Use of BIM for learning engineering – Change of paradigm

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Abstract
This conceptual paper examines strategies for implementation of building information modelling (BIM) in bachelor and master of engineering curricula. There is a challenge to include BIM in engineering curricula at bachelors and masters levels, despite demand from the industry. This study introduces an alternative approach that focuses on BIM for learning engineering. BIM is embedded in traditional topics by use of principles, methods and tools for use/reuse and exchange of relevant information that support learning, and not only accomplishment of tasks. The core elements in the change of paradigm are enabled through viewing BIM as model, modelling and management as methods for applying input, controls and outcomes of information. Development of a 2-year master program in sustainable engineering is used as a case study. Introduced principles can be integrated with other research within education and BIM to enable wider implementation in various learning environments and increase BIM competency in higher education.

Keywords: BIM education, engineering curriculum, learning

1 Introduction

The demand for BIM-related expertise is rapidly increasing in the entire AEC industry (architects, engineers, construction, owner and operators industry). Despite this BIM is included to a limited degree in the engineering curriculum at bachelors and masters levels. This situation is hard to solve due to lack of BIM experience at a scientific level within higher education. Focus is often on software skills presented by professionals from the AEC or IT industry. Scientific lecturers are included in the BIM-related education to a limited degree. This can contribute to the gap between learning engineering and learning BIM. Introducing new topics in an existing study is often very hard as it implies that some existing course must be taken out and replaced by the “new” topic, which is BIM. Even in development of new study plans will BIM as a separate course have to “fight” against traditional topics like structure, building technology or facility management.

This study starts with a short presentation of BIM education and research, followed by examples of ongoing discussions about BIM’s future in education. The intention in this is to open up for factors that can support changes in paradigms. This is followed up in the next part, which goes into the research question, and it is related to exploring educational approaches that can be used to improve both quality and quantity of BIM in higher education. This is done by exploring proposals of three perspectives and the uses of three methods. This solution intends to embed BIM in existing curricula by supporting professional learning. To give practical context, the ongoing development of a 2-year master’s program in sustainability in structural engineering and building technology at Oslo and Akershus University College of Applied Sciences (HIOA) in Norway is included in this paper. The result is summarized before the last discussions and proposals for further studies.

The applied profile of this concept paper is presented for use of three perspectives of BIM and three methods for use in learning in the AEC industry.

2 Understanding BIM in research and education

2.1 Research related to BIM in education

There are a large number of pedagogic theories and principles, but there can be a distance between pedagogic and practical professionals. It has been hard to observe that BIM has been a topic within the pedagogical research community. On the other hand, education is well established within the BIM research community as illustrated in Table 1. This enables sharing of experiences from courses and development of ideas for future education.

Table 1 Education as a topic in BIM-related scientific conferences

Conference	Year	Themes and Topics at the conference
eCAADe	Yearly	Large number of topic within education and use of software tools. Collaboration with other relevant initiatives.
CIB W78	2015	Education in Construction Informatics
CIB W78 and ISCCBE	2014	Education and Training under Cutting Edge Development
ISCCBE	2012	Computer-Aided Education and Training
ISCCBE	2010	IT Innovations in Education
ISCCBE	2008	Computer-Aided Education
ECPPM	2014	Not listed
ECPPM	2012	Education and life-long learning

eCAADe = Association for education and research in computer aided architectural design in Europe
ISCCBE = International Society for Computing in Civil and Building Engineering
CIB W78 = IT in construction, Int. Council for Research and Innovation Building and Constr.
ECPPM = European Conference for Product and Process Modelling

2.2 Status of BIM in higher education

The status of BIM in higher education has two perspectives. The first perspective is how many schools have implemented BIM and to what degree. The second perspective focuses on how BIM is, or can be, implemented in courses.

