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Should BIM change the Language of Engineering Education?

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Abstract

Over the last decade the construction industry has been introducing building information models (BIM) as the way to represent buildings and communicate about them. In teaching engineering, we are also creating representations of buildings and communicating knowledge about them. While teaching, we conceptually refer to the very same real world objects that now have an explicit conceptualization in a BIM environment. This explicit conceptualization did not exist in the age of drawings and paper documents.

The question that this paper asks is this: Due to BIM, communication in the industry changed. Should communication of engineering knowledge – teaching – change as well and how?

While much has been written about teaching BIM and incorporating BIM into the curricula, this paper is exploring the general impact of BIM on engineering education. Based on a high-level model of engineering communication, five scenarios of the interplay between BIM-influenced engineering communication and teaching are presented. The paper argues that ignoring BIM may create a cognitive dissonance between study and industrial work. We are finding that the impact of BIM is twofold: vertically there is a need to establish a reference between knowledge concepts (in teaching) and information objects (in information models). Horizontally BIM is an integration technology that allows for a more holistic design and planning. Both the language of individual courses as well as cross references and synergies among courses should change. A "T" style structure of the courses around BIM is proposed.

Keywords: engineering education, building information modelling, engineering communication, curriculum development;

1. Introduction

BIM can stand for building information models, building information modelling or (most appropriate) building information management. It has radically changed the communication in the construction industry and the representation of buildings. Note: what we say about buildings holds true for any product of the architecture-engineering-construction (AEC) industry.

Radical is the change of communication language: the set of symbols and the way in which they can be combined to transfer ideas. In traditional communication, engineers used geometrical elements, formulae, numbers and natural language as symbols. How they can be combined was defined by standards about engineering drawings, rules of mathematical notation and grammars of natural languages. Intelligent human observer was able to interpret combinations of primitive symbols into complex engineering concepts. In a trivial example of Figure 1, she was able to recognize a beam with a concentrated load from a few lines on paper.

In BIM, the symbols are not generic geometric, mathematical or natural language elements but objects with properties. Objects belong to classes or families. The advantage of these objects is that computer algorithms, not just humans, can parse them and use the information associated with them. They are defined in a computer readable language. BIM standards strive to include all objects – all symbols – required to exchange information about

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buildings so that there is no need to resort to generic graphical or natural language elements. BIM defines a finite language to communicate about buildings that ideally would leave little to human interpretation. BIM equivalent of Fig. 1 is in Fig. 2.

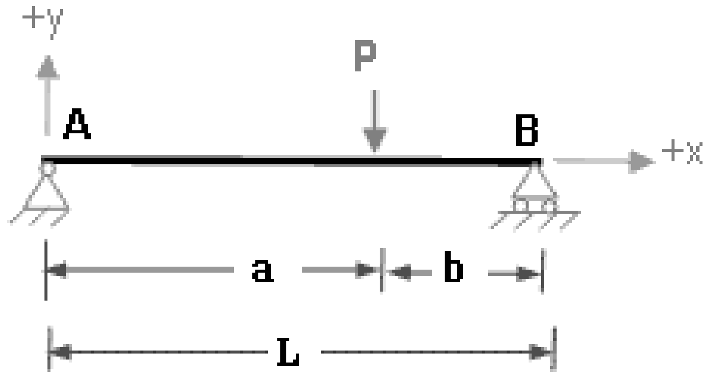

Figure 1: Beam with a load – unstructured representation.

```
/* beam A-1 - beam axis along global x axis ------------------------------- */
/* cardinal point = 1 - bottom left */
/* enhanced definitions intruduced in IFC2x4 - IfcBeamStandardCase --------- */
#1000= IFCBEAMSTANDARDCASE ('0juf4qyggSI8rxA20Qwnsj',$,'A-1','IPE220','Beam',#1001,#1010,'A-1',$);
#1001= IFCLOCALPLACEMENT (#100025,#1002);
/* set local placement so that the z-axis is co-linear to the beam axis ---- */
/* the y-axis (cross product of x & z axis) is up direction of profile ----- */
#1002= IFCAXIS2PLACEMENT3D (#1003,#1004,#1005);
#1003= IFCCARTESIANPOINT ((0.,0.,0.));
#1004= IFCDIRECTION ((1.,0.,0.)); /* local z-axis co-linear to beam axis */
#1005= IFCDIRECTION ((0.,1.,0.)); /* local x-axis */
#1010= IFCPRODUCTDEFINITIONSHAPE ($,$,(#1050,#1020));
#1020= IFCSHAPEREPRESENTATION (#100011,'Body','SweptSolid',(#1021));
#1021= IFCEXTRUDEDAREASOLID (#120,#1030,#1034,2000.);
```

Figure 2: Beam represented as an IFC object.

