Construction Education and Research in Central Europe

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Abstract: Construction engineering and management education in Central Europe, and its relationship to practice in the construction industry, have concepts that could benefit their counterparts in the United States. This paper first describes the system of education in Central European technical universities, then reviews curricula in four cases. University research practices are also examined and compared to U.S. counterparts, as is the role of academics in industry. While there are many similarities between the two systems, there is more technical content in European degree programs, but at the expense of liberal arts courses. They have more decentralized autonomy in budgeting and staffing, with larger staff sizes to support comparable numbers of faculty and students; but they have lower capital equipment budgets. Finally, characteristics of the Central European construction industry that support research and innovation are examined. These include top management's greater interest in technology and innovation, a comparative lack of the legal liability problems, a bid evaluation system which encourages contractors to submit design alternatives, in-house contractor research laboratories, and a more cooperative contract administration climate.

Introduction and Overview

In recent decades, Central European contractors (Austrian, Swiss, West German) have moved to the forefront of technological advancement, innovation and productivity in many types of construction. Their bridge designs, tower cranes, concrete technologies and tunneling methods have become increasingly common in the American marketplace. In contrast, American construction, the undisputed world leader until two decades ago, appears at times to have suffered technological and economic stagnation. The contrast, in part, can be attributed to a stronger emphasis on research and technology in the laboratories and projects of Central European engineering construction companies, a more favorable contractual and administrative structure between owners, designers and contractors that offers real incentives for innovation, and to their closer interaction with universities. While technically driven, the Central European companies still proceed with a rational and pragmatic cost and quality consciousness. The universities, in turn, in many ways appear to have a more practical and yet technically deeper curriculum than their American counterparts.

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This paper combines the experience of four writers to provide information about Central European construction that should be of interest to American practitioners and educators. In recent years, Halpin, Paulson and Willenbrock have conducted extended studies of technologies, practice, research and education in West Germany, Switzerland and Austria (1,2,4). Their activities included interviews and meetings with contractor and owner engineering, management, research and project employees, field visits to major construction projects, and seminars and lectures for university students and professional organizations. Schub is active in both academia and industry in West Germany, and recently spent a year teaching in Switzerland (3). He has provided much of the factual substance and background material in this paper, and has checked the statements of the American authors for accuracy. He also had a sabbatical leave at Stanford, and spent considerable time visiting American companies to gain a perspective on U.S. industry. Although it would be inadvisable to blindly import customs and procedures across cultural and political boundaries, the writers believe that some Central European construction concepts might be implemented in this country for the betterment of industry and academia.

The emphasis in this paper will be on the role of the academic sector and how it interacts with industry. It will begin by outlining the structure of engineering education in Central Europe, and will then describe their curricula. With this background, the paper will outline the structure and interactions between research and professional practice. In its concluding section, the writers will summarize some of the important advantages of the Central European system of construction and suggest which of these might beneficially be considered for implementation in North America.

Structure of Engineering Education in Central Europe

A *"Technische Hochschule"* is an older term for what is now called a *"Technische Universitaet,"* which is an academic institution for scientific and engineering teaching and research. It originated from the polytechnical high schools during the last century in Central Europe. Contrary to other technical schools (*Fachhochschule, Technikum, Meisterschulen*), the professors of a technical university act as researchers as well as teachers. This section will present background information mainly on the *Technische Universitaet* level of education for construction engineering and management.

Admission Requirements to the University.—The entrance requirement to a university is to have a *"Maturitaet"* certificate (school-leaving certificate at a level qualifying for admission to a university) from a *gymnasium* (high school). There is no need for an entrance examination. It is necessary to have this certificate (in some places also called *"Abitur"*) before admission, which implies that social science and liberal arts courses have been taken. That coverage is considered adequate for an engineer, and thus time is not allocated to these subjects in the technical university. Alternatively, students who have completed the *Fachhochschule* (at the level of a junior college) with merit are allowed to study at the *Technische Universitaet*.

