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Towards 'Remote' Learning of Building Materials*

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Lots of practical experience is needed when teaching the science of building materials. However, practical experience requires a well-equipped laboratory, trained technicians and consumes students' time. This paper describes a comprehensive program developed in the department of Civil Engineering at the Technion, Israel, to improve the teaching capability of building materials by improving the efficiency of the laboratory program and to develop a program for a remote laboratory classes.

INTRODUCTION

LEARNING building materials requires lots of practice in batching, mixing, preparing and testing of the various materials in addition to the theoretical knowledge. Unfortunately, despite all the knowledge existing today on the properties of building materials, it is still impossible to design materials to exactly match the desired properties, especially cement-based materials, and therefore practical experience is required.

With cement-based materials, many parameters affect the properties of the product (mainly concrete), both in the fresh and hardened state. The degree of roughness of aggregates, aggregates source, composition of the cement, order of feeding the ingredients into the mixer, duration and type of mixing and type of additives, are only some of the parameters affecting the properties of concrete.

The variety of parameters affecting the properties of concrete and lack of practical experience often confuse the young engineer when he meets the 'real' world for the first time. Such confusion by young engineers was reported also in other countries [1–3] and it seems that more attempts must be given to expose the student to as many actual cases as possible. In the building materials studies, such an exposure is limited by the laboratory capacity, which, in our case, was unable to handle the increasing number of students in the last 5 years (from 250–300 students/year to 450–500 students/year).

This paper describes the attempts given in the department of Civil Engineering at the Technion—Israel Institute of Technology, to provide the student with the maximum experience with building materials and by-pass the limitation of laboratory capacity, labour, time constrains and budget. This target was achieved by building a comprehensive program which includes new laboratory architectural design, library and new multimedia tools to improve the current teaching techniques and to approach a virtual laboratory.

THE BUILDING MATERIALS PROGRAM

Concrete of various types is the principal building material for construction in Israel. The annual consumption of cement in Israel is approximately 0.9 ton/capita [4] compared with 0.3 and 0.5 in the USA and Germany [5], respectively. Lots of attention is therefore directed to a deep study of the concrete science in the department of Civil Engineering at the Technion—Israel Institute of Technology. The department, being the only school of civil engineering in Israel for many years, is committed to present a comprehensive curriculum covering as many relevant civil engineering (CE) topics as possible, in order to prepare the future engineer for the impending needs of the industry.

The CE program is based, therefore, on general university compulsory courses such physics and mathematics, CE compulsory courses in all of the CE fields such structure, materials, transportation, etc., and two streams of courses in specific fields. The flow of courses, leading to more specialisation in the field of Building Materials (BM) in the undergraduate studies, is presented in Fig. 1. As seen in Fig. 1, the program of BM is extensive and includes a wide variety of applications of materials in construction. It should be noted that the emphasis in all the BM courses is on learning the properties of the materials and how to use them properly, rather than structural design.

Learning building materials, especially cement-based materials, requires lots of practical experience, in addition to the theoretical knowledge about the materials' properties. However, practical experience requires laboratory training in small

