GRADUATE LEVEL CONSTRUCTION INFORMATICS CURRICULUM: A PROPOSAL TO MEET THE BOLOGNA STRUCTURE

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SUMMARY

Across Europe, faculties of civil engineering and departments of construction are addressing the structure of the university level education according to the Bologna declaration. The restructuring provides an opportunity to rethink some aspects of the curriculum, including the status of education in construction informatics and computer science. While today the IT tools are used in most courses, there is a significant corpus of knowledge that needs specialized attention in dedicated courses. Some courses must be aimed at fundamental IT knowledge that is required to support core engineering works such as design, planning, construction management and construction itself. Advanced understanding of all aspects of information technology is required for job positions that actively shape the introduction of IT for strategic, management and knowledge worker levels. This is reflected in the proposed schema of four courses, two of which are optional. The author believes that the 2+2 courses over the 4 years of engineering education is a realistic share that construction informatics should have in the reformed curricula. This paper reports on a study that was completed in 2002 for the University of Zagreb, Croatia in 2002, that is reforming the curriculum related to construction informatics. The goal of the paper is not to provide a definitive curriculum, but rather to start a Europe-wide discussion on a harmonization of construction informatics curricula.

KEYWORDS: education, construction informatics, curriculum, syllabus

INTRODUCTION

In one of its reports, the ASCE identified that "electrical and information technology are examples of holes in many programs" (http://www.ce.cmu.edu/~cth/asce/Open-Forum-Discussion-01.htm). An idea, that surfaced in most panel discussions during the last ECPPM conference (2002), was that product model based CAD requires a well-educated user.

The mastering of computers and information technology (IT) is an essential component of engineer's knowledge. A part of this knowledge is on the skills level. This includes the use of certain types of software and the understanding of their underlying principles. At a more advanced level, a student of engineering learns about information technology so that:

(a) one becomes and remains a fluent user of IT,
(b) one understands the role of IT in the construction business and can influence its deployment,
(c) one knows how to communicate with the developers of IT solutions and
(d) one is able to take part in developing specialized engineering software and services.

The authors believe that a civil engineer's specialty could be information technology, on the same level as management, structures, hydromechanics, civil infrastructure etc.

Related work

Works that have been dealing with the use of information technology in the educational process are numerous. They deal with how one could use this or the other technology to teach engineering topics more efficiently. A couple of journals and conference tracks deal exclusively with engineering education.

The papers that discuss the undergraduate curriculum in information technology for students of civil engineering are non-existent in the traditional construction informatics journals and conferences. This omission may be attributed to the non-existence of an organization to bring together the teachers of construction informatics, although some attempts were made in the mid 1990s. For example http://itc.fgg.uni-lj.si/ICARIS/EDITEC/ which is in fact a dead page. While a handful of papers on the topic has been published in W78 and other seminars, only recently a track of conferences seems to be appearing at http://fg.uni-mb.si/CIT@EDU/. The situation is very different in the field of architecture where associations such as the ECAADE have been discussing these issues for quite some time. About 120 references on curriculums may be found in the CUMINCAD database (http://cumincad.scix.net/) alone. A good example in this domain is by Mark et al. (2001). In the field of construction IT we published a curriculum for a master degree level education (Rebolj et al., 2002) that is getting shape in the frames of an ERASMUS project (http://fg.uni-mb.si/ITC-euromaster/).

CONTEXT

This section outlines the context for the curriculum planning - the Bologna declaration providing the overall structure of the study, defines construction informatics to frame the theme of the curriculum and enumerates the jobs requiring IT specialists.

Bologna declaration

The Bologna Declaration (Bologna,1999) on the creation of a European space for higher education of June 1999 is a pledge taken by 29 countries to reform the structures of their own higher education system in such a way that overall convergence emerges from the process at the European level. It was signed by the relevant ministers of most European countries. The Bologna declaration proposes the use of the ECTS (European Community Course Credit Transfer System) system, encourages student mobility across Europe and structures the studies into undergraduate and graduate programs. The undergraduate programs should take no less than three years and the total duration Incl. graduate) no more than five. It has been generally recognized by an association civil engineering schools in Europe, that what is currently understood as "Diploma Engineer" in Central Europe takes between 4.5 and 5 years - an equivalent of the master degree level according to the Bologna structure.