It is hard to find detailed quantitative studies regarding implementation rate. There is also a challenge about methodology related to what BIM is, and of course this type of research requires more recourse than a study following a set plan. However, the general opinion, based on demand from the AEC industry, is that there is need for more candidates with better skills and knowledge about BIM. There is increased interest for BIM in education, both from the AEC industry and from the academia. The NATSPEC survey (Ronney, 2014) shows increased interest and focus on BIM in a number of countries. Following citation illustrates the second perspective about what BIM is in education: *"It would appear that the majority of BIM education available to date focuses on training in the use of particular BIM software packages, particularly seen as a lot of training for professionals appears to be provided by the software vendors. Training for both graduates and professionals in openBIM concepts, BIM management and working in collaborative BIM environments, appears to be still in its infancy"* (Rooney, 2014).

This problem is experienced by other and in a study by Barison and Santos (2010) about BIM teaching strategies, "*it is still unclear how BIM should be taught as most experiences are very recent.*" They identify BIM in education by looking for single courses, interdisciplinary projects and distance collaborations.

Higher education is academically focused, and is therefore not have focus on practical skills in use of on particular software. However, these types of observation indicate that the dominating status of BIM is related to use of software. Measuring the status of BIM in education, both at the school level and within a course must therefore include a better understanding of what BIM really is.

2.3 Understanding of BIM in education

BIM in education has traditionally been identified by use of BIM-based software in a course. However, the above studies and experiences show that the understanding of BIM is much broader and deeper than use of software. It includes collaboration processes and processing of information to serve both understanding and solving tasks. There exist a large number of definitions of BIM in use, which influences BIM in education. Hopkins (2006) expresses this as follows: "…when something is hard to define it can also be difficult to teach…" However, a joint factor is that there is always more than one type of skill that is required. Three elements often emphasized are: Building Information Models, Modelling, and Management.

The importance of taking BIM beyond drawing/modelling with software is because, as emphasized by McGough (2013), "*Teaching needs to be clear that BIM goes beyond that of the 3D model, with efficient information sharing a critical factor which needs to be adopted and understood.*" This perspective is followed up by, "*The solution or challenge, depending how you look at it may be for education to integrate BIM seamlessly within the structure of existing courses and modules rather than attempting to create brand new BIM specific courses or modules which will directly compete for timetable space with existing modules*."

BIM is often presented as a new way of working and collaborating. This has to be reflected in the AEC industry. The industry is complex – and consequences for this are well documented in a five-year research project on knowledge processes. We already knew then that this was an industry with a lot of knowledge. This makes the AEC industry an information intensive industry. However, our business models and solutions have not developed in scale with this development in complexity (Ørstavik, 2012). Crawley et al. (2014) highlight the importance of reflecting the complexity of new ways of working in the following citation: "*The purpose of engineering education is to provide the learning required by students to become successful engineers—technical expertise, social awareness, and a bias toward innovation. This combined set of knowledge, skills, and attitudes is essential to strengthening productivity, entrepreneurship, and excellence in an environment that is increasingly based on technologically complex and sustainable products, processes, and systems.*"

Use of BIM can itself contribute to increased understanding. A study by Peterson et al. (2010) found that use of BIM to support project management education is a good example for this effect. Peterson et al. said, *"Introduction of BIM-based project management tools helped educators of two project management courses to develop class assignments based on more realistic project settings and information to support students with learning how to apply different formal project management methods to real-world project management problems."*

The impact of visualization in learning is important. A study based on civil engineering students by Irizarry et al. (2012) observed an increase of 10% in the number of correct answers for the beam problem when three dimensional building information models were used. A conclusion from this study shows that the use of building information modelling in Civil Engineering and construction management education applications has the potential to be more than a graphic representation tool, becoming a means to enhance student learning.

The UK government has high ambitions of BIM in the AEC industry as shown by the Level 2 and Level 3 approach. This focus is also reflected in implantation of BIM in higher education. The joint reports from The Higher Education Academy (HEA) and the BIM Academic Forum (BAF) present learning outcomes related to knowledge and understanding, practical skills and transferable skills (HEA/BAF, 2013). These learning outcomes are well adapted to be integrated in existing course and curriculum rather than separate BIM courses.

