



Changes in the construction process and the roles in BIM implementation on the example of a public utility building

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Abstract: Resource savings requirements in projects that result from the global resource-saving need stimulate innovation in construction, both in the field of innovative materials and products, and in the improvement of all construction processes. Changes in the project are marked by risks and usually assume the need for additional resources - time and money. Change management differs for a project that is traditionally conducted in a consecutive way from project design to project submission and to a project developed by the BIM approach that seeks to put processes more and more simultaneously. This paper presents a review of the literature that defines the differences between these two approaches and establishes a framework for exploring the possibilities for improving the complex building project created and managed by traditional approach based on the theoretical background.

Key words: changes in project, BIM approach, public utility building, Faculty of Civil Engineering Osijek

Promjene u procesu gradnje i uloge pri provedbi BIM-a na primjeru zgrade javne namjene

Sažetak: Zahtjevi za uštedama u projektima koji proizlaze iz globalne potrebe za uštedom resursa potiču inovacije u građevinarstvu, kako u području inovativnih materijala i proizvoda tako i u unaprjeđenju svih procesa gradnje. Promjene u projektu obilježene su rizicima te obično pretpostavljaju potrebu za dodatnim resursima - vremenom i novcem. Upravljanje promjenama razlikuje se za projekt koji se vodi tradicionalno na konsekutivan način od projektiranja do predaje projekta i za projekt koji je izrađen BIM pristupom koji nastoji procese postaviti u većoj mjeri simultano. U radu se donosi pregled literature koja definira razlike ova dva pristupa te se na osnovu teorijske podloge postavlja okvir za istraživanje mogućnosti za unaprjeđenje projekta složene zgrade izrađene i vođene tradicionalnim pristupom.

Ključne riječi: promjene u projektu, BIM pristup, zgrada javne namjene, Građevinski fakultet Osijek



1. INTRODUCTION

A project is every single human endeavor with a clearly defined goal, carried out in stages within a given time, using a large number of different and limited resources available [1]. Unlike processes that are conducted in cycles and iterations, projects are time-limited and unique. Depending on the type, and considering the tasks of professions stipulated by particular laws, technical solution of a structure can be contained in the architectural, construction, electrical engineering, mechanical engineering and geodetic design of the structure. Design of a structure contains mutually coordinated designs that provide a technical solution and proves that the basic requirements for the structure are met at the main design development level, while the technical solution of the structure given by the main design is elaborated in more detail and harmonized at the working design development level [2].

Construction designs are often subject to changes. Projects deviate from their originally developed plans more often than follow through with them. Change management is one of the segments of construction design management because changes are one of the main causes of contracted cost and time overruns [3]. The changes are related to the design, contracting and construction processes, and to management of a spectrum of information with different forms of communication and interdisciplinary coordination [4]. In case that a significant deviation from the initial change plan at the execution stage requires an intervention, it is necessary to keep establishing new links between activities and resources and updating the dynamic construction plan.

With its Directive 2014/24, the European Parliament offered EU public procurement modernization rules, recommending member states to use special electronic tools, like virtual building model views, software tools such as Building Information Modeling (BIM) and similar contracts for public works and project tenders aimed at achieving integration of project activities and coordination of work of all participants at all project stages [5]. The directive justifies the support of BIM in public procurement projects by the fact that these tools provide more accurate data, up-to-date data and thereby resource saving. The authors [6] highlighted the problems of fragmentation of the architecture, engineering and construction industry, which is one of the greatest obstacles to accepting BIM and realizing its full potential, emphasizing it as greater than overcoming technological problems. It is precisely this fragmentation and lack of experience in interdisciplinary and simultaneous cooperation that were an impetus for interdisciplinary research aimed at assessing the usability of BIM tools and multidisciplinary cooperation when using BIM tools. The results indicate that innovation in BIM training is necessary for advancement of education and practice, with necessary changes in the curriculum design, which must take into account development of the necessary skills, more intensive communication and team coordination skills.