Schools of engineering are taking different approaches to accommodate the Bologna structure, some taking the 3+2 (undergraduate+graduate) some the 4+1 approach. What is important for the discussion in this paper is that some courses need to be part of the undergraduate and some part of the graduate system into which the current studies towards "Diploma Engineer" would develop.

Two year specialized master degree courses, as developed in the context of ITC@EDU project would, in principle, fit in the 3+2 model, however, it may not leave enough room for core engineering topics and may leave too many *other* future engineers with not enough proficiency in informatics.

This paper proposes a structure of courses that could be taken by students in the graduate part of the 4+1 or 3+2 system, without them being called IT specialists. Further specialization in IT may be possible in the last year, if the model is 4+1, borrowing heavily from courses such as ITC@EDU.

Construction informatics

Turk (2002) proposed to use the term "construction informatics" instead of "construction information technology". "Information technology in construction" or "construction IT" is the most commonly used term currently. It was coined at a time of high hopes for recently invented information technologies such as object orientation and the Internet. Years later more sober voices claim that many of the problems in the construction industry, that could be solved by information technology, are not solved, but not due to technical issues. It seems appropriate, therefore, to remove the world technology from "information technology" and leave just "construction informatics".

Informatics studies the representation, processing, and communication of information in natural and artificial systems. It has computational, cognitive and social aspects. The central notion is the transformation of information - whether by computation or communication, whether by organisms or artifacts. This definition can be modified to define construction informatics:

> *Construction informatics studies (the construction specific issues) related to representation, processing, and communication of (construction specific) information in humans and software.*

Historically construction informatics emerged from "computing in civil engineering" but since every civil engineering discipline has started to use computers, only two sets of topics remain affiliated with construction informatics:

- Informatics-related topics that span over several civil engineering disciplines (e.g. product modeling, integration, concurrent engineering, distance working and learning).
- Information support for engineering topics that span several disciplines or life cycle phases, such as construction documentation, management and economics.

These two topics need to be addressed by the construction informatics curriculum. Any other uses of computers are not in the field of construction informatics.

In many ways, informatics has always had a place in engineering curriculum. For example technical drawing and descriptive geometry are addressing the very same communication needs as the modern IFC or STEP models (Turk, 1998). The standards of the graphical language needed to be mastered, just as there is a need today for the student to master the standards for the representation of product models.