2. Related work

The research on the interplay between BIM and education took several directions: (a) how to teach BIM itself – mostly in the context of information technology courses and specialization [1,2,3, 4], (b) how BIM is changing the creative design process [5,6,7]. (c) how BIM is impacting construction management [8,9,10,11] and (d) how is BIM disrupting construction education in general [12,13]. This paper is in the last category (d). It draws from pedagogy research that is concerned with the construction of language and its impact on transfer of knowledge [14,15].

Research on the BIM pedagogy is slowly emerging. Eadie et al. [16] rightly claimed that BIM is more than just technological replacement for CAD and that it requires a new kind of pedagogy – generally a constructivist approach that claims knowledge is constructed by the learner rather than passed on from teacher to learner.

Hjelseth [17] explored three different pedagogical frameworks to integrate BIM with higher education: (a) Integrated Design and Delivery Solutions (IDDS), (b) Technological Pedagogical Content Knowledge (TPACK), and (c) Trinity of BIM as building information model/ -modelling/ -management (BIM3P). He suggested not to teach BIM separately but to make it an integral part of core architecture and engineering subjects. BIM disappears as a separate subject and becomes a tool for learning architecture and engineering.

3. Problem statement

To teach about architecture and engineering we use language. Books and lectures are in a natural language. Engineering concepts might have strict natural language definitions. When represented mathematically they get an implicit information model consisting of the values that mathematics manipulates. However, each discipline, each message (lecture) invents symbols on “as needed” basis. Not only are symbolic representations of a beam different in, say, Structural Mechanics Course and in Wooden Structures Course, there is no common set of symbols and no finite set of symbols.

But when these same students will start using BIM, such a shortlist of symbols (called objects or elements) with a shortlist of properties (called attributes) will emerge. In fact these terms are being standardized in an effort complementary to BIM standardization – in BuildingSmart Data Dictionary [18].

The question is, should the teaching of just about any topic of engineering take into account that there exists a list of symbols (terms) that are routinely used to communicate about buildings. Should those that teach vertical professional courses and are mentioning beams, columns, cantilevers, rebar etc. adapt their language and talk about ifc_beam, ifc_columns etc? Of course, without the ifc_prefix but in the data dictionally meaning. Should they take into account that in their mathematical models, they use values that are attributes of BIM objects? Should the textbooks of just about any engineering course be rewritten, so that language of (a) BIM based industrial processes and (b) natural or mathematical language of education would merge?

4. Communication Models in Industry and Education

This chapter presents semi-formal models of communication in engineering work and in engineering education. The models show that in engineering work the parties communicating are not just humans but software and robots, however, in the education process the communication is between teacher and student which are both human. The role human is a bridge between symbolic representations.

4.1. Knowledge communication

Knowledge has been defined as the ability to respond properly to a problem [19]. The response is a result of processes in the mind. In some cases, the response is information (i.e. spoken, written word); in others, a material activity (i.e. doing something). A well-established model that relates the real world to our understanding of it and to the words and symbols we use to communicate about it, is the meaning triangle [20] (Fig. 3). Things or objects (we shall call these “O”) are items from the real world. Experiences in the psyche or concepts (“C”) are ideas we hold about things in our minds. Words, drawings and other symbols (“S”) are used to so that we can communicate about our thoughts denoting real world objects.

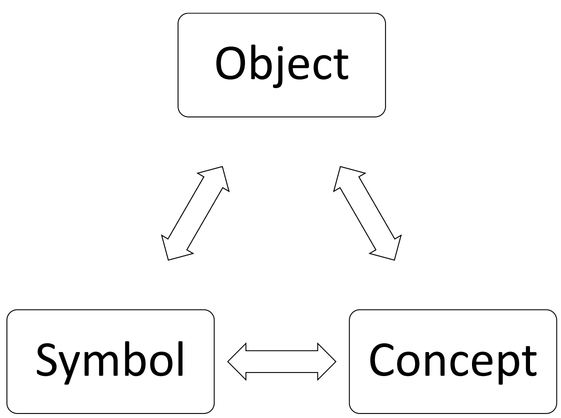

Figure 3: The semiotic (meaning) triangle.