These emerging perspectives indicate a possible change of paradigm for BIM in education. This change of paradigm is related to a decrease of BIM as separate courses using BIM-based software in traditional tasks focus on BIM as an enabler that can be integrated into existing curricula, contributing to development of existing learning outcomes to reflect the needs of the future AEC industry. It is therefore reasonable to question how long the conclusion from the NATSEPC survey (Rooney, 2014) will remain in the next survey. The next part will present proposals and methods for an embedded approach for BIM in higher education curriculum.

3 Framework for making a change in paradigm – Making BIM applicable

The concepts presented in this paper are a combination of three perspectives of BIM and the methods for processing information called the "3x3 BIM concept." The intention with drawing attention to "change of paradigm," is to indicate the connection with the problem: Lack of BIM in curriculum – hard to introduce BIM, hard to find applicable methods. The applicable solution is to use existing curriculum as a foundation – and to make this applicable by presenting the "3x3 BIM concept." This concept is explained by using different understanding of BIM as starting point. Presentation of methods is based on existing method, tool, and procedures in use in the AEC industry.

3.1 Background for the new study program

This concept paper presents examples from an ongoing development of a new 2-year master's program called "Sustainable Structural Engineering and Building Technology" at Oslo and Akershus University College of Applied Sciences in Norway. It is used to present the three core elements that are planned to be used.

HIOA is a multidisciplinary university college. The building engineering study has two directions of specialization, "Building and energy" at the bachelor's and master's levels and "Building technology" at the bachelor's level. "It is therefore decided to establish a master program with a profile on sustainability as continuation of building technology. The candidates will work as consulting engineers with specializations within structural engineering and building technology. Establishing a new study takes time and a complete application will be submitted to Norwegian Agency for Quality Assurance in Education (NOKUT) by 1st February 2016. NOKUT have formal responsibility for approval of study plans (NOKUT, 2015). The first course will then start at 20th August 2017. This timeframe illustrates the challenge of establishing new curricula.

The building technology study has a traditional focus on BIM, They have two associate professors with specialization within BIM. The engineering study have been host for buildingSMART Student seminars for years, and a bachelor thesis from HIOA won the BuildingSMART awards in 2013 (bSN, 2015). In this respect, BIM is familiar and HIOA has both the competency and capacity to set up specialized BIM courses, like use of Autodesk Revit in building technology and Autodesk Robin in structural analysis. An integrated approach, where BIM is embedded into the professional courses, was chosen.

3.2 Study plan for sustainability in structural engineering and building technology

Table 2 give an overview of proposed subjects in the study plan. BIM is not pointed out as a separate subject but embedded into other subjects. Software training is not included in the study plan despite use of software in general and BIM-based software is important both for learning, student work and collaborations. Only one single course includes construction and environmental informatics, however, it is stressed that this must support the ongoing project course at 15 ECT and also be a preparation for a Master's thesis. This perspective supports BIM and shall be embedded in other courses. Students can take the 3rd semester partly or entirely at other colleges / universities.

Table 2 Subject plan with distribution of credits and theme of topics

<table>
<tr><td>Type of study</td><td>Lecturing, minor projects / cases, lab / digital lab. Case based</td><td>Lecturing, medium projects/ cases, exercises, inspections lab / digital lab.</td><td rowspan="6">Summer job / Preparation to Master thesis</td><td colspan="2">Project- and problem based learning in collaboration with AECOO industry and research</td><td>Self-study with mentoring</td></tr>
<tr><td>Sem.</td><td>1.</td><td>2.</td><td colspan="2">3. alternative 1</td><td>3. alt. 2</td><td>4.</td></tr>
<tr><td>7,5 ECT</td><td>Applied computational mechanics</td><td>Advanced structural analysis and loadings</td><td rowspan="3">Digital tools / -processes</td><td rowspan="3">Sustainable engineering in AECOO-industry Project related</td><td rowspan="4">Optional: Studies abroad</td><td rowspan="4">Master thesis Collaboration with industry/ R&D