Jobs

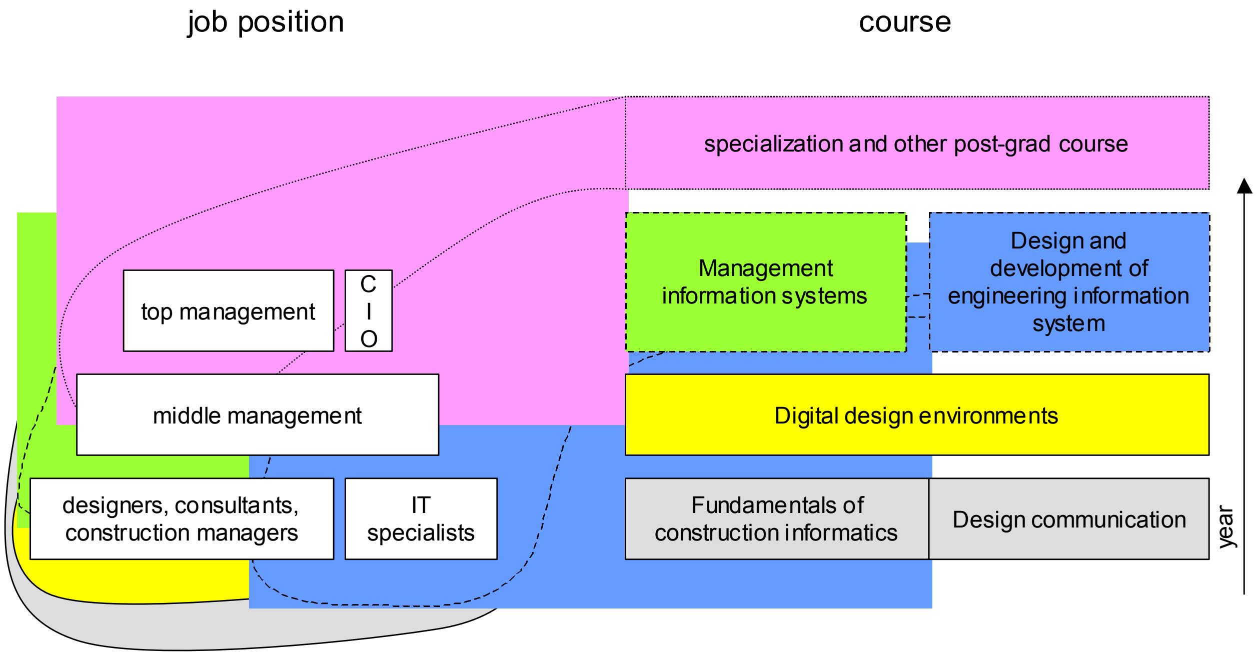

Figure 1 Mapping between the courses and job positions.

It is most likely that a (desktop) computer will be a tool that every engineer will be using, some, however, will be more dependent on information than others.

On the **knowledge worker level**, the engineers doing designing and planning would benefit if they could make a transition towards object-based design; that is, designs, which are composed of well-defined computer represented objects. This requires not only a new generation of tools but a change in thinking as well - a step, which requires knowledge that goes beyond using a CAD package for 2D drafting, for example the ability of information conceptualization. Use of on-line information systems and platforms for collaborative design could be more efficient with the knowledge of communication technologies and the principles of information retrieval.

The complexity of knowledge increases if one moves up the corporate ladder. Construction **management** can be greatly facilitated by the use of information technology; it is also managing the introduction of IT and a higher level of understanding of the technology and its economical and social aspects is required.

Finally, there is a new job that construction companies and all other institutions dealing with the build environment are demanding - an **IT specialist**. The companies have had MIS departments for decades, but they were dealing with traditional management information systems infrastructures that were not very different from company to company regardless of the industry. The handing of invoices, payrolls, accounting, human resources, capital flows etc. does not differ much from industry to industry. If IT is used to support core works - designing, planning and construction, the IT support becomes much more specialized and requires a specialized person to support it - one who is well aware of the topics addressed by the technology.

Just as construction is dealing with one-of-a-kind products, often one-of-a-kind or quite exotic software solutions are required. Because of the high specialization in the field, many programs are quite expensive and developing them in-house is always an option. Many large consulting and construction companies do have in-house software developers. Those that do not, will need a person who will be able to communicate with software engineers and other software developers.

Finally, the market for IT specialists resulting from the proposed curriculum are the engineering software companies.

THE COURSES

This section outlines the four courses; each having a total of 45 hours of lectures and 45 hours of exercises, seminars and/or studio work.

Course 1: Fundamentals of construction informatics (year 1)

Objectives: To lift general knowledge about computer science and IT to a university level; to provide basic skills on using the operating system, office software and drawing programs so that students can use this technology in other classes.

Although most (or even more) of the practical knowledge could be picked up at various courses, a proper (theoretical) background and underlying models and principles should be provided to the students. Lectures should provide the required deeper, longer lasting knowledge, while at exercises students learn how to use latest version of software (where knowledge that grows old quickly).

Topics:

- computer hardware and software,
- theory of information,
- information and material processes
- digital and analog, encoding of information
- roles and principles of operating systems
- networking fundamentals
- information formats (text, tables, databases)
- data models of office software
- fundamentals of computer graphics
    - representation of images using pixels, 2D elements, 3D elements and 3D and 4D objects, difference between drafting and object based design
    - representations of 3D entities using wire-frame, suface and various kinds of solid models
    - visual realism

Related practical work:

- using operating system
- accessing the LAN and the Internet
- using email
- Word, Excel, PowerPoint
- mathCAD, mathLAB, Mathematica
- bitmap painting program
- vector based CAD program

Course 1a: Design communication

Most civil engineering programs had courses on descriptive geometry, technical drawing and documentation. These courses were dealing with how to produce, read, publish and archive design information using traditional means - paper and ink. Instead of grouping all computer related topics into the Course 1, topics related to computer aided drafting could be left out and placed into a modern design communication course that would include some traditional topics as well:

Objectives: To learn how design documentation is produced and read, using traditional and digital media. To augment spatial thinking and geometrical problem solving.

