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EARLY EXPERIENCES OF INTRODUCING MULTI-DIMENSIONAL CONSTRUCTION MODELLING INTO CURRICULA OF BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

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Abstract

Rapid development of computer applications - both in hardware and in software aspects - gives us hope and possibility of integrating multi-dimensional approach into teaching and modelling Construction within usual time-frames of higher education. Actual challenges are fitting time-taking model construction efforts into curricula of university courses and turning multi-dimensional visualization to multi-dimensional modelling via searching algorithmic interrelationships among the dimensions modelled. Our experiences show that to find balance between efforts and results we may introduce Multi-Dimensional Modelling facilities in early years of higher education on voluntary basis and should set obligatory for students of higher years of special courses. The main obstacle of wider penetration of Multi-Dimensional Modelling in Education actually is the still inadequate interoperability of software applications in use when discussing different engineering aspects of Construction according to the subjects of the curriculum. To overcome this obstacle acceptation and introduction of BIM philosophy and IFC data standards would be desired in education too, that aligns with general administrative endeavours to develop standards of data structures to be introduced the following years. Building-up open databases and developing free interfaces among individual software applications are promising ways of widening our abilities to model processes of Construction in a "real-time" multi-dimensional space. The paper reports some early experiences of 6D+ construction modelling via works of students of Construction Technology and Management at Budapest University of Technology and Economics.

Key words

BIM; computer applications; construction modelling; higher education

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1 INTRODUCTION

Construction Industry of our days has to face manifold challenges and expectations. Not only the final products but also the processes of production have to satisfy different kinds of needs (stability, aesthetics, functionality, ecology, etc.) and must obey probably the strictest (legal) regulations ever set against a branch of the economy. When realizing any construction projects decision makers have to consider countless aspects and kinds of resources at the same time. In this Multi-Dimensional Space manifold components of construction have to be kept in hand individually and in close relation to each other. Our education must not only keep up with these challenges but must be a step before actual practice since by its mission Higher Education must prepare future professionals to satisfy future needs.

Due to technical advances and general use of computer technology (nearly all professional fields are assisted by computer applications and practically all our students have direct access to computerized world) the main question is not "if yes or not?", or "what?", but "how" we can introduce multi-dimensional problem solving and modelling techniques within traditional time frames of higher education without laying unbearable loads on our students but with providing them with the widest overlook on available- and on foreseen technical possibilities.

At the Department of Construction Technology and Management of Budapest University of Technology and Economics (BUTE DCT&M) since turn of the last decade we have been systematically testing acceptance (by our students) and suitable proportion of computer aided multi-dimensional modelling techniques applied at discussing countless inter-related aspects of on-site Construction Management. How and what applications our students have free access to (use of which could be obligatory) and how ready they are prepared at particular level of their education to face challenges of working in a Multi-Criterion Space of Decision Making. The paper reports our efforts and early experiences of introducing multi-dimensional construction modelling into educational practice citing individual works ("projects") of our students.

2 FORMING A MULTI-DIMENSIONAL SPACE

When referring to Multi-Dimensional Modelling in Construction up to the first five Dimensions expressed are usually the same: 3D Euclidean Space, +Time and +Cost. Further dimensions are typically chosen from limited resources (human, material, equipment, etc.) of special interest increasing "extent" of Space of Decision-Making not rarely over 10D or even higher. In our context – when discussing feasibility of on-site works – we usually consider all or any selected elements of input (typically all or some selected resources) as 5th Dimension (as "Efforts"), and one or a few selected technical aspects of output (typically some measured and/or monitored characteristics) of the performances as 6th Dimension ("Performances"). For the later most frequently chosen are crucial behaviour of the semi-finished structure and/or that of temporary conditions such as stability, loadbearing capacity, emissions to the environment, or suchlike.

Also considering domains of courses of our Education Programs in Civil Engineering the most frequent arrangement of the Multi-Dimensional Space is:

- 3D Euclidean space, representing the object under examination itself (typically an architectural or structural unit)
- Time, either as date or period, representing dynamism (typically period of accomplishment or of operation)
- Efforts, representing resources necessary to accomplish or to operate the unit (typically financial-, material-, equipment-, human resources and/or combinations) usually in possession of the Contractor

- Performances, representing characteristics of the unit under examination (typically loadbearing capacity, stability, functionality, thermal-, acoustic- and other features) usually defined and monitored as expectations set by the Client