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Degree Qualifications and Procedures.—An important difference here from American universities is that students "visit" lectures and receive credit for attendance by having this entered in the "*Studienbuch*" (a page with a list of all subjects selected for a semester) (or *Einschreibebogen* in the Swiss system). Under the concept of "academic freedom," the student physically does not have to attend the "*Vorlesungen*" (lectures), although most do. Also, in contrast to the American system, the student does not receive a letter grade (e.g., A, B, C, etc.) in connection with visiting the lectures. Grades are awarded at the time of the *Vordiplom* (pre-diploma: first examination, no degree, no bachelor) and the *Hauptdiplom* (main diploma) examinations. In certain cases, specialties not covered on the examinations, such as Wood Construction (*Holzbau*), can be addressed for credit purposes by giving a "*Klausur*" exam (a separate test at the end of a semester). Admission to the main examination requires a pass on these specialty subject exams (i.e., *Klausuren*) as well as credit for all required lectures.

The fact that a student is not given an end-of-semester grade and credit for the series of lectures means he or she will not be able to "put this material behind" until it has been examined on the *Vordiplom* or *Hauptdiplom* examinations. This makes the in-progress objectives and strategies of the Central European student quite different from that of the American student. The American typically wants to take a course and receive a passing grade for the period of exposure to the subject. This grade is determined by work accomplished in the form of assigned problems and tests (exams) administered during the period of the course. Following completion of the course, the student will not normally be reexamined on the material covered (except insofar as the material is prerequisite to other courses taken later). The American student thus proceeds step-by-step in accumulating course credits. When he or she has accumulated sufficient credits, a degree is awarded. In contrast, the European student is preparing for a battery of exams covering a wide set of subjects. These exams are administered twice or more during his or her student career at critical times, typically at the midpoint and the end of his or her study. There is less short-term pressure during individual courses. The lectures mainly provide information and a basis for preparing for these two major sets of exams. One result is that the Central European student is exposed to a much wider range of material than his or her U.S. counterpart. Furthermore, both theory and practice are also covered in depth in large course projects or "*Uebungen*," which are professionally oriented (e.g., full-scale design problems). The diploma candidate also must submit a *Diplom Arbeit* (thesis) after passing the general examinations.

The Degree of *Diplomingenieur*.—The degree "*Diplomingenieur*" (certified engineer, usually abbreviated "*Dipl.-Ing.*") is awarded after a standard engineering education. Undergraduate study terminates with the prediploma and is a prerequisite to entering graduate study and the final examination required to obtain the degree of certified engineer.

Professional Engineer.—In addition to being the basis for awarding the *Diplomingenieur* degree, the *Hauptdiplom* examination, when passed, in effect gives the engineer the license to practice in the state (e.g., Bavaria) in which he or she takes the exam. After graduation, practice as

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a professional or consulting engineer in Switzerland and the Federal Republic of Germany is then possible, whereas in Austria an additional license has to be obtained.

Research and the Degree of *"Dr.-Ing."*—Research is ongoing in the institutes of the major technical universities, much as it is in the United States. There is a similar complement of research assistants, and many are concurrently pursuing *Dr.-Ing.* (Doctorate of Engineering) degrees while they are active in research. However, in contrast to the American system, where service as a research or teaching assistant serves mainly to support the higher priority of pursuing a doctoral degree, the German research assistant must normally give first priority to his or her employment duties. They fit in the research and writing for their degree only as time permits, and many if not most do not finish by the time their assistantship expires (usually about four to six years). As in the United States, doctoral candidates must prepare a scientific thesis to be concluded with a final doctorate examination. In contrast, however, they do not do nearly as much additional course work beyond the undergraduate degree.

The *Dr.-Ing.* candidates sometimes supervise *Diplom Arbeit* projects, thereby gaining expertise in research supervision. Such a thesis may be based on a project that provides help to the *Dr.-Ing.* candidate in pursuing his or her own research.