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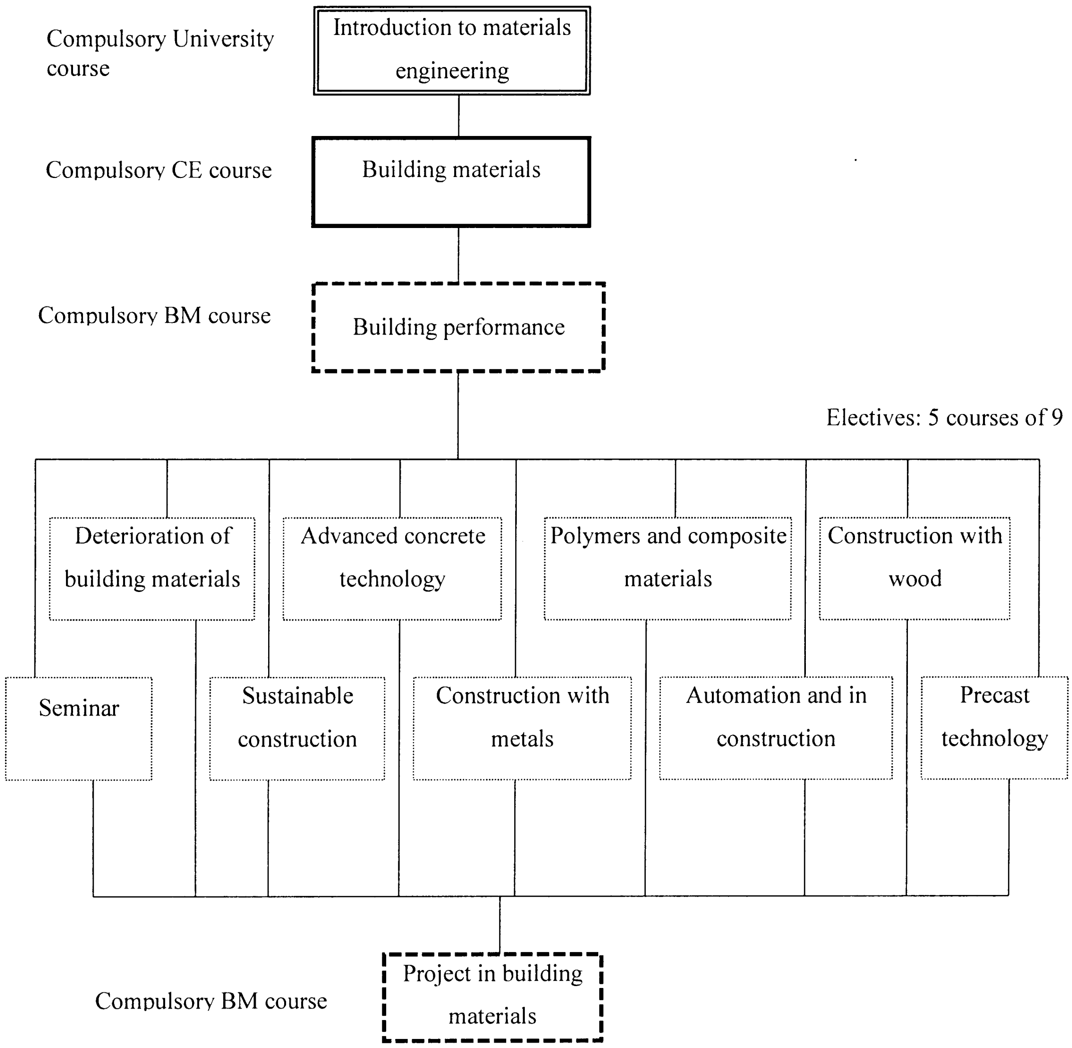

Fig. 1. Flow chart of the building materials courses.

groups, which means high expenses for the university and large consumption of student time.

Steinberg [6] complained in 1995 on the 'ever increasing demands on time and the need to minimise the amount of courses students take'. These demands require a better use of the university resources and student time.

In order to use more efficiently the laboratory and student's time, some attempts were made in the past five years to improve the teaching capability by using computer programs to solve or demonstrate a particular problem such as mix design [7] or the development of internal structure of concrete and its effect on the concrete properties [8], or teaching through projects demonstrating a particular subject. However, these solutions can offer only an answer to a limited number of topics and do not suggest a comprehensive program to the problem.

The ever increasing demand on student time, rising number of students and increased cost of a well equipped laboratory which can allow working in small groups caused two needs:

1. Improve the current teaching ability by using innovative techniques thereby using the laboratory more efficiently.
2. Permit a 'remote' or virtual experience with the building materials.

Five topics were dealt with when the BM program was modified to face the new needs, the first four have already been completed successfully and the fifth is still under design:

1. Change the design of the existing lab.
2. Build an Internet-based laboratory textbook.
3. Build up Internet pages of examples and exercises.
4. Erection of a library for construction methods, equipment and materials.
5. Performing 'remote' experiments.

New design of the laboratory for building materials

The basic idea of the new design of the lab was using the limited space of the lab both for doing the experiments and for oral presentation of the relevant subjects. In many universities, which hold methodical laboratory classes, the classroom is separated from the experimental area. A lot of time is consumed by moving from one room to another, the explanations are disconnected from the actual experiments and the students have no organised place to write or make calculations while performing the experiments.

In order to combine the two activities together, taking into account the nature of concrete works (wet and dirty vs. dry and clean), the laboratory was designed in two concentric circles. The inner one is dedicated to perform wet and dirty work and the external one is dedicated to the clean work. Schematic presentation of the configuration is presented in Fig. 2.

The working table was divided into two sections, distinguished by two levels. The lower one, covered with a marble plate, is dedicated to the 'wet works', and the elevated one (10 cm only of level difference) is dedicated to the 'clean works'. Each table is equipped with all the necessary equipment to perform an autonomous experiment independent from other groups in the lab. A computer, connected to the measuring devices and loaded with the laboratory textbook is placed on the clean table. Dust, which is the 'enemy' of any precise works in a concrete lab, was largely eliminated by using pre-washed aggregates (a common process in Israeli's quarries), and using a small screen which partially hides the computer and by daily maintenance of the lab.

Using this arrangement, the oral explanation of the experiment, together with the experiment itself can be performed in the same classroom without wasting important time for moving from one room to the other. The central zone of the classroom can be used for demonstrations when needed (though a survey showed that students prefer to actually work rather than see demonstrations). The students' attention is directed to the centre at all times, which enables better control of their work.