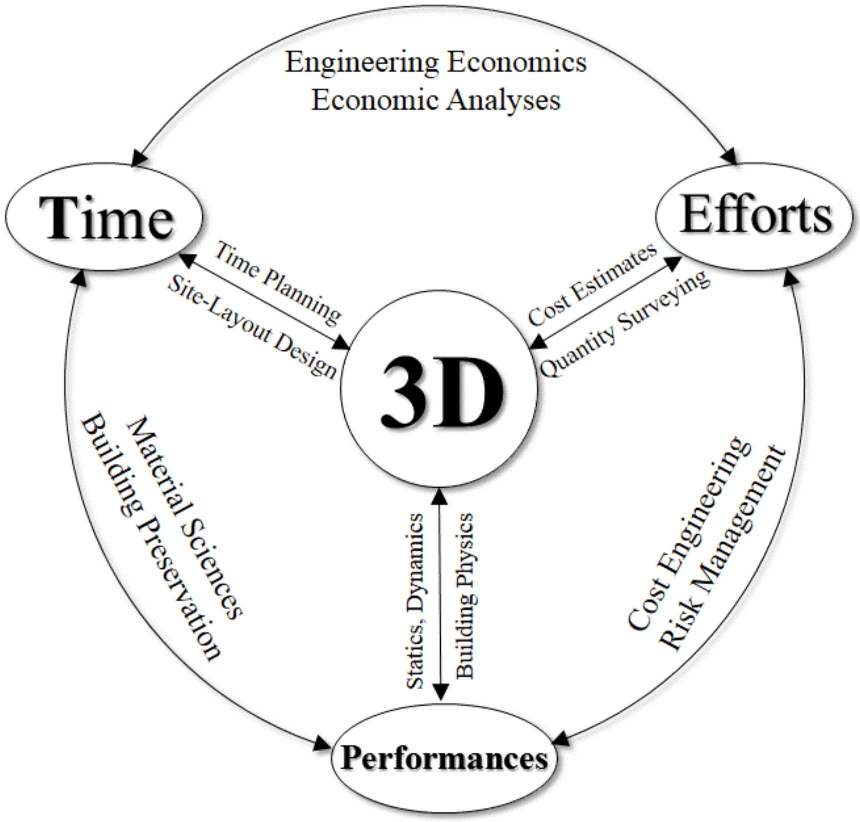

Fig. 1: A 6D model space with disciplines in its sections

It is out of question that projections of Construction Site or Project in these 'panes' (dimensions) are related to each other, though – due to didactical reasons – they are discussed individually or at maximum in pairs in obligatory or elective Subjects of the Curricula. (See: Fig. 1)

3 SOME 'LINGUISTICS'

Forasmuch the word 'modelling' in general is used in various contexts, we have to make distinct interpretations of ways of projecting reality according to abilities inherent in the 'model' constructed. For our discussion we distinguish:

- A mock-up ('maquette') is a static, scaled 'model' of an object (such as buildings, automobiles, ships, beings, pieces of art, etc.) reflecting external appearance only, paying less or no attention to the behaviour of the object projected.
- A Simulation focuses on the behaviour of the object or of the phenomenon, reflecting "action-reaction" or "input-output" relations, but paying less or no attention to real transformations within (between input and output).
- Modelling also focuses on behaviour of the object or of the phenomenon and its input-output relations but with main emphasis on transformations within. It is frequently not associated with fidelity in physical representation ("look") of the phenomenon. Such as 'mathematical model' of local weather conditions, 'structural model' of a building, 'sociological model' of a community, 'network model' of a project, etc.

Due to some slight differences experienced in use of technical terms in British English and in American English – to avoid misunderstanding – we also have to distinguish Construction from Building.

- Building refers both to the processes at the work site and to the facility (house) itself in British English.
- In American English building refers rather to the facility (house) while processes at the work site are generally referred as Construction. (We do follow this later.)

In our context we use the term Construction Modelling in relation with Modelling Construction Sites or Construction Projects with main emphasis on inter-relationships of different aspects (dimensions) of them. In its aims it is close to Multi-Dimensional (4D, 5D, 6D, etc.) Modelling of Construction Processes frequently referred as Virtual Design & Construction [1]. The main difference is that we pay more attention to temporary conditions and structures, to technologies and to resources commanded on/at/to the Site – from the view-point of the Contractor.

4 BIM OR NOT BIM

BIM (Building Information Modelling) is defined by U.S. National Institute of Building Sciences as "*... a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward*" [2]. One of its most essential feature is accepting and promoting IFC (Industry Foundation Classes) data standards (ISO16739) developed and maintained by BuildingSmart [3] to provide smooth and save communication (interoperability) of computer applications developed by individual vendors.

Significance of the later is highlighted by Gallaher et al [4] who identified a 15.8 billion US$ extra cost yearly due to inadequate interoperability of software systems and insufficient communications and data-transfer among computer applications parallel in use in US economy.

Researches and experiences already at the birth of BIM idea drew attention of developers to lay increased emphasis on interoperability of potential applications and suggested introducing BIM into professional education too. They also indicated potential legal conflicts of data possession along the lifecycle of the facility [5].

At this point it is necessary to highlight that promoters of BIM smartly chose the words 'Building', 'Information' and 'Modelling' referring to modelling Information-Flow essential at each Building from inception to final removal. This way – with the Facility in its focus – the main emphasis is on Information Modelling and less on Building Modelling.