In this context, learning is equipping the student with useful Concepts so that she can deal with real world Objects appropriately. Learning can happen in two ways.

First, on the C-O side of the triangle by gaining experiences in the real world. Experiential learning of – for example children - is happening in this way. It may also happen without creating a concept. We call this intuition. The point of

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schools is not to teach intuitions but concepts that can be represented with symbols and linked with among them with theories.

A second kind of learning takes place when we listen, view or read about real world Objects. Symbols, words, drawings, mathematical equations etc. are used for that. This learning is happening on the C-S side of the triangle. Most of the higher education learning programs are taking place along the C-S line. Students do not deal with real world objects but with their symbolic representations – like the ones shown in Figure 1. In vocational education there is practical work where learning takes place along the C-O side of the triangle.

Building Information Models are a very advanced form of a symbolic representation of buildings but are not the only way to represent buildings. Symbolic representations (models) are created to study real world phenomena scientifically or to teach about them. Several such models are created, specifically, for problem that is studied or taught.

4.2. Islands of education and conceptualization

One could argue that a phenomenon of "islands of conceptualization" exists throughout the construction profession, much like the "islands of automation" [21]. The latter idea was used to explain the problems of information exchange in the construction industry. The idea was that there exists computer software supporting specific tasks in the construction industry, however, each of these software programs is an island and can hardly talk to other software. Similarly, islands of conceptualization would mean that for different problems to be addressed scientifically and for different engineering subjects we teach, we choose to conceptualize the real would differently – we have many instances of Symbols and Concepts about the same real world Object (Figure 4). Another way of saying this is that there exist silos of knowledge and silos of learning – each topic in its own course, with its own textbooks and representations.

In teaching and in science this is not much of a problem. The conceptualizations are for human use. Teacher and student are humans. A student can switch from one conceptualization to another as she moves from class to class. Scientists in their silos each study the world with their own conceptualization.

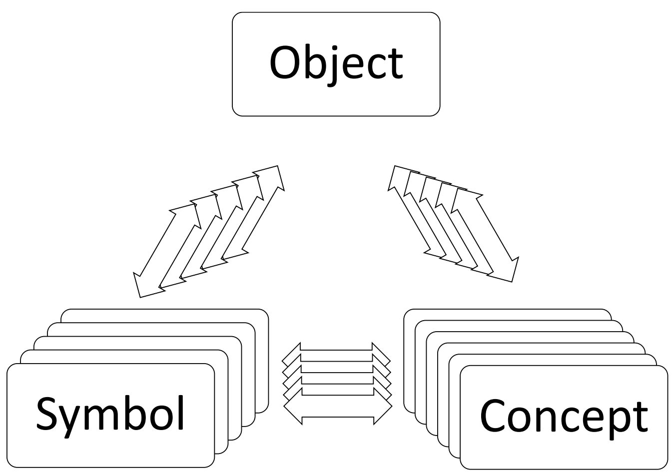

Figure 4: Multitude of Symbols and Concepts while teaching and learning about the same object.

4.3. Communication in Construction Industry

In practice, things are different. The solution for the "islands of automation" problem is supposed to be BIM – building information model - a common symbolic representation of the real would building that any software can use to get information from and add information to. There is a single real-world object that everyone is contributing to – the building being built. And there is a single social network of all people involved. These three elements – real world building, its digital representation and the social network are the three elements that are "integrating" construction industry and countering the fragmentational forces that are a result of a specialization of professions (Figure 5).

In this context construction is about changing the real-world Objects as specified in the Symbolic representations of building designs. Construction is happening on the S-O side of the triangle which has hardly been touched during

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the education process. Symbols (drawings, plans) are indeed interpreted by humans, but also by software and increasingly robots and other automation devices.

The communication in the industry used to be transactional – various people were communicating with each other, often inventing the symbolic representation fitting just the purpose of that communication act and that particular problem's conceptualization. What was going on in the industry was similar to what was happing in the classroom. In a BIM process, however, the information is not exchanged but shared and there exists a single symbolic representation for all purposes.