1.1 Cooperation in a traditional and in a BIM project

The McGraw-Hill Construction SmartMarket Reports publications, which offer analyses for the US market and the growth in BIM implementation from 2007 to 2012 and up until 2015, report about the expansion dynamics of the already developed concept of integrated and multi-dimensional design. The reports show trends in the use of BIM, the profit generated by BIM, investment return index and BIM-related investments, all pointing to its adoption and impact on the market. Concepts that pushed the construction market into BIM are the interoperability and continuous and fast flow of information between design and construction participants and it has been developing in accordance with these needs. The need for 3D modeling for the purpose of obtaining geometric indicators or making 2D documentation from 3D models is additionally emphasized for complex structures.



The complexity of a structure is defined as a dimension that includes design, infrastructure, construction technology, and the like. The authors [7] indicated six key categories for design complexity from most influential to less influential: building structure and function, construction method, urgency of construction schedule, project size/scale, geological conditions and project environment. In this, they state that complexity is not largely related to size but to the specified components. The development of BIM has made it considerably easier to design such buildings and obtain information and 2D projections.

In June 2017, the Croatian Chamber of Civil Engineers joined the international efforts to implement the BIM approach in public use projects by developing and publishing the General Guidelines for BIM Approach in Construction aimed at encouraging the application of BIM in Croatia [8]. With BIM approach, projects are no longer delivered by the traditional but integrated project delivery model.

1.2 Changes in the project and dynamics of changes

Changes occur due to the nature of design and construction. A project is characterized by a large number of participants and by execution technology. An unexpected change can directly or indirectly affect a set of activities, while the effect on activities can trigger a chain reaction and act on the next set of activities. The result of the effects can be in the difference between the planned and the realized execution. The variables of interaction can be specified as different experience of participants, different physical characteristics of the engaged resources, different availabilities and acquisitions of resources, strategies and management methods. The consequences of changes in projects include time and cost overrun despite all the knowledge and experiences.

Change management is defined as part of the process of managing the integration of project monitoring and control. All project monitoring and control processes and many execution processes create demands for changes. The demands for changes may necessitate actions for correcting resulting errors, actions for returning to the planned execution or preventive actions. For success of the entire project it is necessary for the project manager to have the capability to manage and monitor the modification of project elements, especially the scope of the entire project, which is a key performance indicator. It is necessary to follow the key performance principles and understand how to avoid common mistakes. Project modification is a change in some of the critical performance factors (scope, schedule, costs, quality and criteria for project acceptance). A change in some of the critical factors also affects other factors which then influence the project realization. An example of a linked reaction, an increase in project scope increases the amount of works, and thereby the increased amount of works affects the project schedule and project costs.

An increase in project scope in projects with contractual obligations affects the content and leads to changes of the contract. When there is a change, the project needs a way to identify the change, evaluate the impact on the project, inform project participants, and update the schedule if the change is accepted. Horine (2009) brings the classification into types of changes in a project [9]:

- increase or decrease in project scope
- increase or decrease of product property
- increase or decrease of requirements due to performance
- increase or decrease of requirements due to quality
- significant change in target data for turning points
- shift in application or strategy of development
- increase in costs for sources
- increase or decrease in project budget
- change in any of project goals
- change in any of the final acceptance criteria, including return of the planned roles
- change in any of the project-related assumptions, obstacles or dependences



- shift in roles or responsibilities within the project
- decision to move baselines because of the deviations in project realization that cannot be corrected.

Nahod (2010) presents a review of literature in the field of project change dynamics at the construction stage and classifies the change dynamics into intentional and unintentional and further identifies sixteen causes of change dynamics. The dynamics of planned activities is intentional dynamics, the direct outcome of active interventions. The positive impact of the dynamics on the project is projected as the progress towards meeting project objectives. Contrarily, the negative impact of the intentional dynamics on the project is hindrance of project progress and of meeting project objectives. Unintentional dynamics or random dynamics of the system concerns the impacts beyond the project manager's control. It can also have positive and negative effects on the project. Unforeseen events can considerably affect project processes. Changes need to be monitored over time by constantly assessing and evaluating the dynamics at regular intervals. Such a course of action makes it possible to choose more appropriate responses in change management.