With rigorous eyes we can recognize that actual invention of BIM is linking up Architectural and engineering designs (being assisted by 3D facilitated software systems since decades ago) with routines of Facility Management (having been also a Computer Aided Discipline for decades) by composing continuous and related information flow.

The idea is promoted not only by professionals but not rarely by governments too. Recognizing economic potentials of BIM British Government encourages endeavours of the development and penetration of BIM in the UK economy – in co-operation with designers, manufacturers and vendors interested in Real-Estate Industry – since it fits the declared Industrial Strategy [6].

As part of 'e-government' concept Hungarian Administration has also made efforts to standardize electronic communication in Construction obligating contractors to use newly introduced on-line Electronic Site Diary as Building Registers (first in parallel with-, later instead of traditional offline and/or printed or manually kept Building Registers). Though some criticism points at its centralized manner as a non-welcome intention of centralization of the current Administration.

Seeing intensity of penetration of BIM technology in construction industry and also seeing endeavours of governments to ease communication throughout the economy and administration it can be expected that within some years national and/or international standards and agreements will regulate data-flows and data structures in some strategic branches or in the whole of the national or allied (European, American, Asian, etc.) economies.

In this context BIM is expected to become the “interface” while “tools” of multi-dimensional construction (site) modelling will be connected to it via accepted (IFC) data standards providing essential interoperability of computer applications aiding related disciplines of Construction.

5 CURRICULA OF CIVIL ENGINEERING

In general, Curricula of Civil Engineering Programs at Budapest University of Technology and Economics [7] conform to similar courses in the rest of European Countries. It includes some basic courses of essential disciplines such as mathematics, physics, mechanics, dynamics, construction materials, building structures, geodesy, geology, hydrology, highways, railways town planning, etc., together with some supporting courses such as computer applications, management (in general), law, micro- and macroeconomics, history of Architecture, etc.. After specialization (semester 5) special design courses are offered such as infrastructures, railways, roads, bridges, tunnels, high-rise buildings, hydraulics, soil mechanics, building physics, construction technologies, etc.. It could be remarked – as a kind of criticism – that most of these subjects are design oriented, paying no or slight attention to technologies of accomplishment.

On Branch of Structural Engineering curriculum includes 2 obligatory subjects (“Construction Management – Estimates” and “Construction Management – Contracting”) discussing on-site construction management and preliminary project planning in 2 semesters (semester 5 and 6), for altogether 5 credit points. Domains of the 2 subjects embrace basics of time- and cost estimates, site layout design, construction equipment, resource management considerations, procurement systems, network techniques and some aspects of engineering economics. Students have to elaborate individual projects as homework (in both semesters) and have to pass 2 mid-semester tests (semester 5) and a final exam (semester 6), too.

For students of Speciality of Construction Technology and Management six further subjects are offered: 3 technology oriented subjects (Basic Construction Technologies, Finishing Works and Pre-Fabricated Structures) and 3 (site-) management-focused subjects (Managing Large-Scale Construction Projects, Contracting in Construction, and Organizing Erection of Prefabricated Structures) for altogether 20 credit points in 2 semesters (semester 6 and 7). In each subjects students have to elaborate individual projects and they have to pass final exams, too.

Typical Diploma Work (semester 8) of the Speciality aims at Technological Designs of a fictive or of a real project (5-10 students per semester), or at Time Estimates, Resource Management Plans and Site Layout Designs of an on-going actual project – in co-operation with construction companies – and/or at a selected issue of Construction Management, such as Health and Safety Coordination, Risk Management, Quality Management, Sustainability, etc. (10-15 students per semester). Credit value of Diploma Work is 24 credit points. (Earlier – in the 5 years training system – this value vas 30 credit points.)

These later 2 course-blocks (Speciality of Construction Technology and Management – and its Diploma Works) are suitable potentially to introduce multi-dimensional construction modelling approach into curricula. And really, these were/are the basis to do so.

6 EARLY EXPERIENCES

Homework

By the curricula of subject "Managing Large-Scale Construction Projects" (4 hours/week, 4 credit points) students have to elaborate Bill Of Quantities, Time Estimates, Site Layout Design of a fictive project (an overhead crossing to be built of incremental launching- or beam and slab technology, or an industrial hall to be built of prefabricated reinforced concrete elements) as individual project (homework). Considering 14 weeks of the semester + 1 week completion period, elaboration of the project is estimated (expected) to lay 60 hours individual work charge on each student.

Early trials to introduce 4D construction modelling (spring semester of 2012) focused on virtual reconstruction of the construction site at a selected relative date of performance based on the schedule developed by the student. (See: Fig. 2) The main emphasis was on testing multi-dimensional representation techniques using available computer applications.

Software used by the students was mainly AutoDesk AutoCad, GraphiSoft ArchiCad, Google SketchUp (and its 3D Warehouse), MicroSoft Project and MicroSoft Office Environment.