Graduate Research Assistants and Coworkers.—In principle, all assistants are paid by the state, but coworkers (*Mitarbeiter*) paid by third party funds also have a *"Diplomabschluss"* (diploma), and they also are usually employed for five to six years. Assistants do teaching and research work; 30% to 40% of their time can be used for their own scientific research (e.g., for a doctoral thesis). Unless there are insufficient vacancies at an institute, a *Dr.-Ing.* assistant can be promoted to senior assistant. Because coworkers depend on outside research funds, and are 100% dedicated to a particular job, it is more difficult for them to obtain a *Dr.-Ing.* Research assistants are expected to pursue an independent academic research project, and are responsible only to their professor(s). Coworkers perform routine tasks, for example, collecting data, doing library research work, inputting computer programs, and conducting laboratory testing, and are responsible to the professors or assistants.

Some technical universities admit candidates to postgraduate study, which terminates with an additional title of *"Wirtschaftsingenieur"* (similar to a Master of Business Administration degree), a *"Verkehrsingenieur"* (planning and traffic engineer), or an *"Umweltschutzingenieur"* (environmental engineer).

Academic Careers.—To be qualified to offer lectures within the technical university, the engineer or other expert must prove his or her qualifications and ability to lecture at the university by passing a review of his or her credentials as well as an oral and written examination. This examination, called a *"Habilitation"* (Inaugural dissertation), is usually taken several years after the *Dr.-Ing.* examination by those persons desiring to lecture at the university, resulting in the designation *"Dr.-Ing. habil."* By passing the *habilitation* exam/review, the person receives a title recognized by the university conducting the review (e.g., *dozent*), such as university lecturer.

The title of *professor* has a much higher status in Europe and usually implies that the holder of this title holds an endowed chair and is the director of a specialty institute involved in both teaching and research, and has a staff and budget provided directly from the legislative body of the state in which the university is constituted.

Engineering Department Administration and Organization.—Technical universities have several departments (for example, natural sciences, mathematics, physics, chemistry, electrotechnics, civil engineering, materials science, architecture). Each department contains teaching and research groups led by individual professors who teach specialties like concrete structures, traffic-control techniques, soil mechanics, construction engineering and management, and tunnel building. These divisions have the designation "*Lehrstuhl*" and "*Institut*," corresponding to teaching and research groups led by individual professors. They enjoy much more autonomy in budgeting, staffing and administration than do similar divisions within American academic departments, and there can be considerable contrasts in how these matters are handled, even within the same department. The departments as a whole, however, decide on the timetable and teaching schedules, since this needs coordination to meet student curriculum needs.

Educational as well as research work is being done within the institutes. The scope of research and teaching interests is similar to that of an engineering-based program in the United States. In all of the major universities they visited, the American writers found colleagues with whom they could closely identify, and the same held true for the West German writer when he visited the United States. A typical institute within a department consists of two to five full-time professors responsible for scientific tasks (one of whom is the *Lehrstuhl* professor), which is comparable to similar programs in the United States. However, they seem to have much better base-budget staff support. For example, there are four to 10 research assistants (positions lasting a maximum time of five or six years having unspecified work responsibilities) funded by an institute's budget, and two to four "*Mitarbeiters*" (positions lasting an unspecified amount of time for specified research work, usually externally funded). Almost all such positions in American universities have to be funded by soliciting external support, usually from government grants and contracts obtained by competitive—and uncertain—proposal mechanisms. The base-budget funding can give much better stability to support research in European universities, and thus can better support long-term basic research. Secretarial and technical support is also much more generously funded in the European universities, freeing more faculty time for direct research and teaching activities. For example, a group of four faculty would have two or three staff members as secretary, librarian or draftsman, and possibly a few part-time undergraduate student workers, all without seeking external support.

Research Facilities.—In physical computing facilities, major American universities seem to be ahead of their European counterparts, in part owing to generous discounts and donations by U.S. computer manufacturers. For example, it has taken longer for European university (and industry) computing to move from central mainframes to microcomputers, although they are well underway now. Similarly, it will probably

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take longer for them to introduce advanced work stations for computer-aided design (CAD) and artificial intelligence research and teaching.

Researchers in European universities are well aware of this difference. However, although their base-budget funding for office space and support staff is strong compared to most American universities, they apparently are more severely restricted on capital equipment funds or grant opportunities. Given more limited resources, they nevertheless do an excellent job of using them effectively for both theoretical and practical research and teaching in construction engineering and management.