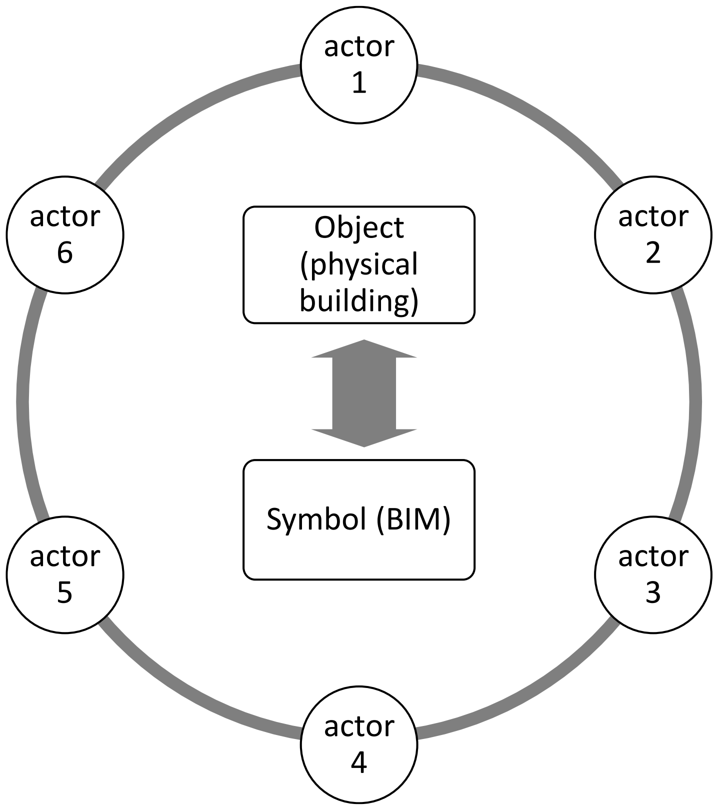

Figure 5: Single building, single symbolic representation, single social network of collaborators are integrating construction in practice.

5. Scenarios

The key problem identified in the sections about therefore is the growing difference in how the industry manages knowledge and information and how does the academia. The industry is forced – by the obvious fact that there will be a single physical building in the end – to integrate information and knowledge. With BIM and related tools it got a powerful tool to do so. Not so the academia. Few problems are caused if learning remains in silos. Until the students enter the workforce.

Therefore, the curriculum needs to change because of BIM technology. In this section we present five scenarios, five different levels on how this could be done.

5.1. Level 1: BIM modernizes teaching of CAD

In this scenario, the design communication courses that used to teach descriptive geometry and technical drawing and that used to evolve into courses on CAD, teach BIM as well. Instead of teaching the students how to document the designs using drawings, 2D or 3D geometrical models, students are taught the use of BIM modelling tools such as Revit, ArchiCAD or AllPlan. Skilled BIM modelers and BIM operators are a result.

Additional elective courses can be offered, for example Building Information Management for future BIM managers or BIM coordinators. Elective programming courses can be offered for languages such as C#, Pyton etc. to educate future developers of smart BIM objects and BIM software extensions.

There are hardly and changes in the structure of the curriculum. BIM is localized in a couple of courses.

5.2. *Level 2: BIM modernizes construction management*

In this scenario, those courses that teach skills that by their nature have an integrative role in the construction processes, take note of BIM. Such courses are courses about construction management. Management integrates varous processes, people, knowledge and resources into a construction process delivering a construction product. Project planning is BIM based. Crude Gannt and Pert charting evolve towards proper 4D BIM. Quantity take offs assume the existence of BIM. Financial flow management introduces the fifth dimension – 5D BIM. Organization and management courses educate future BIM coordinators and BIM managers. Creation of BIM Execution Plans, Information Delivery Manuals and similar documents becomes an integral part of construction management process and future engineers learn about that as a part of construction management courses.

Elective courses on strategic management of and with BIM may be offered as well.

Effects of BIM on education are still localized, however, a need for project based learning is starting to emerge so that management and design communication topics are taught integrally.

5.3. Level 3: Shallow BIM is used in vertical courses

In this scenario, starting in introductory courses on architectural and building design, BIM software is used as a toold for design evolution, and to communicate various stages of building documentation. Then students may switch to BIM tools to document designs created in vertical courses, for example Masonry Structures, Steel Structures, Reinforced Concrete, Bridges and Tunnels etc. In this scenario, these topics are still taught in isolation. Specialized software for the design of, for example, reinforcement, is still taught and used in isolation, however, to document design and communicate results, students switch to BIM software. They learn the language used in BIM software to discuss these concepts and can compare their attributes in BIM modeler software with the theoretical ones in vertical courses.