Acceptance of new modelling techniques applied by students was far above the level expected. Most of the students liked the work though it was assigned for them as an obligatory task and elaboration of site layout design took about 2-3 times more time than necessitated by traditional 2D drawing techniques [8].

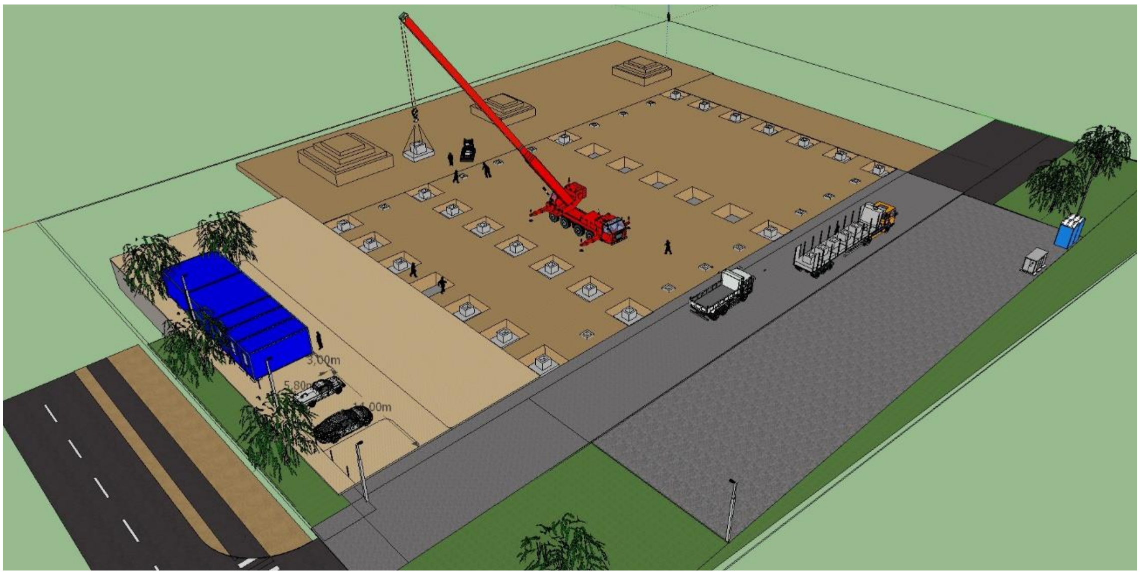

Fig. 2: 4D+ model (phase drawing) of erecting a prefabricated reinforced structure. Detail from home work by Eszter Kovács, student of Civil Engineering, BUTE DCT&M, 2012

To be honest it must be confessed that due to still prevailing software incompatibilities, lack of modelling experiences, and poor available model library (of equipment, construction elements, temporary structures, etc.) engineering quality of the models prepared by the students was far below the quality of the traditional 2D design techniques. (Instability of temporary conditions, improper equipment selection and/or positioning, improper and/or exaggerated temporary structures, situations of extreme hazard or danger, superfluous unimportant details, etc.)

The same time, 4D, 5D on-screen displays and representation techniques proved to be smartly available and readable, and proved to inhere significantly increased informing power.

Having our model library richer and richer semester by semester, our attention could turn from pure representation techniques to engineering quality. Though 4D construction site modelling was temporarily withdrawn as an obligatory task (due to increased workload it lays on the students), and turned to be elective, some of the 20-25 students of the courses do develop 4D+ models of higher and higher engineering quality and accuracy – voluntarily [9]. (See: Fig. 3)