2. CASE EXAMPLE - THE BUILDING OF THE FACULTY OF CIVIL ENGINEERING OSIJEK

In July 2005, the Faculty of Civil Engineering Osijek, having inherited the former barracks space, announced a competition for development of conceptual architectural design in the campus area. The competition lasted until October 2005, by which time receiving 16 works that responded to the invitation for design of an educational building that should be educative and motivational itself by its characteristics. The formal requirement for design included the need for 5,500.00 m² of net area, on a building plot of a regular rectangular shape, with dimensions 132.00 x 49.50 m, area 6.519,00 m². The jury selected the progressive and expressive work of architects Dinka Peračić and Roman Šilje with associates.

The design of the building was largely contemplated through an integrated design of the structural system that is the subject of this paper's research. The building was conceptualized through a simple horizontal organization of functional spaces, while cross-sectional superposition of levels achieved the quality of the central "public" space, which has become the most dynamic and visually most complex part of the building. Shaping of the faces by "cutting" alternating non-rectangular openings, shift of the high bearers on vertical axis have placed the building in the group of complex structures. In 2016, the building was granted an operating permit and was handed over for use to the Faculty of Civil Engineering Osijek.

2.1 Research methodology

In the design process from the competition work to handover of the building, the structure went through changes. The longitudinal structural system consists of five high reinforced-concrete bearers, which are marked as axes A, E, I, O, U in the design. This paper examines and analyzes changes to two high bearers of the east and west faces, A and U, by analyzing three documentation sets during design.

Due to the complexity and distinctive shape of the building (complex geometry of openings and gradient of face girders), 3D modeling was selected as a means of obtaining data for the analysis of changes, which would be difficult from 2D documentation that was the key graphic material of the design. The documentation needed for this paper was provided by the designers and the client.

2.2 Research methods - analysis of quantities and examination of attitudes

A comparison of data generated using the ArchiCad computer program identified changes made between the competition work and the conceptual design, and between the conceptual design and the main design. The geometric changes are manifested as changes in length, height and volume of the bearers, number of openings in the wall face, and changes in the ratio of openings in full wall face. Having analyzed the geometry and changes on the bearers, preliminary interviews with the client, contractor, supervisor and reviewer were conducted. The interviews held with key project participants were aimed at further characterizing the changes and confirming all key participants. Based on the conducted preliminary interviews, a questionnaire was developed to collect attitudes on project changes, communication and tools used. The questionnaire was semi-structured, part of the questions was prepared as closed-ended and part of the questions as open-ended. The questionnaire consisted of three parts:

- questions about the role of project participants
- questions related to information about the role of participants in the changes identified on the building faces
- evaluation of the assumptions in distribution of roles and use of documentation at different project stages including participants' own comments on possibilities for improvement on the specified subject.

The survey was set up using Google Forms service and sent to the following participants: client, reviewer of statics and associates, designers and associates, representative of the beneficiary, supervisor and project manager. Eight persons responded to the survey.

3. RESULTS

3.1 Changes of bearers A and U from the competition work to the main design

Bearers A and U were modeled in educational versions of the computer programs for BIM, Autodesk Revit and Graphisoft ArchiCAD according to the competition work, conceptual design and main design of the Osijek Civil Engineering Faculty building (Figure 1).

