course and the practical capabilities acquired by working with the company.

Table 4. Curriculum table for BIM-based construction engineering.

Year/Semester	Subject Name	Education Method					
		I	O	F	L	P	C
1/1	- Understanding of software				V		
	- 4th industrial revolution and construction				V		
	- An introduction to construction engineering		V		V	V	V
	- An introduction to construction management				V		
	- Architectural geometry				V		
1/Summer	- BIM fundamentals for architecture				V	V	
	- BIM fundamentals for building structure				V	V	
	- BIM fundamentals for MEP				V	V	
1/2	- Building structure				V		
	- Building construction process				V		
	- Building materials	V			V	V	V
	- BIM practice for architecture	V			V	V	V
	- BIM practice for building structure				V		

Table 4. Cont.

Year/Semester	Subject Name	Education Method					
		I	O	F	L	P	C
1/Winter	- BIM practice for MEP				V		
	- BIM practice for analysis and implementation	V			V	V	V
	- Schedule and cost management	V			V	V	V
2/1	- IT information systems				V	V	
	- BIM API fundamental			V	V	V	
	- BIM enhancement for free-form structure 1			V	V	V	V
	- Understanding of building drawings				V	V	
2/Summer	- BIM prototyping project 1	V				V	V
2/2	- Quality and safety management				V		
	- BIM API practice			V	V	V	V
	- BIM enhancement for free-form structure 2	V		V	V	V	V
	- 3D scanning and 3D printing				V		
2/Winter	- BIM prototyping project 2	V				V	V
3/1	- Project planning for BIM practice				V		
	- Industry-joint R&D project 1			V	V	V	
	- Building MEP	V		V	V	V	V
	- Construction regulation				V		
3/Summer	- BIM management practice	V			V	V	V
3/2	- Structural analysis				V		
	- Quantity take-off and estimation	V		V	V		V
	- Industry-joint R&D project 2	V		V	V	V	V
	- BIM and ICT				V		
3/Winter	- Graduation project	V				V	V

Note: I = IC-PBL (Industry Coupled, Problem-Based Learning); O = Online, F = flipped learning; L = lecture; P = practice; C = company joint learning.

In the first year curriculum, all learning is lecture-oriented. BIM software classes are held in either a practice-type or company-linked-type environment, with company experts presiding over lectures. In the second year subjects, all classes, except “quality and safety management”, are conducted using both lectures and practice-type classes, and the subjects named “BIM enhancement for free-form structure” and “BIM prototyping project” are company-affiliated. The BIM implementation technology for the free-form structure is in the form of practice based on the latest technology. For the prototype project, students directly work on a project presented by the company’s experts, which enhances their practical capabilities. The third year curriculum is largely composed of three types: in-depth courses on BIM software and ICT, BIM-based construction engineering and management strategies, and PBL classes, such as research and development jointly carried out by a company. The curriculum aims to help students become BIM professionals by achieving the goals and objectives set by the curriculum through the theory-oriented stages in the first year and the practical-oriented stages in the second year. To verify the achievement of the objectives, corporate experts participate in the assessment.

3.6. Improvement Stage of BIM Curriculum Development

The BIM-based construction engineering curriculum proposed in this study was developed by a systematic course development procedure. For verification, it is necessary to apply the curriculum to a newly opened department of a university [39,46]. In addition, since construction companies hire students after completion of the curriculum and engage them in practical tasks, it is necessary to have a validation process and feedback system from the officials who have expertise in BIM. For the curriculum verification process, we distributed preliminary interview sheets to a total of 10 people, consisting of 3 education experts, 2 experts from private educational institutions, and experts in construction engineering, construction management, and BIM. We collected their answers and then conducted a telephonic interview. The experience levels of the interviewees are summarized in Table 5.

Table 5. Interviewees' experience in universities and the industry.