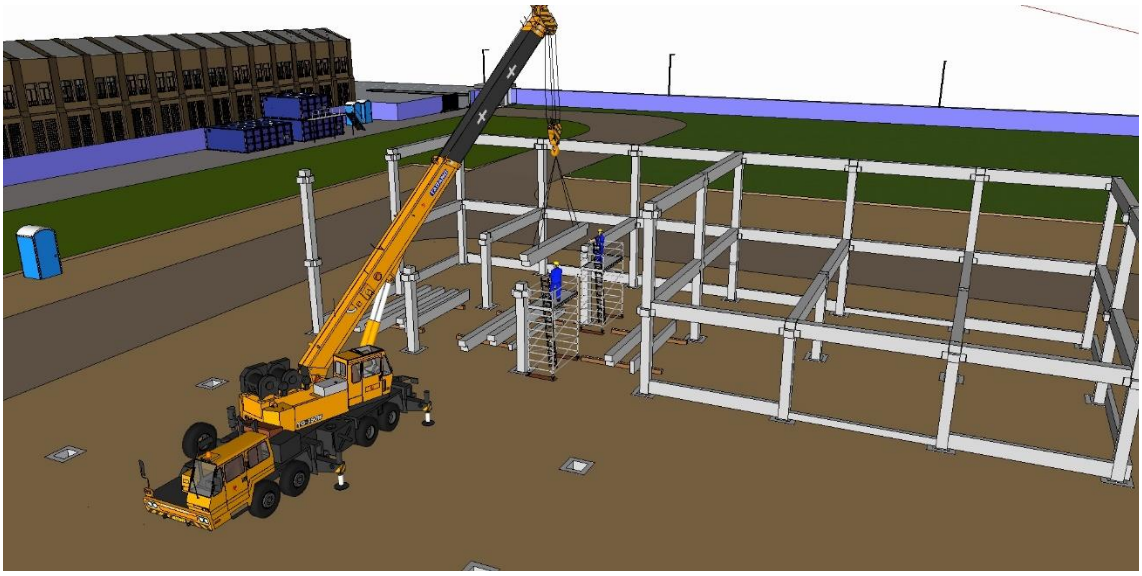

Fig. 3: 4D+ model (phase drawing) of erecting a prefabricated reinforced structure. Detail from home work by Tibor Kézi, student of Civil Engineering, BUTE DCT&M, 2014

It also helps our endeavours that communication of computer applications available on the market is improving (like in case of AutoCad and SketchUp) and thanks for penetration of BIM technology in related computer techniques, students can proceed with their homework course by course with less and less need for re-building their models again and again when studying different features or contexts of their designs using separate computer applications.

Based on these later developments we decided to bring back 4D+ modelling as obligatory task for students of higher courses mentioned above and to examine feasibility of introducing Multi-Dimensional Modelling Techniques in earlier courses (in semester 5 and 6) of Civil Engineering Programs too. At the same time we charge our demonstrators (assistant students) with maintaining (enriching and correcting) our model library available on the INTERNET [10].

Diploma work

At launching each diploma semester we call attention of our students that the credit value of the diploma work earlier (in 5 years education system) was 30 points and we neglect reduction of it to 24 credit points since they have the same time-frame for elaboration and by the end of their studies they gain the same competence in Construction Management as before.

So, considering 14 weeks of the semester + 1 week completion period, elaboration of the diploma project is estimated/expected to lay 900 hours individual work charge on each student, including site visits, interviews, consultations, library works, drawings, calculations, case studies, revisions, corrections, and so on. … It means 9 hours a day, 7 workdays a week through 15 weeks, that is, during the diploma semester “they have to live in their projects”.

In his diploma project **Viktor Horváth** (2010) got the partial task of inventing and testing 6D progression display arrangement on a single 2D screen. (See: Fig. 4) In his elegant solution a 3D model of the building under reconstruction was created by GraphiSof ArchiCad. The 2D display together with free selection and motion of the view point provided 3D representation of the building (facility of the Software). Progression of time (4th dimension) was represented by the progression of the building displayed itself and by a red time bar on the top of the screen. 5th dimension ("Efforts", this case: cumulated construction cost) was represented by a green bar on the bottom of the screen. 6th dimension ("Performances") was displayed by colour codes (this case: stability of earth-walls in brown and load-bearing capacity of concrete structures in green) using shades of the same colours following changes of these features in time.

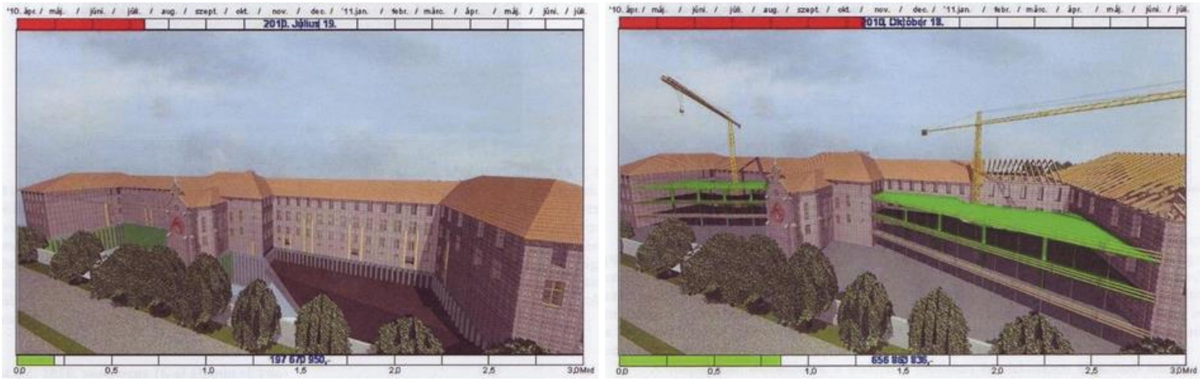

Fig. 4: A 6D Schedule (Progression) representation, details from diploma work by Viktor Horváth, student of Civil Engineering, BUTE DCT&M, 2010

Though elaboration of 3D phased models of the building and gathering all necessary technical- and cost data took extra time, the extra work (~30%) had returned in practice, since the student was applied by Contractor of the Project and the results were utilized in practice directly [11].

