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# Building Information Modeling in Architectural Digital Design Education: Questions and Answers

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The paper presents the results of two last year's research in digital education computing using object-oriented building modeling methods including parametric modeling, component-based design approaching to the concept of building information modeling (BIM) as a base concept of contemporary architectural digital design.

This paper summarizes results of research in BIM application in architectural design, attempts to determine the problems, capture the trends of object-oriented modeling in computer aided architectural design (CAAD) education.

The results of the analysis of various aspects of BIM using surveys of architecture postgraduate students and undergraduate students of the last year are discussed. The methods of statistics for analysis of data are used. The interrelations between various factors of building information modeling as a part of CAAD education are investigated.

The results of the work could be important for the definition of the guidelines for the future of architectural digital design education.

Keywords: *building information modeling (BIM), computer-aided architectural design (CAAD) education, object-oriented building modeling.*

## 1. Introduction

There is a lot of debate referring to the building information modeling problem that is defined by the acronym "BIM". There is not so much hesitation why and what for we need BIM in general. The importance of BIM for the architecture and building in the phases of formation of conception, design, construction and maintenance was discussed in the papers (Garba et.al. 2004, Ibrahim 2006, Cinelis 2010, Cinelis 2011).

However, some important questions remain: why the process of the adoption and use of BIM in the designing and construction practice is slow despite the fact that the appropriate software is available and the subject is taught in universities and architectural schools for rather long period? What is the relation between education background and BIM progress? Our assumption is that the reasons are particularly determined in the academic area.

The academic experiment was made while looking for the answers to some of these questions. The paper includes the results of the research and experiment conducted purposefully for two recent years at university. It also includes the experience of teaching of the CAAD subject based on object-oriented building modeling which is the base of the BIM. The problem was analyzed and generalized using the feedback from the postgraduate architecture students in the form of structured surveys. The results of the work could help positively influence and redefine the content and attitudes in CAAD subjects where BIM methods are used.

The problems related to object-oriented building modeling and BIM in education and their adoption processes in architectural and construction practice are also discussed in some papers.

In the article (Warr 2012) the author analyses different components of the problem of building information modeling. He explores the aspects of information technology, the economic aspects, the problems of copyright of BIM, the choice of BIM applications, seamless connection with the databases and compatibility of the formats, systems interoperability that detain the process of the prevalence of BIM. As a conclusion the author proposes an "open mind" approach to the problem accepting the differences of the information technology today.

M. A. Ambrose (2007, 2009) discusses how BIM alters the way composition, scale and abstraction are addressed in design studio displacing the primacy of abstract conventions with the methodology based on systems and holistic relationships thinking and explores how the academy might prepare students of architecture for a digital practice based on the virtual building model and database management.

Dokonal W. (2008) in his research investigates the state of digital design in small town Europe and tries to give an answer of how they as teachers and architects can give recommendations on how to teach design the new generation of architects while predicting the future of BIM.

The paper by M. Ibrahim (2006) also looks for the answers to similar questions: to understand the needs and identify the directions where the architectural education should go when "we shift the focus toward BIM based CAD in design schools" and "what does it mean to teach modeling versus teaching drafting"?

P. Russell and D. Elger (2008) point out that, as the effect of the new BIM paradigm, not only students become able to use particular BIM software but also learn to take the leadership in building information management. This also means understanding and controlling how the building information flows, how the methodologies that are used by the consulting engineers affect the building models, and knowing what kind of logical inconsistencies can threaten the design intention.

P. Sanguinetti (2009) examines the interoperability issues between design and analysis in professional practice and presents the results of the case study mapping the activities of two interdisciplinary student teams in the early design phases of a BIM-enabled project and proposes a curricular structure expanding professional roles.

The authors of the study (Wang and Wei, 2012) present an architectural education system that includes the visual organization of architectural knowledge and the establishment of teaching process management system with the application named AEIM (Architectural Education Information Model).

The paper by S. Boeykens and H. Neuckermans (2008) discusses advantages and limitations of different representation types, illustrated with examples from current commercial Building Information Modeling applications. The authors present arguments to adapt a hybrid approach, where multiple representations should form a series of interfaces to interact with a building model.