Topics:

- ISO drafting and documentation management standards
    - traditional
    - computer based (e.g. layering standard)
    - specifics of civil engineering drawings
- free-hand sketching
- projections
    - classification of projections
    - analytical and geometrical principles
    - computerised projections
- fundamentals of computer graphics
    - representation of images using pixels, 2D elements, 3D elements and 3D and 4D objects
    - difference between drafting and object based design
    - representations of 3D entities using wire-frame, suface and various kinds of solid models
    - visual realism

Exercises:

- drawing programs (bitmap, illustration, CAD-drafting, 3D CAD, object-based CAD)
- preparation of design drawings in conjunction with another course
- creation of 3D photo realistic drawings

Course 2: Digital design environments (year 3)

Objectives: To understand the role of IT in the construction process both as a facilitator of communication and a media to store information. To understand how IT may be used to make the construction process more integrated and efficient. A passive user, the student should develop the skills to become an active, demanding power user taking full advantage of what is and will soon be available.

Topics:

- communication
    - taxonomy of technology-mediated communication
    - real time and lagged communication
    - internet services, semantic Web
    - workflow
    - process modeling
- information processing
    - information life cycle
    - data, information, knowledge, wisdom
    - representation of information - schema, object, format-family, format
    - the taxonomy of tools and technologies
    - information storage technologies
    - document management
    - databases; relational and object oriented
    - 1D, 2D, 3D, 4D media
    - 2D, 3D, 4D CAD
    - building classification systems, indexing
    - reference models (e.g. RATAS, GARM, FFB)
    - standard schemas (STEP, IFC)

    - neutral formats (EXPRESS PF, XML)
    - electronic data exchange (EDI, EDIFact)

Practice:

- project management infrastructure (Web based, LAN based?)
- practical collaboration on a project work using email, video conferencing, ICQ and:
    - advanced data analysis with Excel
    - desktop publishing (e.g. MS Publisher, Ventura), Adobe Acrobat
    - internet publishing (making a static Web pages)
    - Internet search engines
    - Internet databases
    - Java and XML illustrations
- use of object based CAD

Course 3: Management Information Systems (elective in year 3 or 4)

Objectives: To further understand the role of information technology in a construction company and community. To grow from advanced users (Course 2) to active shapers of IT solutions and policies.

Topics:

- information systems, their role in an organization;
- specialized information systems
    - MIS,
    - GIS,
    - project Webs,
    - industry portals.
- analysis of processes in construction: information, material, business processes;
- models and understandings of the design process
- the modelling theory and approach
    - product modeling techniques
    - process modeling techniques
- management
    - managing of information systems
    - business process re-engineering
    - change management
    - risk management
- social and management issues
    - privacy and security
    - legal consequences
    - economics of IT
- advanced information retrieval
    - data mining
    - AI
    - knowledge management

Practical:

- analysis of IT competency level of an enterprise
- developing an IT strategy
- development of product and process models
- use of risk management software
- examples of advanced information retrieval and knowledge management

- learning from project Webs and distance working software

Course 4: Design and development of engineering information systems (elective, year 3 or 4)

Objectives: To learn how engineering software and information systems are developed so that the student may take an active role in a company's IT strategy. To learn how to develop software himself or to communicate with software companies; that one can be their credible client; that one can manage IT infrastructure that requires constant upgrading.