Industry as “Problem owner” Students as “Problem solvers”</td></tr>
<tr><td>7,5 ECT</td><td>Building physics and building envelope</td><td>Building technology</td></tr>
<tr><td>7,5 ECT</td><td>Professional life cycle assessment</td><td>Service life and upgrading of concrete structures</td></tr>
<tr><td>7,5 ECT</td><td>Sustainable engineering in praxis</td><td>Engineering and environmental informatics</td><td colspan="2">Research methods / Ethics / Academic and professional writing
Elective course
1) Given at HiOA
2) Given at other uni.</td></tr>
</table>

4 Method for embedding BIM in higher education

4.1 BIM education based on the “3x3 BIM concept”

The approach to embed BIM in higher education curricula is based on the “3x3 BIM concept” that consists of:

- The 3 perspectives (with reference to Figure 1)
  - Building Information Model
  - Building Information Modelling
  - Building Information Management
  -
- The 3 methods (with reference to Figure 2)
  - Information Delivery Manual (IDM) representing “Input”, presented in Figure 4
  - Information Take Off (ITO) representing “Control” presented in Figure 5
  - BIM Execution Plan (BEP) representing “Result” presented in Figure 6

The core element in the new approach is to focus on professional tasks, and what type of information these tasks require to be processed. If the information is complete and the methods are predefined, this enables automatic processing. This approach indicates that engineering students become aware of the potential to rationalize working tasks by implementing them into software-based solutions.

4.2 The trinity perspective of BIM

Despite no joint definition established, many definitions include more than one perspective of or type of skills that is required. Three elements often emphasized are: Building Information Model / - Modelling / - Management. Figure 1 presents the three perspectives of BIM as; Building Information Model – Modelling – and/or Management. The B in BIM can be interpreted as building as product (physical attributes) and as process. This is a dynamic model, and Figure 1 illustrates that the perspectives in use of BIM will vary within a project or between projects.

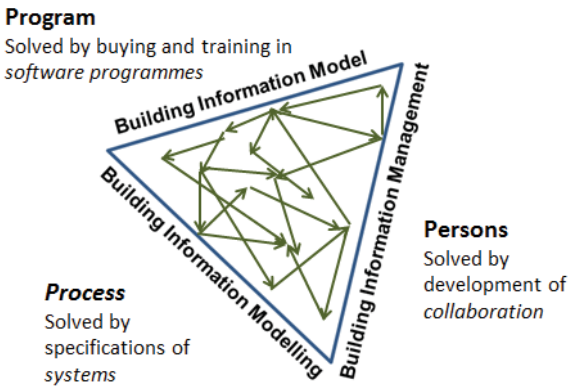

Figure 1 The dynamic changes of perspectives in the BIM trinity (Hjelseth, 2015)

BIM in education is not related to one subject or one approach. This perspective indicates that BIM is not only related to buying and training in use of software. The process focus covers systems for processing, collecting, presenting and storing information. A joint element in all three definitions/perspectives is "information." Sustainability assessments require more information than traditional assessments. The ISO 12911 Framework for building information modelling (BIM) guidance is a technical specification that establishes a framework for providing specifications for the commissioning of building information modelling (BIM). The standard illustration of its focus on BIM process: The desired results determine the required input and controls. The core principle is presented in Figure 2. These principles can be accumulated as presented in Figure 3 (ISO12911:2010).