5.4. Level 4: Deep BIM is used in vertical courses

In this scenario, vertical engineering courses recognize not only the usefulness of BIM to document and share solutions but start using shared conceptualizations introduced by the BIM tools and standards. Vertical engineering courses take note of the concepts, their properties and their relations, as defined in BIM tools and vocabularies. There is an increasingly simple mapping between an attribute in BIM data structures and a variable in equations being taught. It is assumed all inputs can be retrieved from BIM database and all outputs can be stored into BIM database. Analysis software that is used, shares conceptualizations and exchanges information with BIM databases.

5.5. Level 5: Knowledge is BIMified

In this scenario, not only is BIM used to represent designs and to provide information source and sink for the analysis software. Also, professional knowledge, best practices, rules and standards – the knowledge of engineering – is beginning to be encoded as extensions in BIM software or an extension to model checking software such as Solibri [22]. Gradually, vertical engineering knowledge taught to students is not represented in natural language, textbook format but in a machine readable and automatically computable way. Teaching a vertical topic, for example Reinforced Concrete, becomes teaching about the principles behind the modules that can model-check that part of the model or propose design alternatives for that particular detail.

Of course, teaching follows the technology as model checking progresses into more and more intelligible tasks.

6. Conclusions and discussion

The paper has provided a theoretical explanation, why the entire curriculum will need to be modernized because the industry is communicating using BIM: in the industry, islands of automation are growing together, walls of the silos of activities are being taken down. In the academia, silos of knowledge could still be tolerated, because the bridging of knowledge could be accomplished manually. BIM is enabling computer integrated construction. Integrated construction calls integrated education.

In the paper, we have presented five different levels of responses of academia to BIM. Teaching BIM in isolation as a better CAD, via including BIM in integrative topics such as management towards an increasing reliance on BIM in vertical, specialized engineering courses. First for documenting designs, then in designing in BIM terms and finally for encoding knowledge in a BIM compatible way.

The last three levels call for an increasing change in the structure of the courses. Traditionally, specialized vertical courses are isolated from each other, as is the information and knowledge that they manage. BIM creates a shared representation of a building. Several courses are in a position to address the issues of the same building, each from its own perspective. This calls for integrated teaching in a project based way – it calls for “T shaped” courses where the vertical element in the letter “T” deepens the specialized knowledge the course was supposed to give. However, the horizontal element of the “T” connects to the common information model of the building and to the project students are working on (Figure 6).

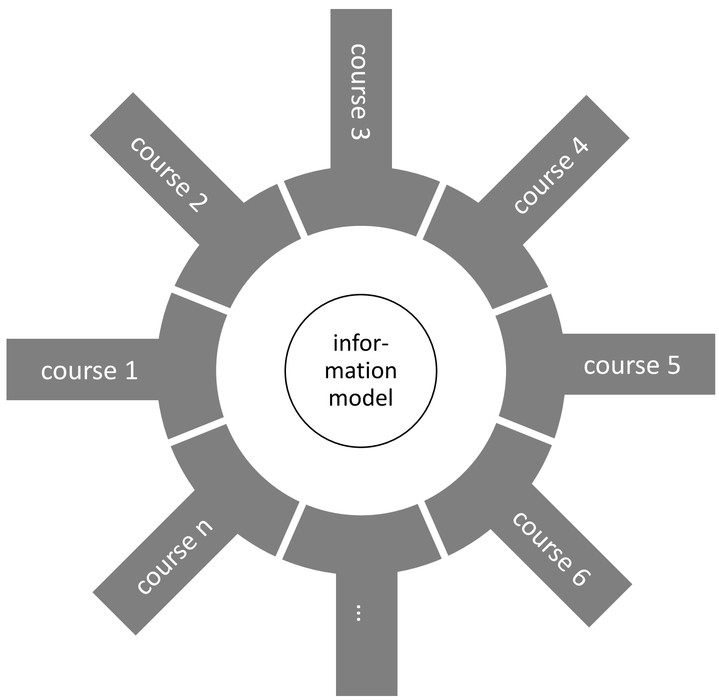

Figure 6: "T" shaped courses, integrating construction education around BIM.

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