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## Towards Better Education of Civil Engineers

Vers une meilleure formation des ingénieurs civils

Wege zu einer besseren Ausbildung für Bauingenieure

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### SUMMARY

A basic knowledge in many fields of science like construction materials, mechanics, structures, analysis, building physics, human aspects, aesthetics etc. is required. This knowledge cannot be gained by an academic programme alone but rather in combination with personal observations and the analysis of objects in practice. A rich repertory of design possibilities should be built up in this way and a critical assessment of their advantages and disadvantages should be exercised.

### RÉSUMÉ

Il est nécessaire de posséder les connaissances de base dans beaucoup de domaines scientifiques: matériaux de construction, mécanique, structures, calculs statiques, physique du bâtiment, aspects humains, esthétique etc. Ces connaissances ne sont pas seulement acquises par des études universitaires, mais elles résultent aussi d'observations personnelles et de l'analyse des objets réalisés. De cette façon, un riche répertoire de possibilités de conception peut aussi être rassemblé. Une évaluation critique des avantages et des inconvénients doit être pratiquée.

### ZUSAMMENFASSUNG

Grundkenntnisse müssen in vielen Wissenschaftsgebieten erworben werden, so in Baustoffen, Mechanik, Tragwerken, Baustatik, Bauphysik, Bedürfnisse der Menschen, Ästhetik usw. Diese können nicht durch akademisches Studieren allein gewonnen werden, sondern erfordern persönliches Beobachten und Analysieren ausgeführter Objekte in der Praxis. Ein reiches Repertoire von Entwurfsmöglichkeiten sollte auf diese Weise angesammelt werden. Kritische Bewertung der Vor- und Nachteile muss dabei geübt werden.



Civil engineering is a fine profession and can give deep satisfaction if the engineer has learned the art to design in a broad way. To make good designs is an art and, like any art, requires intensive studies and work to become a master in this art.

The attitude towards this art of engineering must be that of serving our fellow citizens. Engineers and architects design buildings, structures, traffic ways, bridges, harbours - all needed to serve society, to provide living and homes for masses of people, to improve their living conditions, not only materially but also in culture and fine arts. Therefore we must be aware of being servants and should avoid to serve personal vanity and prestige. We should also be aware that the two professions architect and engineer belong closely together and should cooperate whenever they have to design buildings and structures.

### Judging and analysing structures

Doing this in a good way, both must know many different possibilities for choice. The young engineer must have seen many structures and have them registered mentally. First he must learn to see consciously, to observe and analyse qualities of the building or structure and to inquire the effects on human beings as users or neighbours. In order to analyse a structure, one must have learned the basics of structures. This means the engineer should know the structural systems like beam, slab, plate, frame, arch, suspensions, folded plates, shells, trusses, space trusses. He should know their reaction and resistance to acting forces like dead load, live load, wind, temperature effects, impact etc. Judging structures requires basic knowledge in mechanics, statics, strength of building materials and soil mechanics. He should also have made or seen tests with structures members up to failure.

These fields concern mainly stability and safety against failure, which must be guaranteed in any case. But the effects of a building on human beings are equally important as safety. We have to design for the comfort of the user, for the economy regarding the owner which includes operation, energy consumption, maintenance and durability. To judge these qualities, one must have basic knowledge in fields like building physics - concerning thermal effects, moisture, noise, acoustics, light and colour. Some knowledge in the physiology and psychology of man is needed for understanding the human response to such qualities. Cost calculations for investment, operation, maintenance etc. should be understood. For durability, the behaviour of building materials under climatic and chemical attacks must be known. All these sciences require fundamental knowledge of mathematics, physics and other basic natural sciences as they are usually offered at college level.

### The student's problem - basic knowledge in many fields

For a student it is almost a deterrent to become aware of this wide range of knowledge which should be available for good design ability. But please recall that I repeatedly spoke of basic knowledge, knowledge of the principle laws of performance, sufficient to choose the right solution in principle. One can always call a specialist for detailing. In practice, there is usually a team

of specialists for the design of any important building, but it is always helpful if the members of such a team have such basic knowledge in the different specialised field which helps to understand the specialist and prevents the danger of one-sided partial dictates of specialists.

Studying architecture or engineering therefore means to learn the basics of many sciences, to have them as tools for designing. These sciences shall not govern but serve and help to fulfil the purpose, to satisfy functional needs and requirements. These functional requirements have also a great variety. Sullivan's famous slogan "form follows function" was never meant to refer to the structural form only, the whole building must function not only for physical requirements but also for psychological and emotional desires to provide well feeling and harmony. This involves aesthetic qualities also. This is clearly stated by Fraser Reekie in his book "Design in the built environment" (Bristol Polytechnic) but not implemented in practice.