Róbert Horváth (2012) had the primary task in his diploma project to study and develop automated link (data transfer) among 6+ dimensions of the model space and to test it on a sample project. He developed data transfer routines (Ruby applets and HTML file structures) for exchanging data between Google SketchUp and MicroSoft Project.

List of activities transferred from Google SketchUp to MicroSoft Project was generated based on graphical units defined in the 3D model, while phased display of the building was driven by progression data from MicroSoft Project (based on an MPM network time model of the sample project). "Performance" parameters (load-bearing capacities of monolithic reinforced concrete structural elements) was displayed by colour codes in Google SketchUp (using interactive modelling facility of the software), while display of "Efforts" (equipment, human resources, costs, etc.) was provided by MicroSoft Project (built-in facility of the software). Considering inter-relations between resources and progressions we can conclude that a real dynamic 6D+ model had been developed.

It was a by-product (better said "by-facility") of the system developed by the student, that the designer could perform a kind of "Dynamic Clash-Detection" during the progression of the project. (Not to be confused with "Clash-Detection" of Architectural and MEP plans offered by BIM applications. Here failures of schedule of works could be detected.) (See: Fig. 5)

As part of his assignment the student had to keep records on his work efforts during elaborating his diploma. The final result was disillusive and shocking. Also considering preliminary studies of the student (as software developer) we got 170 % of work-load expected at a usual diploma work! More than 1500 hours – in a semester and for a single diploma work! That was the point when we radically reduced our plans and expectations concerning individual students' work, and focused our multi-dimensional modelling efforts to some special aspects or motions of the construction projects in diploma works afterwards.

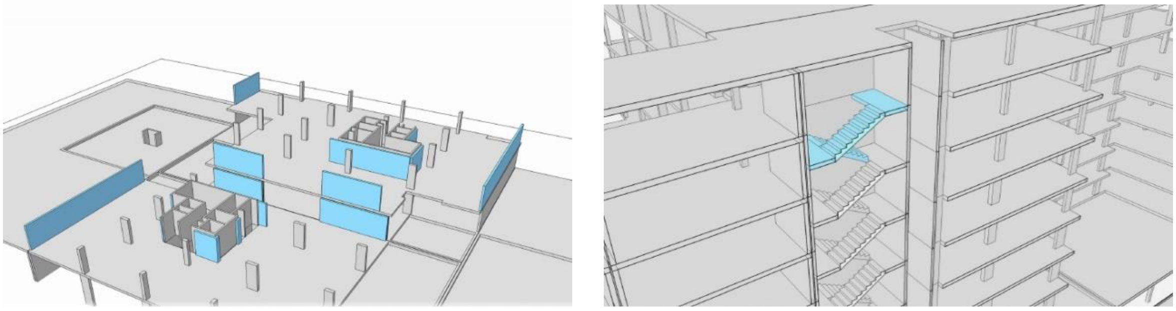

Fig. 5: A by-product of a 6D+ construction model: "Dynamic Clash-Detection". (Formworks of walls above each other may get in conflict; Top floor is finished before prefabricated stair elements are lifted in by tower crane) Details from diploma work by Róbert Horváth, student of Civil Engineering, BUTE DCT&M, 2012

By the time of finishing his studies the student had two job invitations. One by the Contractor of his sample project and another one by a German company, to work as a BIM administrator [12].

As part of his diploma work **Zoltán Szél** (2013) had to develop time schedule of on-going structural works of reconstruction of Castle-Bazaar, Budapest. During the consultations difficulty of excavating more than 50.000 m^3 earth from a narrow space between historical buildings to be preserved and a newly built 13 m high pile wall had revealed. As a by-product of his work (not included in original assignment) the student proved feasibility of his solution in a 4D site model for period of mass excavation with main emphasis on the narrow space and on temporary conditions, including transportation-, positioning- and manoeuvring heavy equipment [13]. (See: Fig. 6)