Funding.—Most funds for teaching, research and purchases are defined over several years by a central university *gremium* (board). These costs are carried by the state. An institute typically has about $30,000 per year available for general expenses beyond personnel costs. This minimum guaranteed budget, though not sufficient for large research projects, enables the professor to do some research work independently. This has advantages (e.g., independence and freedom) and disadvantages (e.g., research may be too theoretical, or may duplicate research done at another university). In addition, some believe that there is little motivation in this kind of "free" research, and there may be less development and clarification of ideas such as happens in developing proposals for competitive evaluation and in preparing project reports. Internally budgeted research is more likely to drift along.

Should there be greater research work to be done, then money from outside is sought. Funds from outside sources (industry, private foundation endowments, government construction agencies, etc.) have to be raised independently in order to conduct additional specific research tasks. The organization and management of the research work is done in each case by the professor of the institute.

Faculty Consulting and Private Employment.—As in the United States, faculty have the possibility to search for individual part-time private employment and consulting. Professors also are asked to act as consultants within code committees, *Fachgremiums* (boards of experts), and associations. These consultations are honorary acts, but acting as an expert witness in courts of law is not. In general, there is a stronger feeling that teaching and research work should not suffer from such additional employment. Therefore, in Central Europe the long-term private activity of a professor is an exception, as mostly firm and irrevocable long-term contracts are made. Furthermore, private employment by professors or assistants needs special approval from the university. A percentage of the private income is usually taken for the use of rooms and equipment needed at the university, and related personnel costs have to be reimbursed to the university.

Industry Involvement in Academia.—Industry-sponsored research is not common in Central European university construction engineering and management programs. Industry consulting requested from professors is common, for example, in evaluating change orders and bid alternates. Occasionally industry is interested in the use of university facilities, like computers, testing laboratories, etc. Often professors are invited to participate in industry-sponsored seminars and to give lectures.

Role of Proof Engineer.—In some countries of Central Europe there are regulations requiring the checking of structural calculations and steel reinforcement on construction sites by a proof engineer. Leading university professors often fulfill this role. Through quality assurance, this is a preventive measure to avoid errors. If an error does occur, the responsibility of the proof engineer is not entirely binding.

The proof engineering concept may extend beyond simple checking of regulations and codes. There is a long established tradition of seeking *Gutachten* or independent evaluations from university experts. In this case a university chair or expert acts as an impartial arbitrator in evaluating or certifying a given situation. This activity is viewed as an important service to the profession and the industry. *Gutachten* can be given in any of the specialty areas of civil engineering. Reimbursement for such work may accrue to the university or the person(s) performing the evaluation depending upon the given situation.

Research Procedures and Administration.—Research projects financed by the budget of the university do not need the approval of the university board. Projects sponsored externally have to be approved by the university board and are monitored by the university administration, especially if they require tax-free industry contributions.

The following examples show how the handling of a similar project, the development of a computer program, would vary depending on the source of funds:

1. Development with institute funds. Characteristics of the algorithms and requirements for the program would be given by the professor. The assistants would then program and test the algorithms.
2. Development sponsored as an outside research project. Characteristics of the algorithms would be given by the professor. Requirements for the program would be defined by the research team (coworkers) in cooperation with the contracting entity. The assistants would program the algorithms. The research team would test and use the program.
3. Development within the frame of private consulting. Characteristics of the algorithms and demands for the program would be defined by the private employer. The professor would program and test it himself or let the assistant do the programming and testing.

Construction Engineering and Management Curriculums

Construction management (*Baubetrieb*) as an academic discipline evolved over the last 80 years within Central Europe. One reason was that machinery increased within building technology, water management, and tunneling at the beginning of this century. Later on *Leistungsberechnung* (calculation of the performance rates of resources), *Kostenrechnung* (cost estimating and control), *Verfahrenstechnik* (construction methods), *Arbeitsvorbereitung* (operations planning) and *Ablaufplanung* (project scheduling and control) were added. Today, construction management also contains the fields of *Bauwirtschaft, Investitions und Unternehmungsplanung,* (construction economics, investments, and market planning), construction law and computing, which is represented at one or even two departments.