### Grasping practical experience

Learning in universities or other schools is not sufficient for becoming a good engineer. The student should travel a lot and see and analyse many buildings or structures. He should make sketches or photos. To be skilled in drawing free-hand sketches is most important and often neglected nowadays. He should further visit many construction sites and shops of craftsmen or fabricators or, even better, work there for some while, because he must know how materials are machined or made and put together or how construction or erection is going on. He should have the possibilities of construction and fabrication in mind when he designs larger structures because quite often construction possibilities set limits or influence costs and economy.

The student should also not hesitate to contact the engineers who are responsible for the structure which he visits or the field- and resident engineers on the site and ask them the many why's which came to his mind when he tried to analyse what he has seen. Such field discussions can be most helpful. Studying buildings he should also ask the users, he would often be surprised to hear the complaints and accusations by users about bad performance of buildings which have been designed even by famous architects.

This background of learning is most important because the design abilities improve with the quantity and quality of structures which the engineer has consciously seen and studied and registered mentally. He must have a rich repertory of design possibilities to draw from when he starts himself to design.

### The design process

The design begins with collecting all data of functional requirements, of use and purpose of the building, desired visual effect. Further data are needed of the site, ground conditions, climatic situation and orientation, economic limits, neighbouring and environmental consideration, local availability of materials, of energy, of skilled labour etc.

With these data in mind, the structure gets its first hazy shape in the imagination of the designer. The pencil transfers it on



paper. After the first sketch a second, a third sketch is made. Different solutions are compared, evaluated and put aside for further brooding and contemplating in the mind - best over night. Then new sketches are made, now to scale, checking the various and manifold requirements, looking at proportions of building masses etc. At this stage, the designer, architect or engineer should show his sketches to his partners. The task of designing is so complex in our days that nobody should have the ambition to make a design all by his own. Early discussions with experienced or specialised partners are most helpful because three or four heads see and think always more than one and they look and judge from different view points. This early collaboration is mainly necessary between architect and engineers. Criticism should be welcomed and digested. In this way the design begins to grow out of babyhood. It is still a long way to maturity for implementation.

If one thinks that the design will fulfil all functional requirements, then it should be shown to and discussed with laymen, with friends, preferably with ladies of good taste. I do this even with my bridge designs, and it is often surprising how their impression and remarks help to improve the design.

#### Design analysis and the role of the computer

So far no statical calculation was necessary because the required structural dimensions are usually roughly known by experience. But for the next step of the design procedure, rough hand calculations should be made in order to get the dimensions of girders or critical structural members sufficiently large for sound constructability. Some structural detailing may also early be done for critical points.

Many engineers these days run large computer calculations before they have a clear picture of the structure and its important details. The computer should not be used before the structure's design has reached some maturity. The computer is undoubtedly an important aid for the engineer especially in the final state, but it is often misused to impress the client and to waste a lot of paper. The ability to make rough hand calculations must be cultivated also in the future, mainly for quick and reliable checking of computer outputs and for getting the ability of sound judgement for structural dimensions.

The engineer must also be aware that the computer cannot design and cannot produce innovations. Creativity is still the privilege of the human mind, and creativity is badly needed to solve the design problems of the future. Therefore we must place the computer into its correct role - the role of a technical tool. With good software, it is indeed a very capable aid, allowing complicated calculations which were not possible in former times. As an example I may mention the Olympic Stadium in Munich. The calculation of the exact geometric lengths of the many thousand strands and ropes for the networks could only be done successfully by the computer for which Professor John Argyris had prepared a special programme just in time.

Most design can be based on well proven and established solutions out of our repertory, but the tasks and means change and therefore we should always search for improvements compared with the tradition. This means critical thinking - to be doubtful, sceptical

and suspicious about the soundness of earlier solutions. The human mind is not perfect, and a lot of our views and thinking are based on traditional prejudices, sometimes on superstition or on the effect of the famous hidden persuaders (Vance Packard) which are engaged by the salesmen of our big industries. This is especially true in architecture which is so much governed by undigested fashions. Just take the façades of buildings, especially those of high-rise buildings.

#### Some functional aspects

Essential functional requirements are not fulfilled if such buildings have glass façades in the heat of Texas as well as in Calgary with temperatures  $-30^{\circ}$  C, and if these curtain walls are equal towards south, east, west or north. The reflection of clouds on the glass may please an architect as it is reported of Mies van der Rohe, but it does not benefit the user who has to suffer behind the glass or the owner who has to pay the bill for energy consumption in summer and winter time. Large façade areas covered with plain concrete in the style of brutalism cannot satisfy either, they hurt mainly our natural aesthetic senses.