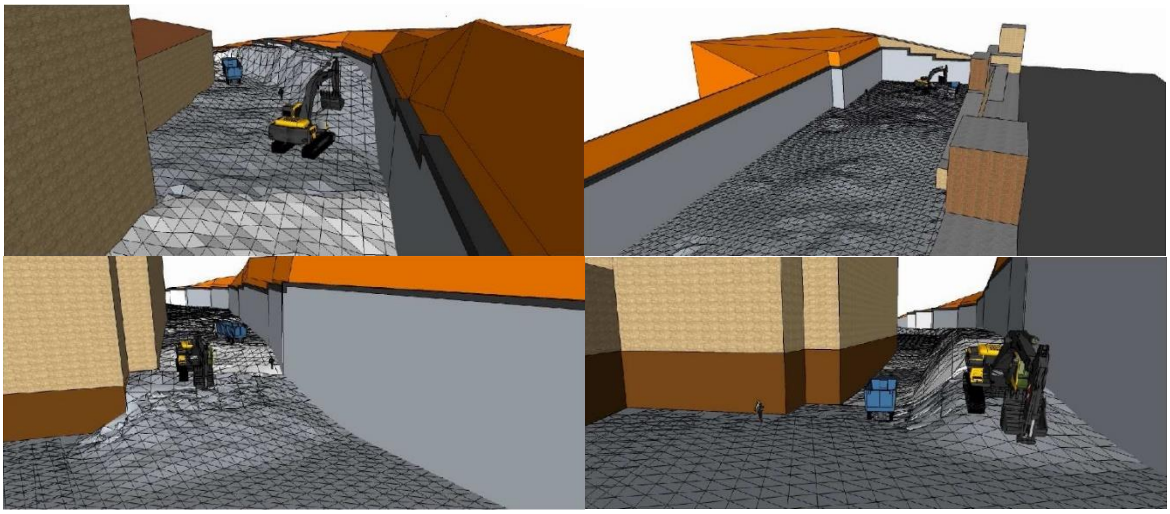

Fig. 6: 4D model (phase drawings) of mass excavation from a narrow space. Details from diploma work by Zoltán Szél, student of Civil Engineering, BUTE DCT&M, 2013

A semester later – at the same construction project – **György Pregitzer** (2013) had to prove feasible cooperation of the six tower cranes erected for the structural- and finishing works, with main emphasis on conflict-free operation of the cranes and free access of deposits and temporary stores. (See: Fig. 7) All difficulties of the project emerged from its location – at the feet of Castle-Hill, close to the bank of the Danube and to the famous Chain Bridge. Narrow access roads, mass transportation, highly exposed touristic destination, sensitive conditions, strict regulations …

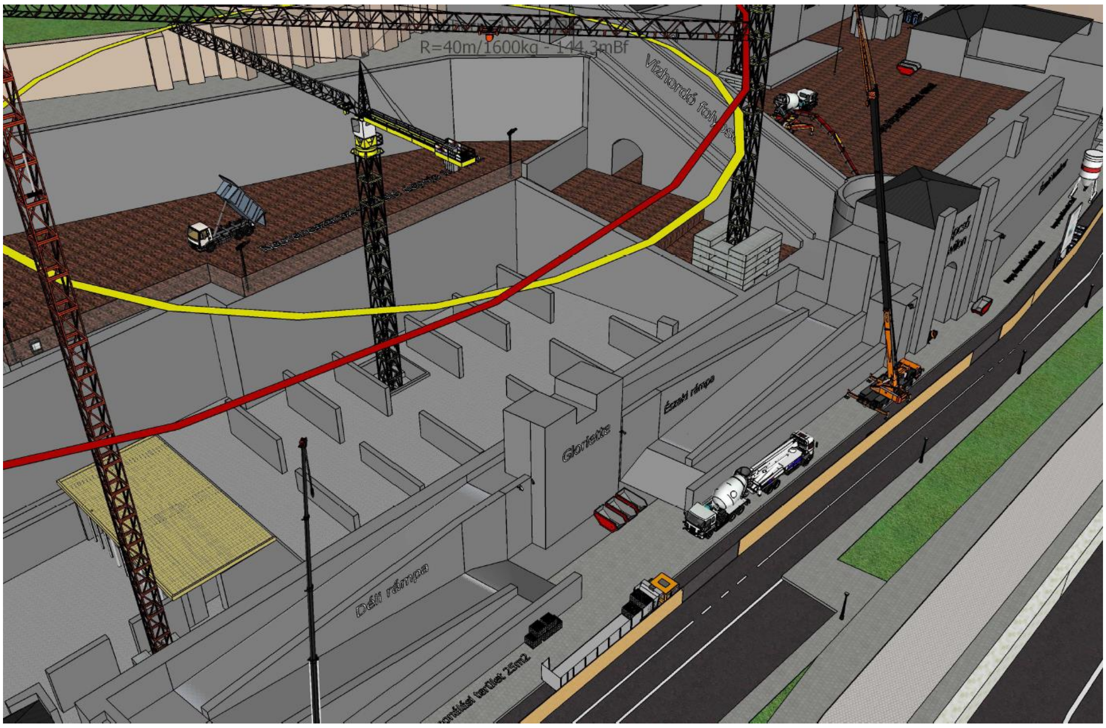

Fig. 7: 4D construction site model of operating more tower cranes simultaneously during structural works of an exposed project. Detail from diploma work by György Pregitzer, student of Civil Engineering, BUTE DCT&M, 2013

As usual (we have to say) this model also served a by-product. The student got in love of his model so, that with the help of his friend they prepared a 2 minutes animation video – out of obligation – that can be downloaded from home page of BUTE DCT&M [14].