## 2. Methods

The research conducted during the last two last years was both theoretical and experimental. Following methods of the work and research were used: conceptual architectural design with computational design tools, experimental parametric object-oriented architectural modeling (AEC modeling), interchange of designing data, critical analysis and surveying, analysis using descriptive statistics. For the evaluating of the associations Cramer's V measure of associations and the test independence based on Chi-Square statistics were used in this work. The computation work was implemented with the statistics analysis software SPSS (Norušis, 2008).

It is important to realize and to define common objectives of the course that relate also to its contents:

- Parallel using two CAAD software environments to explore main objects and phases (procedures) of the object-oriented building modeling while generating and editing the complete building information model;
- Using formal and non-formal analysis methods to define important issues of digital design using BIM and to track the interrelations between various factors of modeling process.

BIM in our opinion should be considered not as a definite software product or identified with it. BIM is an approach, an ideology of the construction activity that should outlive the design because the data of BIM will be used when designing is over. On the other hand a valuable complete BIM requires software capable to handle appropriate problems but inevitably having both advantages and disadvantages.

The idea to use two applications Revit Architecture and AutoCAD Architecture in one course (4 academic hours in a week) was challenging from the point of view of the time budget.

What were the main issues of our course based on object-oriented building modeling? We sought to make the course rather problem-oriented than object-oriented, to prepare the students to accept and handle the situation where BIM is a means of *interoperability,* where interdisciplinary approach to designing, construction and maintenance is feasible.

The students in the course fulfilled two exercises of conceptual modeling and the final work as a BIM of the building and its surroundings. Appropriate topics starting from conceptual modeling were presented parallel in both software environments. Important idea was to underline the *evolutionary* aspects of BIM instead of static fixation of earlier developed paper sketches. Another substantial issue was the aspect of *associativity* between various parts of geometric model and non-geometric documentation elements of the project that should set up from the very beginning of the design and help to control the alteration of quatitative design parameters during designing process. Thus the value of information emerged during real-time feedback thanks to the *extracted information* for decision making in early design stages.

The quality of the final design is achieved when the comparisons of the design *alternatives* are possible. As an illustration of the significance of the integrated information of BIM implemented in one semester was the heating energy analysis of concurrent architectural design solutions (Cinelis, 2011).

Recent years of the evolution of CAAD software have an evident impact to the functions of semi-automatic *conversion* of various objects of computer graphics and AEC objects in their diverse combinations. Those functions provide great possibilities for digital design when used in an expedient and creative ways. This was also one of the main points in the course.

## 3. Results and discussion

At the end of the last course totally 59 students expressed their opinions in the survey that included five logical parts reflecting various aspects of the problem (Fig. 1). The survey process and results were in no way related to the marks of students. Many of postgraduate students as the young professionals had already had some architectural working experience.

The first part included three main and one additional question about their level of knowledge of information technology (*IT*) and computers in general, knowledge and practise from various fields of computer graphics (*CG*), computer aided design systems and particularly AutoCAD (*CAD*). That was an attempt to capture the level of computing competence of the students in general in expectation to find the factors and associations with the positive or negative attitude to BIM.The second part comprises of three conceptual questions evaluating the *complexity / simplicity*, *viability* in the future and positive / negative influence to architectural *creativity* of BIM. In the third part two questions were included about the use and viability of intelligent parametric AEC objects in comparison with simple *two-dimensional* drawings and non-parametric *three-dimensional* CAD objects. The fourth part forms a group of four questions intended to evaluate the *efficiency* of the use of the AEC objects and various typical AEC modeling procedures. The efficiency is considered as the ability to achieve the result using less time, actions, mental efforts or the ability to make the work easier. This part is not software-dependent and evaluates the technology in general.

The last fifth part was created in order to compare *two software* environments Revit Architecture and AutoCAD Architecture from the point of view of functionality and behavior of definite parametric objects.

The answers of the questionnaire were measured in ordered scale (for example, “little-good-very good-excellent”) or as the simple lists of names in nominal scale (for example, “Room/Space - Wall - Roof - …”).