Field	Interviewees	BIM Experience (Years)	Position	
Academic	Universities	Interviewee a	12 years	Assistant professor
		Interviewee b	15 years	Associate professor
		Interviewee c	10 years	Assistant professor
	Education institutes	Interviewee d	7 years	Lecturer
		Interviewee e	6 years	Lecturer
Industry	Interviewee f	10 years	BIM manager (construction company)	
	Interviewee g	7 years	BIM manager (BIM company)	
	Interviewee h	10 years	BIM deputy manager (construction company)	
	Interviewee i	12 years	CEO (BIM company)	
	Interviewee j	15 years	CEO (BIM company)	

The evaluation forms were e-mailed to interviewees and the answers were collected. In addition, telephonic interviews were conducted for all 10 interviewees to obtain more comprehensive and detailed comments on the evaluation information received in writing. The main points for evaluation requested in the interview are as follows.

- Assessment of the overall framework of the proposed BIM-based construction engineering curriculum;
- Learning goals and objectives;
- Assessment of the relevance of learning topics and their association with learning goals and objectives;
- Assessment of the subject, procedure, and lecture method of the curriculum organization table.

The comments received from the group of 10 experts are summarized in Table 6. Based on the comments and suggestions of these experts, the above four parts were evaluated and revised. In particular, the experts consisted of academic experts from universities and educational institutions, and industry experts from construction companies and BIM companies. Their comments suggested varied orientations depending on their respective affiliations. University professors suggested that along with practical education, construction engineering knowledge and theory should be included also. Instructors from BIM educational institutions, which are not universities, emphasized the participation of industry experts in the curriculum and adaptation to the practical work environment through use of different software. Among industry experts, BIM managers working for construction companies rated the students capabilities after completion of the curriculum as a critical issue, and for this purpose, the association with companies was an important feature of the curriculum. On the contrary, the CEOs of BIM companies responded that the curriculum should not only enhance BIM competence across broad areas but also enable students to set up their own companies in the future. Through the improvement stage, the BIM-based curriculum was revised, and supplementary points

addressed in the interview and the revised curriculum were actually implemented in the newly opened “department of BIM converged construction engineering” in the university.

Table 6. Experts’ input for improvement of BIM-based CE (Construction Engineering) curriculum.

Expert	Comments
Expert a	<ul style="list-style-type: none"> - A review is required to check if the curriculum can be followed by first year students without problems. - The coursework should be carried out in conjunction with construction engineering subjects or with BIM, and teaching methods should be reset to reflect this connection. - It should be feasible to organize the curriculum in association with the existing construction engineering subjects.
Expert b	<ul style="list-style-type: none"> - Construction engineering professors should teach construction engineering subjects, while practical experts should teach BIM subjects. As for the joint initiative with companies, both types of experts should participate and contribute. - Although the BIM education curriculum is specialized for practical tasks in a real-world job, overall theoretical education on construction engineering and management should also be regarded as important.
Expert c	<ul style="list-style-type: none"> - BIM practice lectures should focus on tool mastery. CE and CM utilization strategies for each function should also be taught. - Because BIM projects are team-based, it would also be helpful to have lectures in groups.
Expert d	<ul style="list-style-type: none"> - Need to unify assessment methods for student performance; it is also important to involve industry experts in student assessment. - It is necessary to consider diversification of BIM modeling software, such as Google Sketchup and ArchiCAD.
Expert e	<ul style="list-style-type: none"> - Since BIM professionals will be active in diversified ordering and contract environments, such as lean construction or pre-construction, training in these aspects is also required. - Adaptation training for actual working environments is needed for the students to understand how the project is executed and to be immediately put into real projects.
Expert f	<ul style="list-style-type: none"> - A separate framework is needed for the development of student’s competences by grade-based assessment of students per semester. - In particular, companies that would hire them should be able to participate in the curriculum, such as in the education, management, and assessment.
Expert g	<ul style="list-style-type: none"> - As the construction industry trends are not only related to BIM, but also to ordering and contract methods and other smart construction and construction IT technologies, it is recommended that the latest technology education, such as IT, robotics, and deep learning, be combined in addition to the construction industry information. - To complement the relatively weak construction engineering knowledge and skills, operation of the curriculum in connection with construction engineering is needed.
Expert h	<ul style="list-style-type: none"> - Since first year courses are full-time education, it will be more efficient to establish a separate plan for linking companies with students to give them a sense of BIM skills. - In particular, corporate mentoring will be helpful in cultivating working-level talents from an early stage.
Expert i	<ul style="list-style-type: none"> - Although this curriculum takes the form of an agreement with a company, in the future, the curriculum should empower students to develop new types of services and even engender their own startups. - Unlike large corporates, in BIM companies, often the employees oversee the entire BIM project. Hence, strategic training for construction project management and BIM operation is required.
Expert j	<ul style="list-style-type: none"> - Some subjects, such as BIM, API, and BIM-ICT, are thought to be related to the essential skills and qualities required for BIM professionals, and subjects similar to these should be added.