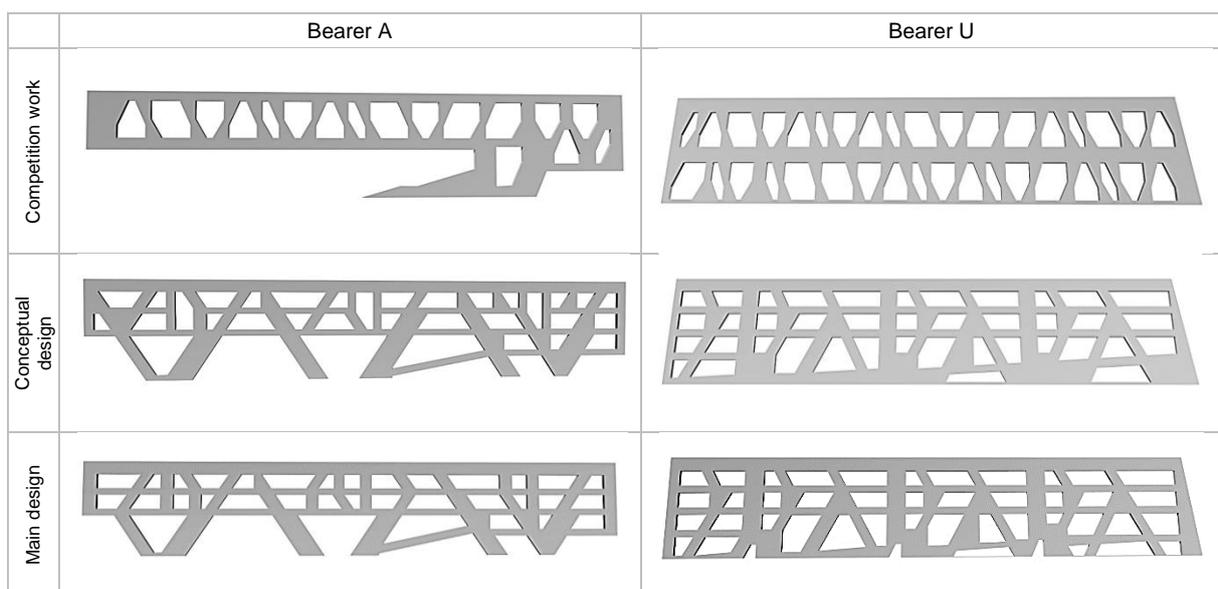


Figure 1. Illustration of the design of bearers A and U through project stages



Information from the developed models were collected for comparison of shapes, ratios, and layouts of openings, which were expressed quantitatively, and changes were assigned to the classification of changes in shape, function, technology, and quantity (Figure 2 to Figure 4). Six models were made, three solutions for each bearer, and the changes were classified according to Horine (2009).

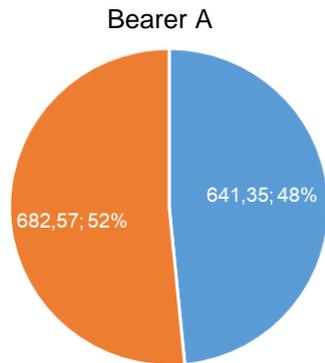
The survey questionnaire and interviews with the project participants were aimed to examine which tasks the participants perceived, with which tools and how intensively they communicated, as well as how they assessed the collaboration and tools they used. By examining the changes, it can be observed that most changes belong to the type of changes in product properties, specifically the static structural properties in the case of the observed building. They are followed by the changes due to quality that can be interpreted as the changes that are also indirectly caused by previous changes and changes due to performance and increases and decreases in project scope that occurred at the stage between the competition and development of the conceptual design. Table 1 presents changes on high bearers of the Faculty of Civil Engineering Osijek according to the classification of project modification types in Chapter 1 of this paper.

Table 1. Classification of changes on high bearers of FCEOS according to Horine [9]

Increase or decrease in project scope	change in length and height of the bearer as a whole change in shape, number, layout and size of openings change increase in volume of concrete
Increase or decrease of product property	change of the static system - change in number, size and base support points of girders change in shape, number, layout and size of openings change increase in volume of concrete change extension of the horizontal beam along the entire length of the wall change in running bearer walls vertically and change in width of bearer wall horizontally (opening-to-opening spacing) change in number and height of horizontal beams in relation to floors
Increase or decrease of requirements due to performance	change in layout and area of openings in relation to floors change of construction technology - placement of concrete in formwork change - small change of gradient of individual openings and their shape
Increase or decrease of requirements due to quality	change of the static system - change in number, size and base support points of girders change in the size of clear (open) area change of openings, joining some openings into a whole, dividing some openings change adding a new number of openings for windows and doors

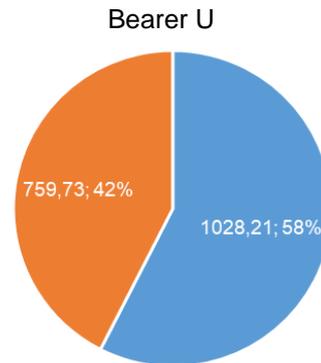


Competition work



■ Bearer area (m2) ■ Bearer openings area (m2)