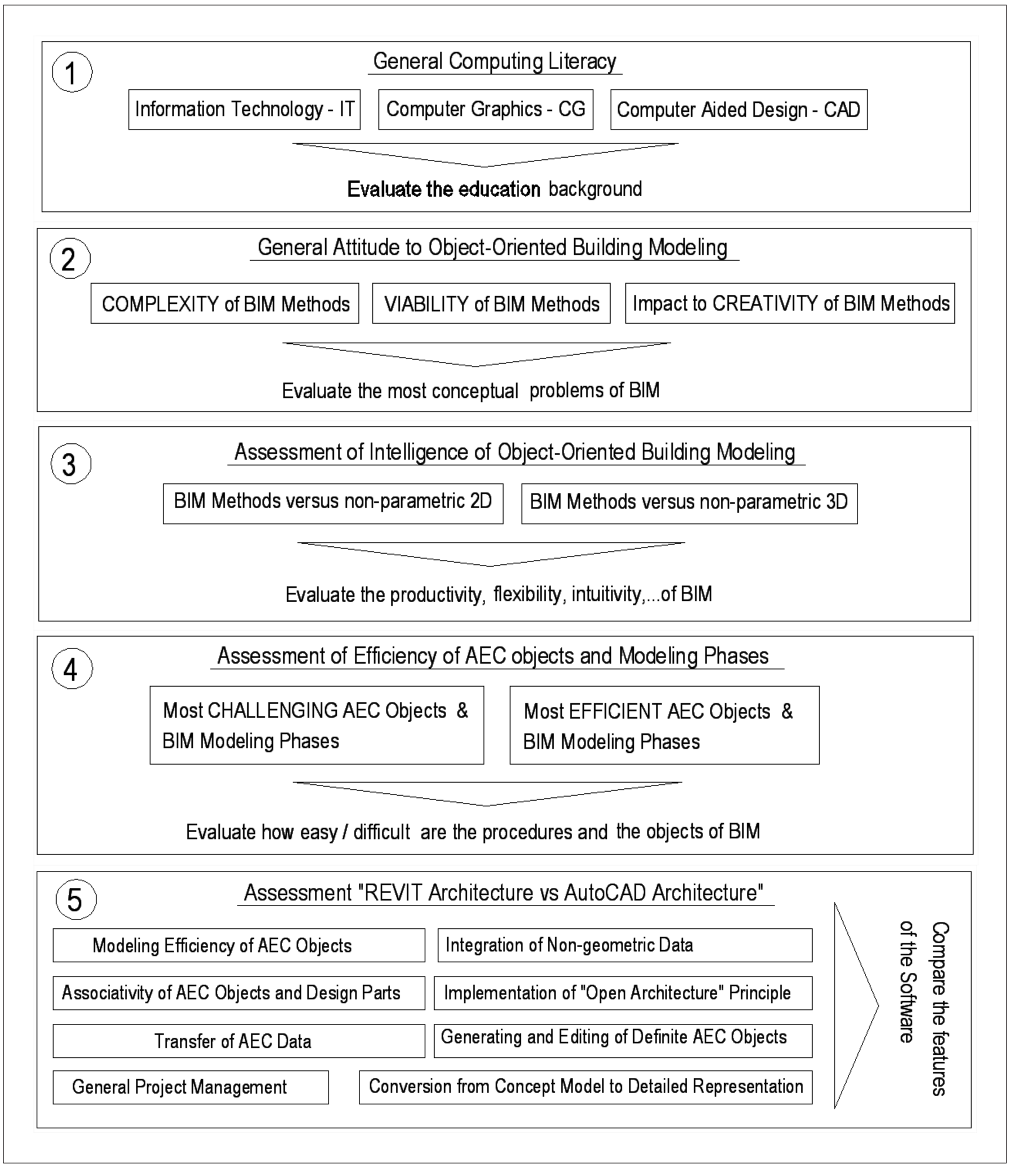


*Fig. 1. The aspects of the assessment of architectural digital design competence and BIM*

More than a half of young architects as the respondents believe they are only on the second level ("Good") in the measure scale of IT knowledge (Fig. 2) what does not create very good assumption for digital design computing competence and particularly for BIM. We expect to achieve more promising chart that would be symmetrical in comparison with the recent one and with the score approaching to 57.6 % for the third level ("3 Very good") in the nearest future.