Internet-based laboratory textbook

As a general rule the lab was designed as a paperless class, prepared for the next millennium. The laboratory textbook of the compulsory course in building materials was the first one to be translated into HTML format [9], and images describing the various experiments were added. The textbook, including the description of the entire laboratory exercises, was placed on the Internet in order to enable students to prepare themselves for the class before it begins, and to arrive more prepared for the class assignments. Valuable class time was saved this way. The form on which the experiment results are written was prepared as part of the textbook and the students fill it in during the class. Unfortunately, we realised that students tend to surf to undesired Internet sites during the class so we had to disconnect the computers of the lab from the external world. Therefore, the students had to print out the reports at the end of the class and finish the calculations at home.

Remote access to examples and exercises

During class it appeared difficult to be restricted to the limited number of examples and exercises which usually appear in textbooks. Discussions, which develop during the lectures according to the personal experience of the students, make it impossible to prepare the examples in advance. Previously, these examples were placed in the department's library, and the students could photocopy them. However, it was too complicated, and quite often the papers were lost. Now the website of the course serves as a dynamic tool to refresh the examples and fit them to the discussion in the classroom. Needless to say, the improved dialogue between the students and the lecturer extends beyond the regular class hours.

Library for construction methods, equipment and materials

A unique laboratory of construction methods, equipment and materials was erected as part of the

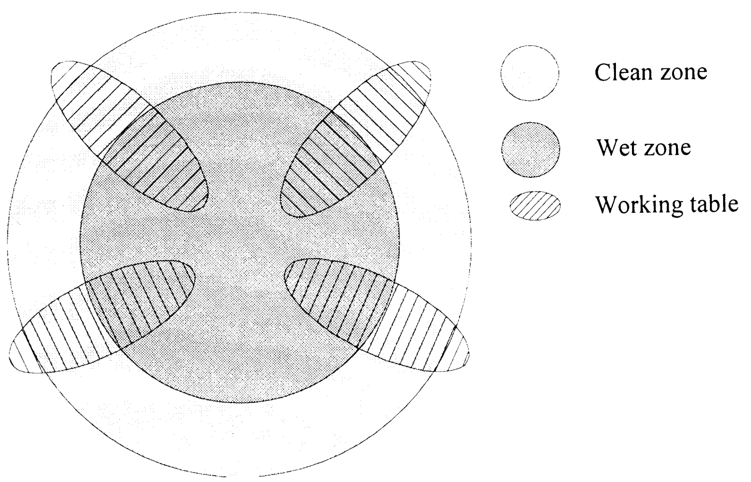

Fig. 2. Schematic presentation of the laboratory new design.

attempts to narrow the gap between the building site and the classroom [10].

The laboratory was erected in order to gather in one place all the relevant information on construction methods. However, the tight link between construction methods and equipment to the technology of building materials, led to the build-up of a large library collection of items which are also related to building materials. Among these items are found:

- scale models of construction equipment;
- catalogues;
- exhibition of building materials;
- videotapes;
- computers connected to the Internet with links to other sites;
- software.

Some of these aids are located inside the building materials laboratory itself (mainly exhibition of building materials) and the others are located in the construction engineering laboratory, which enables the CE students more flexible access.

Remote experiments

All the above mentioned tools are used to increase the efficiency of studying and prepare the student better for the laboratory. These multimedia tools are used today as the main teaching tool in some teaching programs [11] though not in teaching building materials. Apparently, they cannot replace the actual work at the lab and the self-impressions one obtains while experiencing with the materials by himself. It is obvious that no communication media existing today can imitate the feeling one gains while trying to smooth the surface of concrete. However, with the proper use of interactive intelligent tools it might be possible to allow the student to experience almost real interaction with the materials, thus providing him with tools to observe and analyse the materials he works with without using a real lab.

The advanced multimedia tools can also be used to perform 'remote' or virtual experiments. In order to perform a virtual test a large database containing short video movies, text, audio and animation is needed to cover all potential cases of material preparations, including the cases in which bad material is prepared.

For example, mix design of concrete for a specific need requires the design of mixing ingredients and preparation of a trial mix. Quite often, the trial mix does not meet the requirements in terms of workability, flowability, cohesivity, air content, early strength, final strength, heat development, and many other parameters. In order to achieve all the requirements, modification is needed together with another trial mix. Several iterations are needed to achieve the desired mix. A virtual exercise on this subject includes the following steps:

1. Providing the student with element information: required strength (early and late), dimensions, service conditions, etc. Drawings can be provided, where the students needs to analyse the information themselves.
2. Providing materials information: information on the various aggregates, cements and additives. This information can be provided directly, or by linking to virtual experiments on the properties of the materials.
3. Mix design by the student using common methods, manual or computerised.
4. Comparison with information exists in the knowledge base of the system.
5. Presentation of a short movie on batching and mixing, coinciding with the mix that the student designed, as if the student had instructed the technician.
6. Presenting the results. The student is required to virtually perform some actions on the fresh concrete in order to estimate its fresh properties: pour the concrete, smooth the surface with a trowel, examine for segregation, testing the slump, unit weight, air content, and other parameters. According to his judgement, the student needs to correct the mix, and start the process over again.
7. After being pleased with the properties of the fresh concrete, the properties of the hardened concrete are 'tested' and corrections to the mix are induced. Mixing is performed once again to test the effect of the proposed changes.