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TABLE 1.—Comparison of Semester-Week-Hours

Construction management courses (1)	West Berlin (2)	Munich (3)	Vienna (4)	Zurich (5)
Basic	8	8	9	24
Specialized	14	27	23	29
Total hours	22	35	32	53

Degree Programs.—The lower-level courses (mathematics, physics, chemistry, mechanics, geodesy, materials technology, jurisprudence, practical economics) are required for all students of all departments. They lead to the previously mentioned *"Vordiplom."* After the prediploma, the upper-class courses start with engineering major subjects (e.g., mechanical engineering, civil engineering). These are separate for different departments.

Owing to the increase in technical and educational science within construction engineering during the past 20 years, specialized courses (*Vertiefung*) are integrated into the last two or three semesters; 20–50% of these are part of the technical studies for the major degree. This, in turn, is culminated by the *Hauptdiplom* (final examination) and thesis (*Diplomarbeit*).

Construction engineering and management specialization courses start in the fifth semester at most universities, which is equivalent to graduate study in the U.S. In some universities they start in the third or fourth semesters, but only in Zurich do the courses start in the first semester.

The number of courses, recitations, and seminars varies greatly. Table 1 compares courses in semester-week-hours at four technical universities. Normally, one semester week contains 26–28 hours of courses (45 minutes/hour teaching time).

The contents of the courses also vary greatly. By dividing the course content into six main parts, the percentages listed in Table 2 are obtained for the four universities mentioned above. This is based once more on the number of semester-week-hours for recitations, courses, seminars within main courses, and specialized courses.

The European curriculum exposes the student to a much broader spectrum of material on the way to his or her degree than does the U.S. counterpart. In general, the level of coverage is also deeper in the European system. In areas like *Baustoffkunde* (building materials), a wide range of topics is studied; for instance, the design of stairwells (*treppen-*

TABLE 2.—Comparison of Course Content, in Percent

Content (1)	West Berlin (2)	Munich (3)	Vienna (4)	Zurich (5)
Construction market	26.8	11.7	10.8	19.7
Construction equipment	32.8	10.9	17.6	10.9
Construction methods	19.5	15.1	20.5	12.8
Construction operations	15.9	19.4	11.8	20.0
Project management	0.0	32.3	13.3	20.9
Construction economics	5.0	10.6	26.0	15.7

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hauser) and structural analysis of arches are covered in detail.

***Praxis:* Programs that Enable Students to Obtain Practical Experience.**—The *Diplom Ing.* candidate must complete a certain number of weeks of practical training with a selected company to learn about the practicalities of engineering work. This may be with a design firm or a construction firm. It is not required of civil engineers in Switzerland.

Time and Schedule to Obtain Degree.—The minimum time required to obtain a degree is eight semesters (four years) after entering the university, but it usually takes 10 to 12 semesters (five to five and one-half years) to obtain the final exam due to prediploma exams, the main diploma exam, and the actual independent diploma thesis work. It is further worth noting that, owing to compulsory military service that usually takes place before the initiation of university studies, the students start as well as finish at a more mature age than is typical of American students.

During the winter term the course of lectures lasts from the end of October until the end of February (four months), and during summer term from the end of April until the end of July (three months). The time in between the terms is open for self-study, for programs that enable students to obtain practical training outside, or for various exams.

Tuition.—Tuitions are very low ($100 to $200/yr) in Europe in comparison with the U.S. All universities are state-supported; there are no private universities. The objective of the university is to make education readily available (at very low cost) to properly qualified students (i.e., with proper admission credentials).

Professional Practice

The visits by the American writers to Central European countries yielded a number of general impressions and some specific cases that support an overall feeling that the climate for technological advancement in engineered construction is indeed more favorable there than in the United States. First, senior management and administrative people in both owner agencies and engineering construction companies still seem to be dominantly engineering and technical people, with a current knowledge of and active interest in the state of the art in their field. It is not clear what this does to their management abilities, but it does provide a sympathetic climate for research and innovation. In contrast, there is a tendency in the United States for such people to abandon their technical "roots" (if they had any), see themselves as "past that stage" of career development, and pursue management and administration as a seemingly more prestigious and certainly more lucrative profession in its own right.