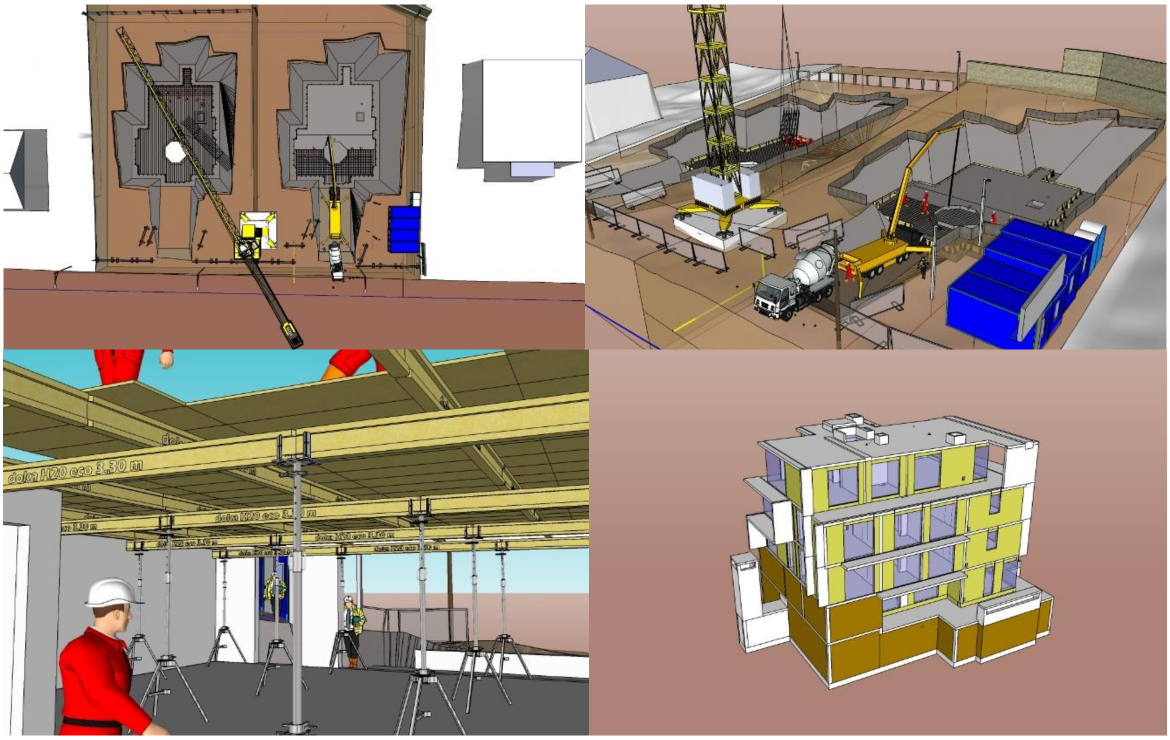

Fig. 8: 4D+ construction models of a smaller-scale development project. Details from diploma work by Dávid Bene, student of Civil Engineering, BUTE DCT&M, 2013

Applied at a smaller-scale Real-Estate Development project **Dávid Bene** (2013) elaborated 4D+ models of more construction phases with increased emphasis on temporary conditions, auxiliary structures, heavy equipment and technology. (See. Fig. 8) As part of his diploma work he analysed thermodynamic features of structural elements and that of the whole buildings to estimate and classify external power consumption of the buildings. As 6th dimension ("Performance") he used colour codes to identify structures of differing thermodynamic characteristics. The voluntary extra work (~60%) had significant return in practice since the project was of interest of the student's family-owned Construction Company [15].

7 CONCLUSION

The paper reported efforts and early experiences of introducing multi-dimensional construction modelling into educational practice at Budapest University of Technology and Economics. After defining a multi-dimensional space and discussing modelling facilities provided by up to date computer techniques we introduced curricula of Civil Engineering Programs and pointed at the potential fields and timing of integrating multi-dimensional approach into education methodology. Finally we introduced some results of our students citing their individual projects (homework and diploma works). Summarizing our experiences and expectations we can conclude the followings:

- Work with Computer Aided Multi-dimensional Modelling Techniques is far more accepted by our students than was expected. The main obstacle of wider penetration of it is the still inadequate interoperability of software applications in use at discussing different engineering aspects in domains of subjects of curriculum.
- To overcome this obstacle general acceptation and introduction of BIM philosophy and IFC data standards in education would be desired. These endeavours are assisted by modern market policy of software vendors providing free or easy access to their products and data bases for practitioners of education (students and lecturers).
- General administrative standardization of data structures providing interoperability of computer applications is potentially expected within some years – on the basis of international agreements, technical/professional standards and/or legal regulations.
- To find balances between efforts and results we may introduce multi-dimensional modelling facilities in early years of higher education on voluntary basis, and should be set obligatory for students of higher years of special courses. It can be promoted by maintaining free-access model libraries and by motivating students via their own business interests.

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