The exposure of the structural skeletons of multistory buildings or even the exposure of installation pipes (Centre Pompidou Paris) is nothing else but a search for sensation to satisfy vanity and has nothing to do with fulfilling functional requirements. God has protected the skeletons and bones of all his creatures, including man, with a thick pelt and skin. So our buildings need a protection against the different climatic attacks and this protection should be different, depending on the kind and strength of these attacks.

#### Architecture in crisis

The architecture of the last 50 years has come into a bad crisis, mainly because it did not fulfil basic requirements of human comfort and well feeling or social needs. The psychic requirements had been almost totally neglected. The sense for aesthetics and the capability of sound aesthetic judgement has been widely lost in our whole society (not only amongst architects). Ugliness of built environment makes the human soul sick and causes depression or aggression. In an ugly environment crime grows like mushrooms. People long for more beauty, for more humanitarianism in our cities.

Architecture should not be styling the exterior following fashions like functionalism, international style, brutalism, post modernism and how all these ideologies and fashions were called. Architecture must develop to fulfil human requirements, physical, psychic and emotional requirements. This is a challenge in the near future for creativeness in our professions. Engineers and architects must learn again the basics of psychic desires and requirements, the basics of aesthetics and also the basics of all what is needed to make users feel comfortable. Challenge is also raised by ecological requirements, a wide field of which I may only mention the necessity to get clean air and water, to save energy and to switch to solar energy.



### The role of building physics

A new architecture satisfying these requirements cannot be gained by nostalgia, by going back to Palladio or the other old styles. We must get away from considering architecture mainly as styling, as shaping for exterior visual appearance. The new façades must be developed to function in all the aspects which I have mentioned: better thermal insulation, sun shades different for west, south and east which give thermal insulation to windows at night in winter time. We need new heating systems like electric low temperature radiation from ceilings or walls which in combination with more thermal insulation allow to reduce energy consumption down to 30 % of what we consume now. In addition, such heating avoids air pollution. We also need good natural ventilation of the rooms, better acoustics etc. etc. There are so many things which must be changed and improved in order to gain satisfactory living conditions in our cities.

This challenge concerns mainly the engineers who can help by their training in rational thinking, by their scientific approach, technological know-how and creativeness, by which new solutions for a better architecture can be created and hereto, knowledge in building physics is more important and fruitful than in mechanics and statical analysis.

All this is a great challenge for the next generation towards learning, learning in a broad sense, learning also outside the universities which often are limited to old and well established sciences. It must be a learning from real life, from the needs of our follomen. The challenge calls for creativity, for research and innovations - not in opposition to technology, but for a more human technology considering also ecological aspects, knowledge and requirements. We can have confidence in the future, but we must go to work with courage in order to solve the problems.

### Importance of aesthetics

I mentioned several times aesthetics. For me there is no doubt that aesthetic qualities of our built environment are as important as economic materialistic aspects which had priority so far. Aesthetic qualities have an enormous influence on social and ethical behaviour and hereby on the psychic health of man. Buildings and structures have aesthetic qualities which impress people mainly subconsciously. Man has a natural sensitivity for aesthetic qualities of the visual appearance of his environment. The majority of the people of a certain cultural origin agree on the judgement if objects are to be classified as beautiful or as ugly. Beauty causes pleasant feelings and can be enjoyed, ugliness causes discomfort and can even hurt. P.F. Smith [1] says that "aesthetic perception has developed into one of the highest capabilities of our nervous system and is a source of deep satisfaction and joy". We must learn again to analyse these aesthetic qualities, and we shall find that there are rules for good and bad in aesthetics and that the old masterbuilders have applied such rules with great success. Such rules or guide lines are outlined and explained in [2].

Aesthetics are again a wide field for learning and this learning should be done with the whole society in order to get more under-

standing for the real values of aesthetic qualities for human satisfaction, values for which it is worthwhile to spend money. Such learning is also the supposition for better designing abilities which give satisfaction and happiness by better design results. Learning pays!

R. Fraser Reekie speaks in the preface of his book of "the urgent task of abolishing ugliness, dreariness, squalar and all offensiveness from towns, villages and countryside, restoring and producing visual pleasure in the environment, so that life can be lived therein more healthily and happily".

#### Closing remark

Remember, it is not only the visual appearance of our built environment from the outside, but as well the comfort and beauty of the inside of our buildings where we spend much more time which counts for a healthy and socially sound development of the future of mankind. Engineers and architects are challenged to learn, search and work for this aim.

Manifold studies in different fields and an alert sense for human requirements are needed to acquire good design abilities. Cooperation with specialists can improve the result. On this background designing is a pleasure and gives satisfaction rewarding the efforts. Most importantly - designing should always be done with the attitude of serving and giving, which brings more satisfaction than pretending and taking.

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