4. Implementation Stage of BIM Curriculum Development

After the improvement stage of the “BIM-based construction engineering education curriculum”, which was developed using the systematic course development approach, the course was implemented in the educational curriculum of the “department of smart convergence engineering”, which was recently established in Hanyang University, ERICA campus. There are four majors in this department, one of which is construction IT convergence.

The proposed BIM curriculum was applied to the educational curriculum of the department of construction IT convergence. This is a complete curriculum, reflecting most of the set learning

goals and objectives, learning topics, and subjects. Through this, the department became the first in Korea to establish a separate department for the development of BIM professionals. It has established itself as a novel department in which major companies in the construction industry in Korea, including construction companies, BIM companies, construction designers, CM companies, and software vendors, participate in the overall process of the curriculum.

5. Summaries and Conclusions

The purpose of this study was to develop a BIM-based construction engineering curriculum. To achieve this, the learning goals and objectives of the education were established in order to cultivate accomplished BIM professionals that can immediately perform practical tasks from the point of hiring. The curriculum was developed using the system course development approach. Through the application of systematic course development, the learning goals and objectives of BIM courses were established and the learning topics were established based on these. In particular, a curriculum table was developed by arranging learning topics satisfying the requirements of departments, namely a three-year curriculum and employment with companies in the second year. To review and supplement the developed curriculum, we conducted interviews with construction engineering and BIM experts in industry and academia, and the revised learning goals and objectives, learning topics, and curriculum were implemented in a newly opened department at Hanyang University, ERICA campus. Using the logical development process, the maturity of the curriculum was verified, and upon actual implementation, the value of the curriculum was validated.

Above all, the advantages of this educational curriculum is that it reveals the problems in the existing curricula from a practical standpoint, such as theory-based lectures in traditional Korean universities or extreme practice-oriented learning in public and private educational institutions. The BIM demands of the construction industry could not be satisfied by these approaches. Simply inserting BIM into the existing construction engineering curriculum does not enable the development of the level of BIM personnel required by the construction industry. To overcome this, the systematic course development application was applied and the curriculum was improved through discussion and collaboration with various industry experts. In particular, it is a great advantage that industry experts can incorporate their needs into the curriculum by participating in various activities, such as curriculum operation, student education, evaluation, and collaboration.

Korea's BIM education remains at a very primitive level from the perspective of industry demands and technical requirements in comparison with foreign countries with advanced BIM implementation levels. The BIM-based construction engineering curriculum, newly developed for the enhancement of capabilities which can handle theory, practical tasks, and creativity for the resolution of actual problems, provides a logical approach that can be utilized for future BIM curriculum development, not only in Korea but also abroad. It can also be used to develop curricula in other areas based on pedagogical principles.

This study presents the results of implementation of a new type of BIM curriculum. Through future research, we would like to present strategies of operation, student selection, evaluation, and business linkage for the implemented curriculum. In particular, we aim to develop the curriculum further through quantitative evaluation of the quality of the curriculum proposed in this study and the value gained in terms of meeting company demands.

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