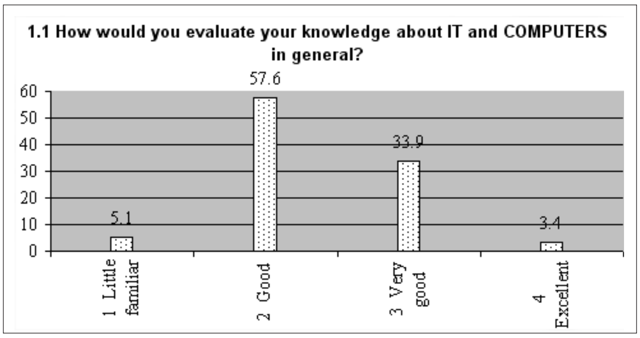


*Fig. 2. Evaluation of IT and computer knowledge*

The numbers of working fields related to computer graphics (information visualization, modeling, rendering, animation, GIS) is rather equally distributed among respondents (Fig. 3): approximately each one quarter of them have the knowledge and experience respectively in one, two, three or four fields. This index reflects rather good activity of the students in the CG area.

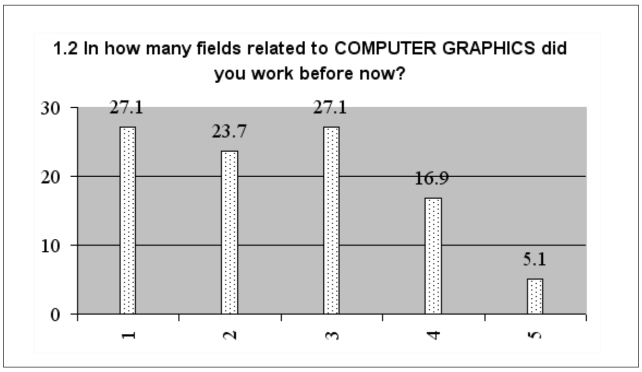


*Fig. 3. Evaluation of computer graphics knowledge*

The knowledge and experience of CAD systems different than AutoCAD are not high (Fig. 4). In our opinion, this illustrates the fact that people do not have enough motivation and feel no necessity to invest the time into the studies of alternative systems while being students.

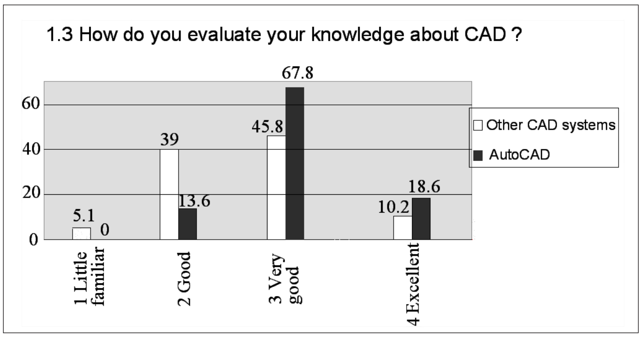


*Fig. 4. Evaluation of CAD knowledge*

The distribution of the percentage of the answers about the complexity of parametric architectural programs in the second part of the survey is astonishing (Fig. 5). This explains one of the reasons why the adoption of BIM is not an explosive process. This question was intentionally provided with five classes of answers and definite detailed descriptions of them to avoid rough evaluations and misinterpretations. The majority of the respondents (83.1 %) believe that the use of the software demands the extensive efforts and time investment. Only very small number (8.5 %) of them rates the programs as relatively easy to adopt and no one thinks it could be productively used immediately.

On the other hand, it seems that we can be rather optimistic about the nearest future of digital architectural design if we look to the results of next two questions (Fig. 6 and Fig. 7). Almost half of the architects are going to use BIM and the other half of them will definitely use BIM in the future. Even the larger part (61 %) of the respondents