Topics:

- life cycle view on software in information systems
- IT strategies
- principles of software engineering focusing on design and analysis
  - UML method
- risk management and quality assurance in software projects
- programming paradigms
  - database programming and SQL
  - structured programming
  - object-oriented programming
- programming language
- assessment and evaluation techniques

Practical:

- software engineering tools used to make software design
- software development in Visual Basic, C, C++, C#, SQL, Java or FORTRAN.
- software assessment and evaluation

TEACHING AND LEARNING METHODS

We only outline some basic principles. Each deserves a detailed study, which is outside the scope of this paper:

Demonstration, theory, experiment/exercise. Teaching information technology is challenging. Due to a fast progress in the area, the teacher needs to refresh the lectures on a yearly basis. He is faced with students, who may have much higher skills in using a particular tool. While it appears one could go a long way by just being a proficient user of a software package, deeper understanding of first principles is required, just as with any other engineering topic. Where boring theories compete with a more attractive button-pushing, the motivation can be achieved by showing some stunning results and explaining later, thus in the demonstrate, theorize, experiment order.

Project&problem based learning. One of the main challenges of construction IT remains computer integrated construction. So why not use IT to integrate existing courses, particularly at senior levels. Collaboration with core engineering topics is essential. Practical work and exercises should address the needs of other courses and provide examples from that domain, so that the use of the tools is motivated and placed into a construction context.

Teamwork. IT provides numerous solutions for teamwork, virtual teams and distance working. All these work patterns should be practiced in the course, rather than only lectured. Ideally, teams would not consist of members from a single institution but expand beyond its organizational limits e.g. include architects, computer scientists, software engineers, mechanical engineers etc. Teamwork provides good environment for cooperative learning and student teach-back.

Cooperative learning. During Group Recollection, students are informally organized into teams to recall and apply information. Students collaborate and work in teams to create, solve problems, and complete projects. It teaches valuable work skills and ethics that parallel the actual workplace. Teamwork may or may not involve computers or technology. Faculty's roles are to facilitate teaming and the group learning process.

Student teach back. In this method, students teach-back portions of the curriculum to fellow students (and the instructor). Probably best paraphrased by Dr. Russell L. Ackoff, "The worst way to learn anything is to be taught. The best way to learn anything is to teach." The Teach-back method allows students to become the teacher and to thoroughly understand and internalize information. As students become comfortable in teach-backs, their work skills improve dramatically and they become much more effective tutors and teammates for each other. Faculty's roles are to mentor and support students as they prepare for and lead class activities.

Self directed learning. Informatics is different from other engineering topics in the fact, that the knowledge needs to be constantly and rapidly updated. What is therefore more important for the informatics courses than any other in the engineering studies, is to teach the students how they can learn by themselves and how to use numerous information sources nowadays available on the Internet, including distance learning. This method is performed by the student in a self-directed manner, typically on a computer workstation. Computer Based Education Modules (CBEs), CD-ROM, Distance Education, Intranet and Internet are typically used. Students move through material at their own pace and gain valuable experience in self-directed learning. Self-directed learning is an essential skill for students to possess in order to succeed long-term in a rapidly changing information society. Faculty's role is to set objectives, make learning assignments, and assist students in directing their own learning.

Involvement of the industry. Developers from engineering software companies, re-sellers of software packages, CIOs and IT managers of construction companies may provide a valuable insight into the real challenges that the students would face after graduation as well as share the experience they gained while solving real-life problems that are not too often tackled by the faculty.

CONCLUSIONS AND AGENDA

The potential users of construction informatics knowledge are all civil engineers. A deeper knowledge and understanding is required by the project and company managers and the shapers of IT solutions, both in internal IT departments as well as in specialized engineering software companies. A four-course structure has been proposed that addresses these three categories of users. Teaching methodology needs to include project/problem based work and the use of resources for distance learning, because these are ways in which knowledge can be kept up to date after the students graduate.

Associations that assemble educators in construction informatics, such as the CIB W78, IABSE WC6, EAPPM, ASCE should give more attention to the development of **harmonized undergraduate curricula** in construction informatics. Such structure could achieve the mobility and compatibility of degrees awarded by different schools, as required by the Bologna declaration.

There is a need for broad **comparative study** of how construction informatics teaching is structured across Europe and world-wide that would cover more than half a dozen institutions. Such a study could assess the current state and provide future directions.

A **digital library of open courseware** and open *source* courseware could assist in developing high quality teaching materials as well as enable the students to revisit a topic from a perspective of another professor. Interuniversity links and project work spanning several institutions would not only provide a motivation for the use of advanced IT (such as distance working and communication tools) but also expand their cultural horizons and prepare them for a work in a global network community.

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