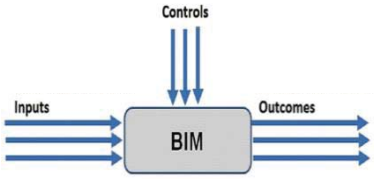

Figure 2 Framework in the BIM process

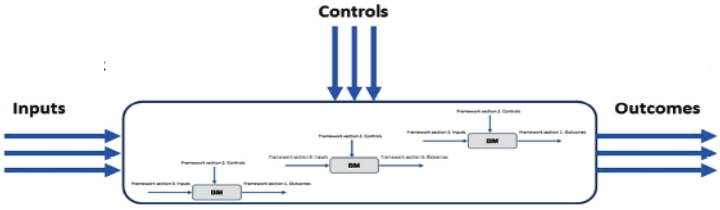

Figure 3 Interaction of BIM sub-processes

4.3 Specification of relevant input – Information Delivery Manual (IDM)

The Information Delivery Manual (IDM) approach corresponds to the modelling perspective of BIM. IDM is based on the buidlingSMART Process standard which is founded on ISO 29481-1. Building information modelling -- Information delivery manual -- Part 1: Methodology and format (A revised version will be published in 2015). This method specifies relevant information to be exchange for defined tasks.

Learning relevance: Especially useful for learning and understanding designing and engineering / construction processes. Can be included in topics learning For collaboration and coordination, Use of process maps based on Business Process Model and Notation (BPMN) is very useful methodology for identifying who is receiving which information from whom at what time, as illustrated in Figure 4. Process maps can be produces by freeware, such as Bizagi modeller (www.bizagi.com) or similar software, or can just use tables and boxes in word processors.

The professional information that is required is specified as exchange requirements. This list of information can be specified by spreadsheets or tables in word processors. To know what information is relevant, one has to know what information is required in, e.g., a formula or as criteria for assessment or in compliance checking. Subject-like structure calculation or environmental assessment needs a lot of information. The content of information in the BIM file (e.g. IFC) can be verified by use of software presented in the next sub-clause.

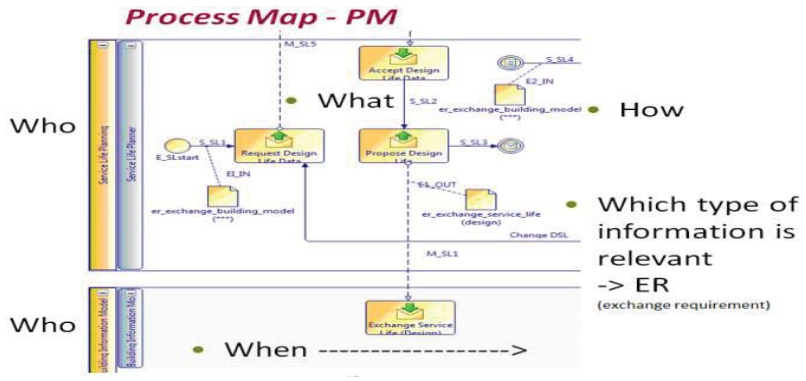

Figure 2 Use of Process map to understand the building process (Hjelseth, 2015)

IDM has been used in student projects and theses. The Norwegian buildingSMART site has databases of BIM-related master and bachelor theses. The following list shows that IDM is a common element in theses: Anders Qviller, Kjetil Ramstad and Tobin Rist in 2011, Natalia Marszalek in 2010, Cathrine Mørch in 2009 and Magnus Baggetorp in 2007 (bSN, 2015). BuildingSMART International has collected a number of IDMs that can be downloaded from: http://iug.buildingsmart.org/idms/information-delivery-manuals (Karlshøj, 2011).

4.4 Control of relevant information – Information Take Off (ITO)

This method supports insight, overview and control of exchanged information in the BIM file. It gives hands on experience with the "I in the BIM" and can be used as supplement to IDM to be aware of relevant information.

There are two types of software that can be used:

- Model viewers: Open source IFC viewer software
  - there are multiple viewers available with its pro and cons.
  - in addition, the authoring tool can be used to explore content
- Model checkers: Commercial software for information take off and/or model checking
  - Solibri Model Checker (SMC), Autodesk Navisworks and Tekla BIMsight can be used as representatives of this type of this software. Querying by use of BIM server is an option for more BIM technical studies.