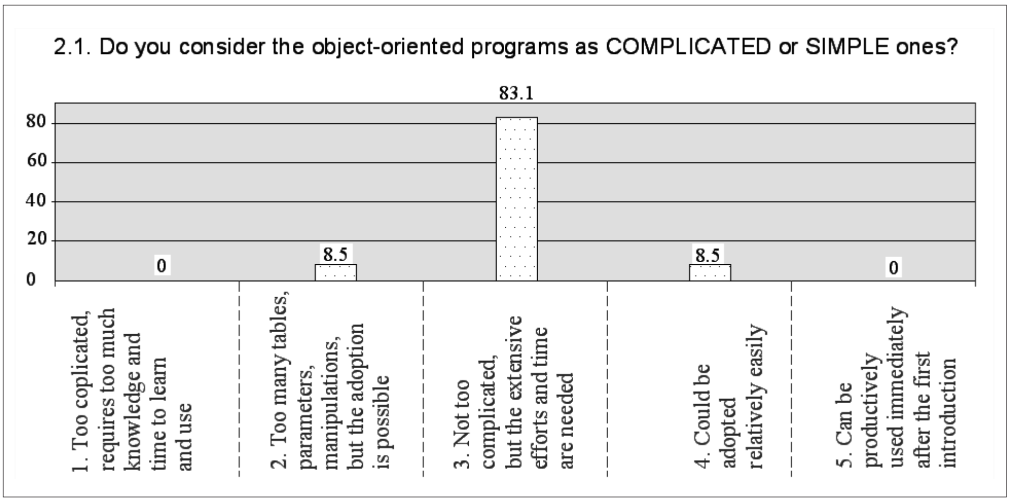


*Fig. 5. Evaluation of complexity of object-oriented programs*

are sure that the software is capable to support creative architectural design work and the third of them have positive attitude in this respect.

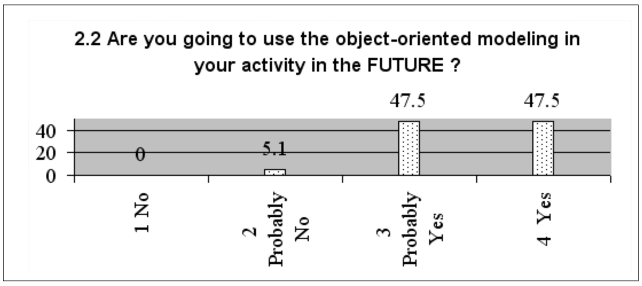


*Fig. 6. Evaluation of viability of object-oriented modeling*

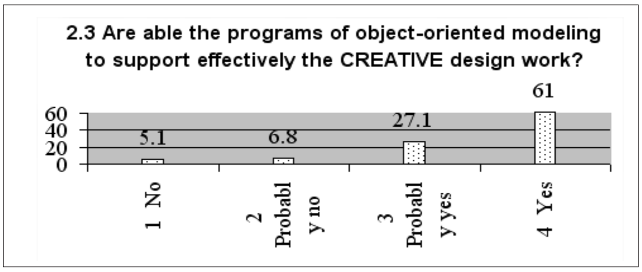


*Fig. 7. Evaluation of the impact to creativity of object-oriented modeling*

However the distribution of opinions and the graphic character of the shapes of the next two charts differ from previous ones significantly when non-parametric 2D drawings and 3D objects are compared with object-oriented modeling (Fig. 8 and Fig. 9). The peaks of the arch of both

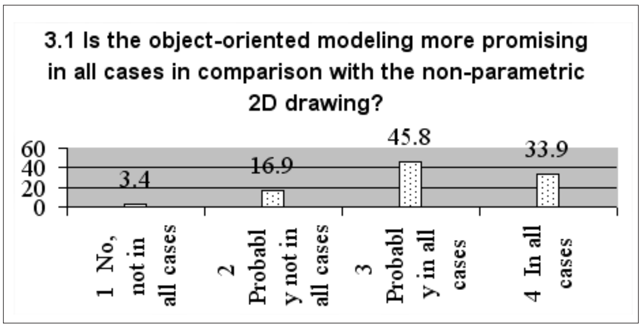


*Fig. 8. Object-oriented modeling versus 2D drawing*

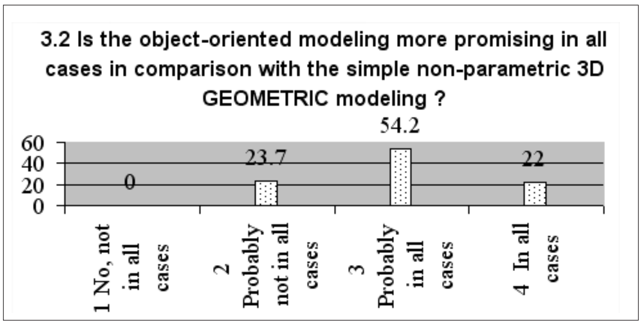


*Fig. 9. Object-oriented modeling versus non-parametric 3D models*

charts are shifted to the left, which means that the architects have more skepticism to BIM in this respect and in some cases it will not be used in favour of usual simple 2D or especially 3D geometry.