The heart of the system is its comprehensive database, and a 'virtual trowel'. The fast and smart computer program analyses the proposed solution, and presents the student the situation he created. In addition, the student can 'order' the system to perform any standard or non-standard test he wishes, and ask for a new mix. The system analyses the new situation and presents a new mix.

A virtual trowel is the tool that allows the student the sensing of the mix he created, the feeling that is currently missing when making a theoretical exercise in mix design. The virtual trowel is based on a dynamic joystick that has four degrees of freedom. Two degrees of freedom are movement in the yz plane (see Fig. 3) and the two additional degrees of freedom are rotation over the x and z axes. This configuration was determined after consulting with experts dealing with robot's arm movements and it appeared that proper transfer of vibrations to the trowel and variable resistance to its movement can transfer the user the almost true feeling of real concrete. Additional degrees of freedom (movement along the x axis and rotation over the y axis) can allow any desired movement and rotation in space but will require much more computer power that is currently needed for handling the other multimedia tools.

Such a virtual dialogue, using all the multimedia tools (text, images, movies, animations, audio,

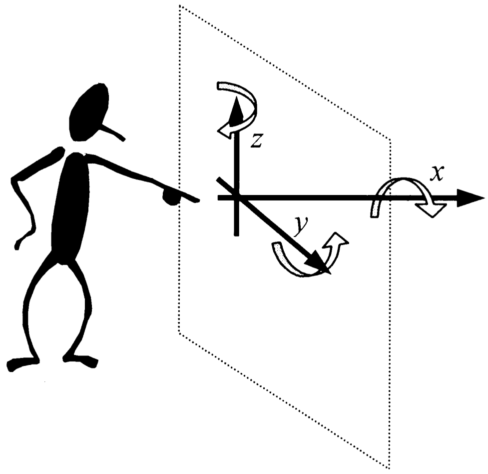

Fig. 3. Six degrees of freedom in space for the trowel movement.

virtual trowel and computing power), can prevent the need to perform actual experiments and bring the student more prepared to a variety of actual cases. In complicated situations where the solution to a problem needs some art, which is hard to impart without practical experience, such a system is an enormous advantage.

CONCLUSIONS

Modern multimedia technology was used to improve teaching capabilities of the building materials courses. Rising numbers of students, limited capacity of the laboratory and the development of new materials brought the need to acquaint the students with the materials and testing methods, and develop their judgement abilities to be able to distinguish between good or bad products without expanding the expensive laboratory.

A comprehensive program that included several aspects was developed:

1. Improve the efficiency of the current laboratory using a new design, and building a new library that is dedicated to construction methods, equipment and materials.
2. Use the Internet as a tool to introduce the student with the experiments he is going to perform in the lab thus allowing him to arrive more prepared for the class.
3. Build a multimedia program which can train the student in all aspects of materials design and making without doing any actual experiments.

Parts 1 and 2 of the above program have already been completed successfully. The students reported feeling more satisfaction from the lab and the technician announced that they had achieved a better connection with the students. However, some students complained about overloading of activities in the lab. Deeper investigation of their complaints showed that many of them came unprepared to the lab, despite the availability of the lab program via the Internet. It appeared that many of the complaining students have never used the Internet before and they were afraid of the 'new' technology. Those who prepared themselves before the class reported high levels of satisfaction from this format.

With the new program we were able to handle the increased number of students (approximately 500 students/year compare with 250–300 previously) more easily and to extend the laboratory program with some additional topics at the same time. A survey, done in the past 7 years, showed that the level of student interest in the course of 'Building Materials', which the laboratory classes are part of it, was increased from a level of 3.6 to a level of 4.1 (of maximum 5.0). Other evaluation criteria, such as evaluation of the content or of the lecturer, were not changed in that period of time indicating that the change in the student interest can be attributed to the change in the laboratory program.

The third step is still under construction. The whole concept is new and needs lots of preparations, both on the concept and methodology of operation, and on building a wide knowledge base which will include all possible cases of material preparation.

It is expected to believe that completion of the program will enable students to have a better access to the building materials laboratory, also to students from institutions where there are limited resources, and thereby to improve their understanding and knowledge in this field.

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