Model viewers / -checkers have a number of other functions that can support learning and insight into the engineering project. The function for information take off and bill of quantity are especially relevant. Figure 5 illustrates presentation of relevant information by use of the information take off in Solibri Model Checker software (Solibri, 2012). This function enables classification, identification and colour coding to support focus on relevant information.

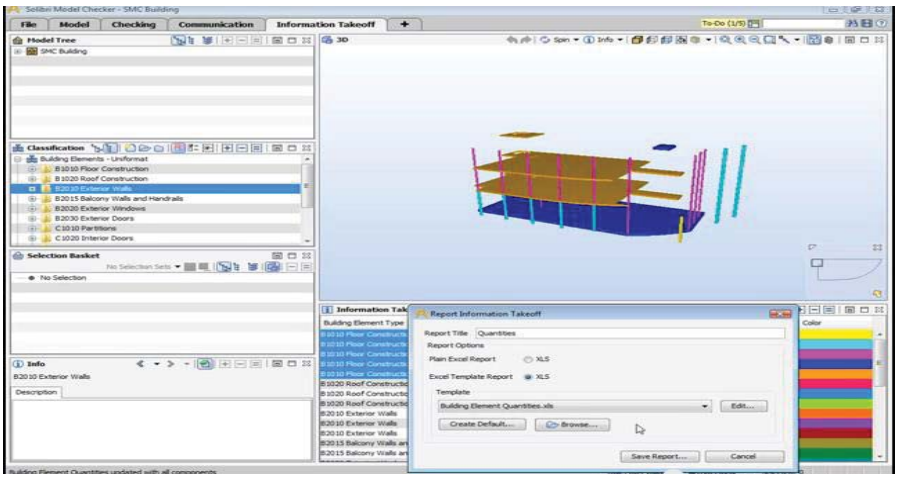

Figure 3 Information take of in Solibri Model Checker - (Solibri, 2012)

Learning relevance: All subjects who use software for calculation, assessment and documentation where one must know the foundation these tasks. This is especially useful for subjects who focus on information about the building and all its components/building parts, e.g., investment cost calculation, life cycle cost and CO_2 calculations. These subjects often include discussions about foundation for results, and in this respect can an information take off list be useful. The information centric approach can support understanding of compliance checking and automation of engineering tasks, being aware of knowing what is possible to program into computers and what is to be done manually.

4.5 Information management – BIM execution plan (BEP)

The purpose of a BIM execution plan (BEP) is to set focus on the management aspect of BIM. BEP contributes with setting all the IDM's in a system. Due to software support like SMC, it helps students to understand that information is an asset (likewise physical objects of products) to the IDM and makes this more "practical." There is an increasing number of BEPs available. Most of these do offer templates and other solutions that contribute to make these plans applicable. The UK BIM specification BSI PAS 1192-2 (2013) is under development as ISO 19650 standard (ISO 19650, 2015). Figure 6 is used in both versions and this illustration can be used as a framework for information management that can be supported by use of BEPs.