The aim of the fourth part of the survey was to find out the most efficient and challenging types of AEC objects (Fig. 10) and most efficient and challenging typical procedures of generating and editing of the design solutions (Fig. 11). There was no surprise that the distributions of the percentage of answers were in rather broad range: from most challenging “Connections / forms between objects” procedure (almost 31 %) and most efficient “Wall” (almost 20 %) object to the least problematic “Floor / Slab” object (5 %) and “Concept” (5 %) procedure. As it was expected the charts tend to appear not strictly symmetrical in the same figure because it was allowed to designate fully freely the types and the number of the objects and procedures.

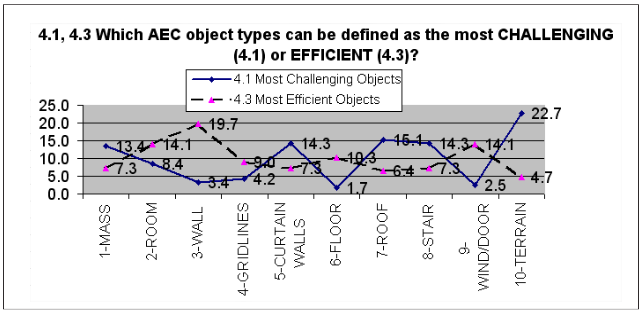


*Fig. 10. Evaluation of AEC objects types*

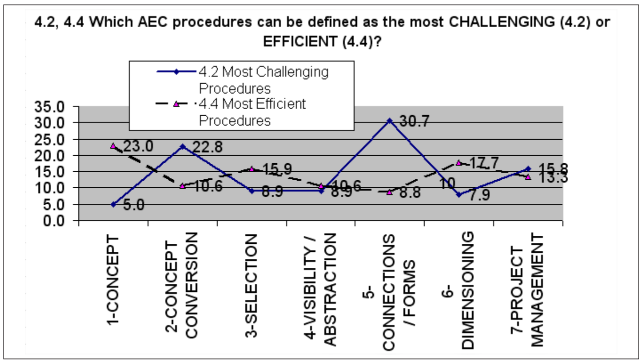


*Fig. 11. Evaluation of generating and editing procedures of AEC design solutions*

Significant generalization of that part were two classifications of the efficiency classes of the types of objects (table 1) and procedures (table 2) with the threshold value between 14 % and 16 %.

The last part of the questionnaire was intended for the comparison of main objects and procedures of the systems Revit Architecture and AutoCAD Architecture (ACA) and included twelve questions (Table 3) with assigned four answer options (Fig. 12). It is not surprising that Revit hits most of the positions because it is a modern program designed for an architect trying to capture a large part of the intuitive behavior of the architectural design process. It could be only astonishing that the number of votes for Revit for all questions except one is significantly bigger in comparison with ACA. In our opinion it could be at least