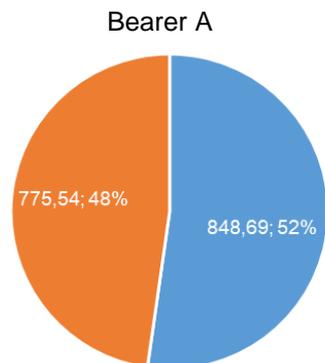
Figure 2a. Ratio of the areas of walls and openings in the total area of bearer A



■ Bearer area (m2) ■ Bearer openings area (m2)

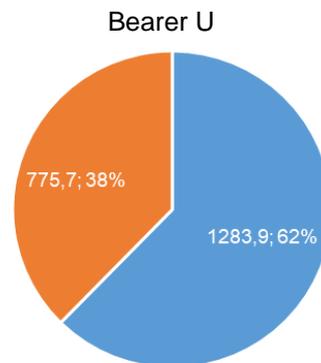
Figure 2b. Ratio of the areas of walls and openings in the total area of bearer U

Conceptual design



■ Bearer area (m2) ■ Bearer openings area (m2)

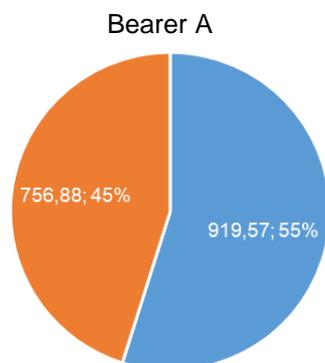
Figure 3a. Ratio of the areas of walls and openings in the total area of bearer A



■ Bearer area (m2) ■ Bearer openings area (m2)

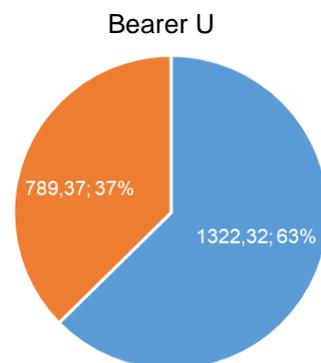
Figure 3b. Ratio of the areas of walls and openings in the total area of bearer U

Main design



■ Bearer area (m2) ■ Bearer openings area (m2)

Figure 4a. Ratio of the areas of walls and openings in the total area of bearer A



■ Bearer area (m2) ■ Bearer openings area (m2)

Figure 4b. Ratio of the areas of walls and openings in the total area of bearer U

3.2 Results of the questionnaire - roles, responsibilities and communication

In the first question of the survey questionnaire it was necessary to choose one of the traditionally used names of construction participants. Responses indicate that two construction designers, and one architect, client, reviewer, supervising engineer and project manager responded to the survey. Although one person identified himself as project manager, in the question requiring the definition of the task taken over, there is no answer about the tasks of project manager but the client stated that one of his tasks is to monitor and control the project. In the tasks stated by other participants, nobody described the task of project manager.

According to the survey results, the respondents who are independent project participants are the structural designer and the reviewer and they represent a minority; others who represent the majority, and are part of the team and they are: representative of the beneficiary, supervising engineer, architect, project manager, client, associate reviewer. According to the answers, the architect is part of the largest team in which 18 persons have certain tasks. The architect and the reviewer have the highest involvement at the stage of the competition work and conceptual design, while the structural designer also has high involvement in the conceptual design. Later responses show that the structural designer had a high collaborative role. The structural designer, reviewer, architect and client are fully involved in development of the main design.

In relation to the BIM approach that calls for all participants from the beginning of the project, contractors and project managers should be involved at the level of the conceptual design. The difference between the traditional and the BIM approach is also indicated by responses of four participants related to the competition work and main design and three participants related to the conceptual design, who pointed out that they were not involved in any of the design development stages.