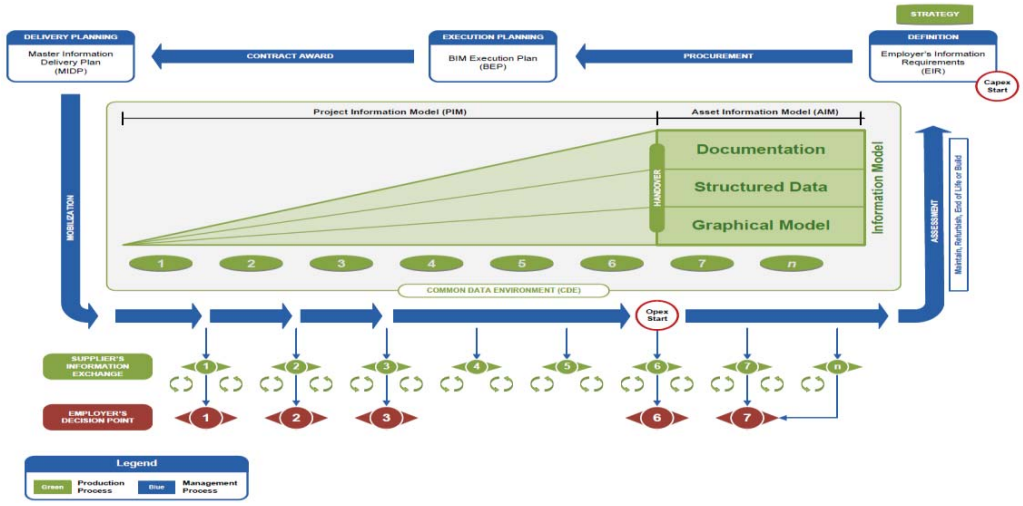

Figure 4 PAS 1192-2 Project delivery cycle (PAS 1192-2:2013)

BIM execution plan (BEP) is the first planning issue in the project delivery plan in the information management circle. The purpose of BEP is to develop and disseminate structured procedures for the adoption and implementation of BIM in projects – this can also be applied in education to set focus on allied Information can be regarded as an input factor likewise work and building materials / building products. BEP is applicable though use of solutions as the Penn State BEP (2015), CPIx BIM Execution Plan (2015), Designing Buildings Wiki (2015) or others. These frameworks include templates for practical use.

Learning relevance: All subjects that include collaboration, coordination and decision making. These processes require relevant information and the BEP concepts prepare the engineering student for future roles within information management. BEP enables a foundation for learning new ways of working and collaborating. Dealing with information can often be experienced as ad hoc task discovered during the work – use of BEP be a tool to organise these tasks in a systematic way.

5 Results

This study presents a concept for an embedded approach for use of BIM to support learning of engineering subjects in both new and existing curriculum. The proposed concept is called "3x3 BIM concept" and is based on:

- Three perspectives of BIM as a trinity of Building Information Model, Building Information Modelling and Building Information Management. A dominating perspective can be adapted to a learning outcome.
- The three methods proposed are: Information Delivery Manual (IDM) specification of relevant input in a professional task, like structure calculation of compliance checking and software for control of information exchanged between software. Solibri Model Checker or IFC viewer are examples of relevant software for exploring information take off. This method contributes to understanding required information needed in advance of use of a BIM Execution Plan as a method that supports understanding for collaboration projects.

The proposed perspectives and methods have separate deliverables that can be related to professional understanding and to performance of learning objectives in existing courses. By this, BIM competency can be a deliverable (IDM-, ITO-, BEP-reports) at the same time as it performs professional works in existing courses.

6 Discussion and further research

6.1 Impact of this concept

The impact of an embedded approach can enable an increase in BIM competency in higher education. The most important benefit with an embedded approach is that no existing, traditional subjects have to be removed. Increased focus on BIM can therefore be achieved without big formal changes in study programs.

BIM supports the learning process by increasing awareness of facts or information used in professional works. The change of paradigm will be a change from talking about BIM, to embedding it into practical use. A proposed concept, and support with other initiatives presented in this study, can support this change of paradigm.

6.2 Connection to ongoing research and frameworks

The proposed concept can be further developed, integrated or supplemented the education topic within the BIM research community, or by other frameworks. In this respect, the Integrated Design and Delivery Solution (IDDS, 2015) are relevant in relation to BIM and industry collaboration. The Conceive-Design-Implement-Operate (CDIO) framework is relevant in relation to development pedagogical solutions and for collaboration with other educational institutions (CDIO, 2015) enables further studies and collaboration.

6.3 Maturity index for BIM education

Different types of maturity indexes for the industry are established. However, an index for BIM in education; indicating both degree and type of implementation appear to be missing.

6.4 Further experiences from HIOA

This concept paper presents an ongoing development of a study program. Further research will follow up development of this study, especially influence from the AEC industry. When the study is, hopefully, established in 2017, students, teachers and industry expectations and outcomes will become subjects for research. HIOA is interested in contact with other educational establishments to share experiences and research collaboration.

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