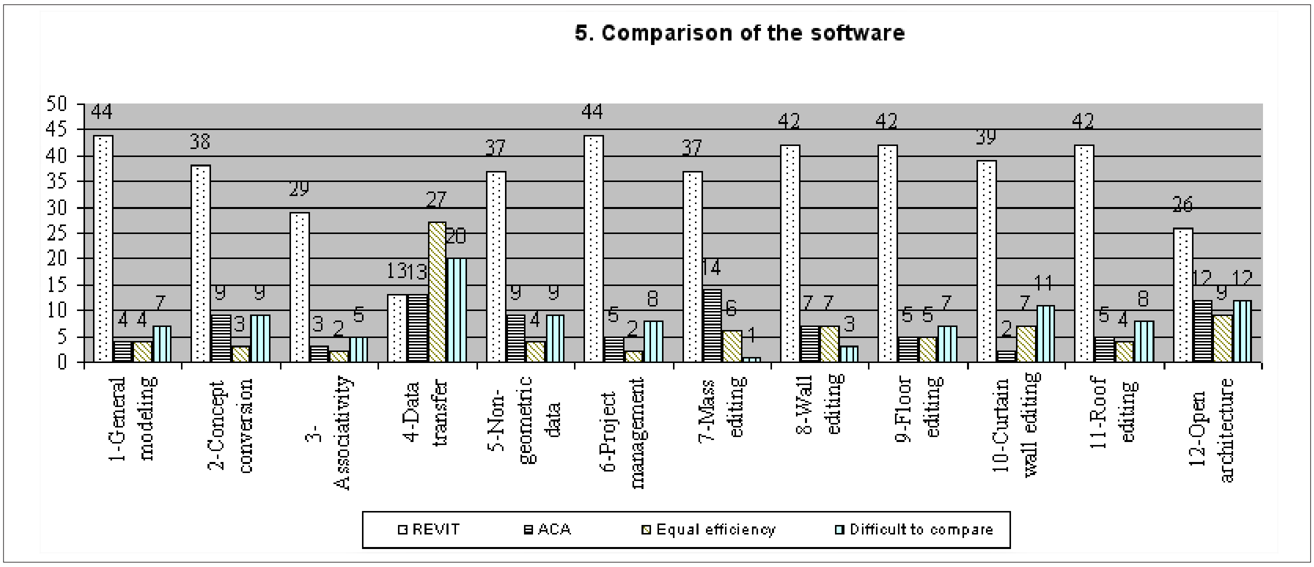


***Fig. 12.*** *Comparison of the applications*

two reasons of that occurrence. Firstly, the respondents are students who keep in their minds the requirements for the academic designs that are not the same as the requirements for real-life projects. Secondly, informal direct talks to the people prompt the conclusion that one of the reasons of that could be a psychological factor that can be described as "better is the thing I know better".

We implemented statistical analysis to estimate relationship between answers to questions from different logical parts of questionnaire (see Fig. 1). Two statistically significant associations from the same two parts were found.

There is a significant relationship between answers to question 3.2 "Is the object-oriented modeling more promising in all cases in comparison with the simple non-parametric 3D geometric modeling?" and answers to question of priority between Revit and ACA 5.8 "Which system has more efficient functions of the wall generating and editing?" (Cramer's V coefficient $C_v = 0.337$, $p < 0.05$).

There is also the relationship between answers to the same question 3.2 and answers to question from the same part 5.2 "Which system can be pointed out as more smooth when converting the conceptual model to detailed design representation?" (Cramer's V coefficient $C_v = 0.421$, $p < 0.05$).

Therefore we can predict with the probability of 0.95 that the respondents who preferred Revit in questions 5.2 and 5.8 also evaluated higher parametric AEC models in general. In other words the people who appreciate the functionality of parametric architectural objects tend to use the program like Revit.

Some other relations point out the significance of general computing and digital design competence when we analyze the relations between pairs of answers to questions from the parts 1 and 2 of the questionnaire. There are the significant associations between the question 1.1 "How do you evaluate your knowledge about IT and computers in general?" and the question 2.2 "Are you going to use the object-oriented modeling in your activity in the future?" (Spearman's correlation coefficient $r_s = 0.292$, $p < 0.05$).

Also two other correlations could be marked out: the question 1.3 "How do you evaluate your knowledge about CAD?" with 2.1 "Do you consider the object-oriented programs as complicated or simple ones?" ($r_s = 0.295$, $p < 0.05$) and the question 1.3 with 2.2 ($r_s = 0.297$, $p < 0.05$).

These correlations can be interpreted that people with higher general IT and CAD competence tend to accept easier BIM and are more motivated using it.