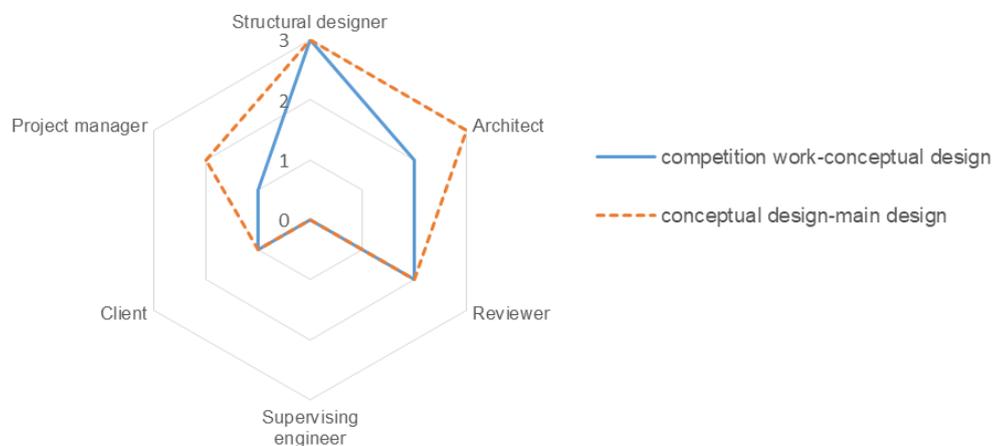


Figure 5. Comparison of participants' involvement in changes on the face

The decisions on changes on the face of the building at the stage between the competition work and the conceptual design were mostly initiated by the reviewer and structural designer for structural reasons, and according to Horine [9] these changes are classified as *increase or decrease in product property*, most other changes are indirect due to changes of the structural system and they closely cooperated with the architect on this issue. Four respondents were involved in change of the structural system on the face, and three in the design of openings (Figure 6). Changes related to the quantity and construction technology of the final wall layer were not considered at this stage; they were not considered in changes between the conceptual and main design either.



In the changes between the conceptual and main design, three participants were involved in changes involving design of openings, structural system, the amount of openings and construction technology of the structural part of the wall and the method of bonding layers of the multi-layer wall. The fact that the contractor was not involved at these project stages was later reflected in problems during execution of the observed structures.

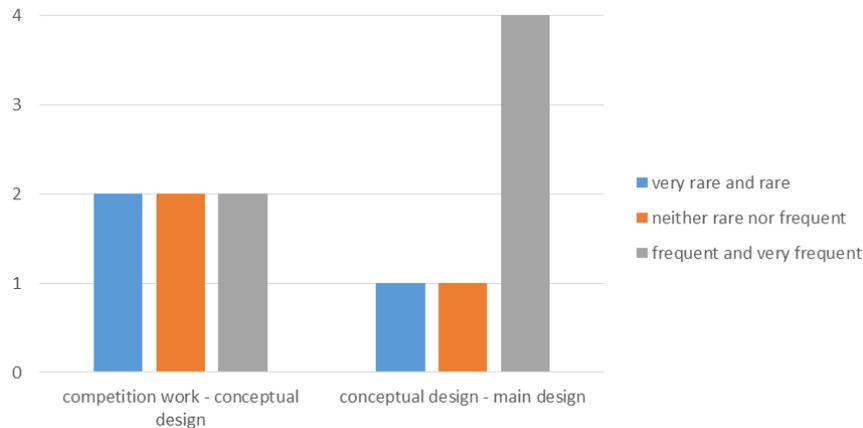


Figure 6. Assessment of the intensity of communication on changes on the face

3.3 Results of open-ended questions and comments of participants in the project

The respondents responded to ten open-ended questions that were aimed at collecting attitudes on the distribution of roles in the project, communication methods, media and intensity in the project and during changes. Respondents' comments on roles in the project point to the lack of additional specialists for completely specific fields of construction but also to the lack of project managers. The structural designer states that a "*more specific terms of reference*" are required with conditions for execution, "*higher-quality data*" from public authorities. The architect states that the project lacked the roles of "*concrete technologist, feasibility and maintenance expert, graphic designer and artist*". The supervising engineer points out the importance of close cooperation between the architect and the designer "*already in the development of conceptual solution*". If this cooperation is absent, major or minor changes to the building design subsequently regularly occur for structural reasons, as was the case with the example of the building of the Faculty of Civil Engineering Osijek. The client very clearly states and emphasizes that "*project management is missing*" at a higher level with the proper project manager "*with knowledge of economics, construction and architecture*."

In questions on the responsibilities for changes on the face, the respondents did not express a single doubt about insufficient roles. The architect states that the initiated changes are caused by "*elaboration details*" that come with details of the required documentation. As a team, "*they managed changes and, together with the structural designer, made key decisions based on the beneficiary's requirements for internal spaces and information from the fire protection designer*." By their experience and knowledge of the project, the supervision states that changes on faces are the result of elaboration of the structure, fire protection system and interior layout of rooms according to the terms of reference amended by the beneficiary.