Second, the project development format in the U.S. discourages design competition at the proposal stage, being based more on the historical qualifications of the designers than on the proposed solution or design approach. The credentials of the designer are reviewed, but his or her concept of design is seldom a major consideration in the selection process. This leads to very conservative and unimaginative engineering. It supports the "safe" approach designed to limit liability and to stay away from innovative solutions that might be costly.

European contracting procedure encourages a design competition among vertically integrated design-construction firms on many major projects. The designer must not only present credentials and qualifications, but must also submit sufficient design material so that the proposed design can be evaluated. The evaluation typically is in terms of: (1) Structural concepts; (2) safety; (3) cost of construction; and (4) aesthetics. The importance of each of these factors is based on the type of project and other considerations. The design must not only address purely engineering considerations, but also the construction methodology. This is why bridges in Switzerland, for example, have become famous for the integration of design and construction engineering to achieve both cost-effectiveness and beauty.

Third, the division between design and construction in the U.S. has in some cases led to an adversary relationship between the designer and constructor. As is well-known and publicized, the legal climate in the United States has begun to paralyze innovation in many if not most fields, and most certainly in construction. By regularly charging and suing each other, our contractors, engineers and owners are as much to blame as the much-maligned third parties for this deteriorating situation. Europeans are incredulous when they hear stories of what have become routine litigation situations in the United States.

Fourth, perhaps because they are not so immobilized by the fear of risk and legal liability, many European agencies support contract award and administrative procedures that both encourage and reward innovative thinking by contractors. The most prevalent of these incentives is the solicitation and careful review of contractor-originated alternatives to the owner's design. The alternatives submitted often involve major changes in design concept (for example, changing from a cantilever to a launched girder method for a concrete bridge), and obviously involve considerable design expense by the contractors even when many companies are bidding in the competition. Often a respected third-party "proof engineer" is employed to ensure the impartiality of such comparative analyses, and this person is frequently a nationally respected university professor. The reward for the contractor in making this investment is that a real innovation that saves on cost or schedule, or improves the quality or functionality of the project, will have a very good chance of making it the successful bidder. This is reinforced by the fact that the contractor's alternative design normally will be one that accommodates methods in which the contractor has special expertise or equipment that in turn help assure the success of project execution.

Success in bidding is followed by a generally more favorable climate for contract administration. There is considerable flexibility even in public agencies for negotiating contractual (cost, schedule, etc.) and technical (design and methods) issues both before and after contract award. Both alternative bid submittals and negotiation are virtually forbidden under the legal constraints that encumber almost all United States public contracting agencies.

Finally, the combination of these and other factors has led to the establishment of genuine and well-funded in-house research and development efforts, including laboratories staffed by advanced-degree engineers and scientists, in major engineering-construction companies. The

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R & D, in turn, leads to patentable and licensable technologies that add to the companies' marketing strength. Some of their products are successfully marketed in the United States. Although this mechanism is well accepted in other sectors of U.S. industry, it is almost nonexistent in our engineering construction companies.

Conclusions

This section will summarize some of the important advantages of the Central European system and suggest which of these might beneficially be considered for implementation in North America.

In general, Central Europe has a strong and advanced construction industry whose capabilities and characteristics are too little understood in the United States. In many areas their technology is ahead of ours, and there could be considerable potential benefits to both sides if Central European contractors could more frequently joint venture with our firms to solve problems in American bridge and underground construction, among others. American companies could also learn a great deal from their approach to research and technological advancement. Given the Europeans' strength in the international market, there would also seem to be potential benefits in greater cooperation on foreign work.

Universities in both the United States and Central Europe have a similar task in the educational and research field. Responsibility lies mainly with their respective faculties. The difference, however, lies within the personnel and financial funds of the teaching and projects. Central Europe has fixed research and teaching funds for an institute. Larger research projects also need external funds in Central Europe.

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