***Table 1.*** *Efficiency Classes of the AEC Objects*

| Most efficient | Average efficient | Most challenging |
|---|---|---|
| **1.** 3 – wall (19.7 %) | **1.** 6 – floor (10.3 %) | **1.** 10 – terrain (22.7 %) |
| **2.** & **3.** 2 – room, 9 – window / door (14.1 %) | **2.** 4 – gridlines (9.0 %) | **2**. 7 – roof (15.1 %) |
| | **3.** 1 - mass (7.3 %) | **3.** 5 – curtain wall, 8 – stair (14.3 %) |

***Table 2.*** *Efficiency Classes of the Procedures*

| Most efficient | Average efficient | Most challenging |
|---|---|---|
| **1.** 3 – concept generating (23.0%) | **1.** 4 – visibility and level of abstraction of objects (10.6 %) | **1.** 5 – connections of objects (30.7 %) |
| **2.** 6 – dimensioning (17.7 %) | | **2.** 2 – conversion of the concept (22.8 %) |
| **3.** 3 – selection of objects (15.9 %) | | **3.** 7 – project management (15.8 %) |

*Table 3. Questions for comparison of AEC objects and procedures of Revit and ACA*

| | |
|---|---|
| 5.1 | Which system do you prefer in the point of view of *3D modeling* of architectural objects? |
| 5.2 | Which system can be pointed out as more smooth when *converting the conceptual model* to detailed design representation? |
| 5.3 | In which system the concept and techniques of *associativity* between different parts of design can be used more efficiently? |
| 5.4 | Which program has better functionality of *transferring* of the models from one program to the other one? |
| 5.5 | Which system in your opinion has better practical use of *non-geometric data integration* methods? |
| 5.6 | In which system the issues of the whole *project management* are solved better? |
| 5.7 | Which system has more efficient functions of generating and editing of the *mass* objects? |
| 5.8 | Which system has more efficient functions of the *wall* objects generating and editing? |
| 5.9 | Which system has more efficient functions of the *slab / floor* objects generating and editing? |
| 5.10 | Which system has more efficient functions of the *curtain wall* objects generating and editing? |
| 5.11 | Which system has more efficient functions of the *roof / roof slab* objects generating and editing? |
| 5.12 | In which application the principle of *open architecture* of the system is used more successfully (the styles, the types, families; their modification / transfering between projects, program versions; the functionality of the IFC format; transferring of dimensions and fonts; application of the interface programming languages). |

## 4. Conclusions

The results of the survey evaluating general computing literacy of the students were important to ascertain a lack of the basic expertise in information technology in the early years of studies. The same is true when speaking about knowledge of CAD systems other than AutoCAD that is used in many subjects in universities. The architectural schools have to seek for a broader and deeper IT understanding what will also be a good assumption and intellectual basis for the BIM and digital design computing competence in the future.

After the research it is evident that the respondents took the factor of complexity of BIM software very seriously and this was not influenced by any other factors because almost every respondent pointed out the same answer. This could be interpreted as one of the most significant impediments in the process of wider adoption of BIM. On the other hand there are positive attitudes clearly visible when evaluating the factors of viability and the impact to creativity of BIM methods.

The results of survey confirm the statement that mainly because of the various problems of graphical representation of the BIM architectural information, the relevance of traditional both two-dimensional CAD drawings and non-parametric three-dimensional models still remains. It is likely that they will be used in rather wide extent in combination with BIM in the nearest future. In addition bearing in mind the versatility of the geometric language the architectural schools should keep 2D drawing and 3D modeling in their curriculum. These objects and methods still cannot be fully replaced by BIM in practice.

One of the essential results was the discovery of the most challenging and the most efficient AEC objects and typical AEC procedures using classifications based on the survey statistics. The classifications could be used both as the reference to CAAD teachers to let them know which BIM topics should be enhanced during the course and as the recommendations to software developers in order to create more convincing CAAD procedures.

Searching for the answer to one of the most popular questions in designing practice the comparison of two architectural BIM applications were fulfilled. The results indicated clear tendency among architecture students in most cases with much higher rates for Revit. In some cases it could be used for reference. However in our opinion we should not extrapolate these results to the whole architectural community in general mainly because of the limited real designing experience of the students.

The answers of the survey and preliminary analysis of the BIM situation in designing and construction business promote new questions for the future. One of the most interesting and important questions is: how we can handle the diversity of computer aided design data that is varied by its nature to provide a fluid communication channel from the project originators and architects to constructors and maintainers?

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