At the stage between the conceptual and main design, the focus of changes is shifted to construction technology, but changes in the fields of design, structure and quantities of openings are still initiated.



The architect and the reviewer, who are also the main actors, point out an excellent distribution of roles during development of the competition work, conceptual and main design, the structural designer considers the distribution of roles to be very good, while other participants do not have a clear view on this issue. The problem of remoteness of architects from the construction site is indicated as one of the problems.

On the question of the use of graphic material in communication, the architect, structural designer and reviewer consider it very good, while other participants in the project cannot give an assessment. The duration of the project conceptualization, definition and implementation stages (from 2005 to 2016) lead to outdated development tools. The problems with changes in equipment are also manifested because of the newer equipment in relation to the advanced years of the project. A comment is present that record keeping at the beginning of project development was not at a satisfactory level and that "*applying FIDIC contract models would help the projects.*" Along with FIDIC contracts, it is assumed that possible improvements are to advance the quality of project documentation, reduce the probability of errors and inconsistencies in project documentation, speed up the work, and increase competitiveness.

Respondents described the method of communication in the project as satisfactory with a comment on the negative external impact on the project of "*long waiting for the decision of the Government of the Republic of Croatia on relocation of substation underground cables.*" On the questions about the importance of this subject, five respondents answered that the questions were well formed and within the subject, one respondent answered that he could not form an opinion because the focus on the subject was unclear to him, and one respondent asked for an individual interview on the subject. Seven respondents believe that the subject is important with the remark: "*if it leads to a solution of better design work process.*"

4. DISCUSSION AND CONCLUSION

The case study of the Osijek Civil Engineering Faculty design gives an overview of changes presented for the design conceptualization and definition stages - development of the competition work, conceptual and main design. The changes are presented by creating and analyzing the 3D model. The differences between the changes on bearers A and U can be established by inspecting the changes. Bearer A had more intense changes - there was a substantial change in the ratio of openings to full bearer, where the area of openings at the design stage was greater than the bearer area but with a decreasing trend and the number of openings almost doubled - from 17 to 31. The ratio of openings on bearer A was reduced by 7% while on bearer U it was reduced by 5%. The large cantilever of bearer A planned in the competition work was changed to another static system, which caused major changes that were then considered in the context of function. This change also caused changes in the interior of the building. These changes could only be solved by management decisions.

After identifying changes using 3D modeling, types of changes were associated in accordance with Horine's classification [9]. Changes due to quality, which in this case is the quality of the static system, also point to management decisions during changes on the face, as well as changes in scope (dimensions of bearers and the ratio of openings in full wall) in all project steps. The sequence of changes in spatial planning documentation that includes the campus area in which the Faculty of Civil Engineering Osijek is situated is identified as unintentional, external dynamics, which is the decision of the competent authority [3]. Unintentional dynamics is problematic for the project because project management and control becomes more difficult.

In the example of monitoring changes on the face of the Faculty of Civil Engineering Osijek based on information collected from project documentation, interviews with participants and survey questionnaire, we can conclude that the changes on faces are



intentional and that the dynamics of the observed changes was related to the decision-making processes and changes in technology and technique.

The results of the survey questionnaire indicated to a great extent the cooperation and distribution of responsibilities between the architect, structural designer and reviewer. Communication between the professions was not through 3D models and 2D documentation was used. The initiators of changes were the reviewer and the structural designer for structural reasons, and these changes indirectly lead to further changes. Initial changes were caused by the details in the development of documentation. Lack of expert roles for specific fields and lack of project management at a higher level are emphasized.

It is clearly evident that application of the BIM approach would facilitate more efficient cooperation between professions, higher-quality and faster development and exchange of documentation, overview and control of the project. Probability of project modifications would be reduced because all participants would have access to complete information on the building model, which is electronically shared in a common environment, and which is fragmented in a traditional approach to project management. Lack of project management at a higher level would be covered by the role of BIM manager who would have a leading role in facilitating, managing and participating in project solutions, especially in initial project stages.

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