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Design and Construction in the Work of Architects and Civil Engineers

Projet et construction dans le travail de l'architecte et de l'ingénieur civil

Entwurf und Konstruktion in der Arbeit des Architekten und Bauingenieurs

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SUMMARY

Since the professions of architect and civil engineer have developed from that of the master builder, difficulties arise with the great variety of structural possibilities, with comparing alternatives and selecting the optimal structure in view of the overall design. Architects settle for a certain structure too soon and consult the engineer too late. Engineers are too concerned with theory, calculation and standards, whose apparent perfection has drifted far away from reality. They know too little about design and form. Both architects and engineers have not learnt to cooperate in a team at university, where their education needs to overlap.

RÉSUMÉ

S'étant développées à partir de la profession de constructeur, les activités des architectes et des ingénieurs rencontrent des difficultés avec la variété des possibilités de construction, avec la comparaison de variantes et le choix d'une solution optimale pour la construction. L'architecte se décide trop vite pour une solution et fait trop tard appel à l'ingénieur civil. Ce dernier se préoccupe trop de théorie, de calculs et de normes, dont les exactitudes apparentes le font s'éloigner de la réalité de l'acte de construire. L'ingénieur civil sait trop peu du projet et de la conception. A l'Université l'architecte et l'ingénieur civil n'ont pas appris à collaborer et leur formation devrait être complémentaire.

ZUSAMMENFASSUNG

Seit sie sich aus dem Baumeisterberuf heraus entwickelten, haben Architekten und Bauingenieure Schwierigkeiten mit der Vielfalt der Konstruktionsmöglichkeiten, mit dem Gegenüberstellen von Alternativen und dem Auswählen der für den Gesamtentwurf optimalen Lösung. Architekten legen sich zu schnell auf ihnen Bekanntes fest und ziehen den Bauingenieur zu spät zu Rate. Bauingenieure beschäftigen sich zuviel mit Theorie, Berechnung und Normung, deren scheinbare Genauigkeit sich von der Wirklichkeit des Bauens zu weit entfernt hat. Sie wissen zu wenig vom Entwerfen und Gestalten. Beide, Architekten und Bauingenieure, haben auf der Universität nicht gelernt, zusammenzuarbeiten. Ihre Ausbildung braucht einen Überlappungsbereich.

1. DESIGN AND STRUCTURE

Speaking in mathematical terms, design and structure can be regarded as universal set and subset. In this case "design" - the universal set - will mean all activities necessary to plan buildings or groups of buildings according to their material or idealistic purpose. "Structure" - the subset - should stand for the part of planning activity concerning the technical composition of buildings. Therefore the structure is part of the design - a fact which I would like to emphasize.

2. THE MASTER BUILDERS AS ARCHITECTS AND ENGINEERS IN ONE

During Antiquity and the Middle Ages excellent works of architecture and engineering were created. If one examines this with todays scientifically supported methods one will generally find that structure and form correspond well. We perceive the harmony merely by looking at those buildings. Form and structure follow the flow of pressure-forces, sometimes - just think of gothic cathedrals - in such an ingenious statical system that even engineers with modern-day aid from statical analysis and strength theory could not improve on it. There is no doubt: the master builders of Antiquity and the Middle Ages were in our sense both architects and engineers in one.

Of course, the historical buildings that have come down to us represent a selection of good quality. Poor quality did not survive. Therefore, the correspondence between form and structure in buildings and probably the identity of architect and engineer in the master builders, too, were generally much more seldom than the surviving buildings suggest. Besides, I do not regard corresponding form and structure as the only scale to measure the quality of a product of architecture or engineering in general. It is also true that some of the master builders were, in modern terms, more engaged in preliminary planning and designing whereas others, more proficient in building techniques, carried out execution planning and supervised the construction site. But, principally, architecture and civil engineering were not separated during Antiquity and the Middle Ages and precise scientific methods were not yet applied to designing buildings and their structures.

It is similar during the Renaissance. The so-called "experimenting masters" of Italy dealt with mathematics and geometry and also became involved with physical and mechanical problems but these contacts between the practice of building and theory, between architecture and science did not influence the profession of the master builders much. The development of science was independent of practical application, without contact with planning and building activities. The improvement of mechanics, statical analysis and strength theory was mainly the work of mathematicians and physicists.

3. THE BUILDING ART DIVIDES INTO STRUCTURAL ENGINEERING AND ARCHITECTURE

The real development of statical analysis as a branch of theoretical mechanics began in the 16th century. The scientific discoveries were first applied to solve practical structural problems in the 18th century, to check stability and dimension building components. Analysis for structural engineering was developed during the 18th and particulary in the 19th century mainly in France where Genie-officers received education in sciences predominantly in mathematics. They applied their knowledge to structural problems especially in civil engineering and bridge building. While structural analysis developed in France the industrial revolution took place in England. The increased coal output initiated substantial progress in iron production. This is where structural analysis came in handy to calculate the structure exactly and design it most economically. The development of iron production and that of structural analysis became linked to each other and influenced one another. Scientifically supported structural engineering began to compete with traditional architecture.

During the first decades of the 19th century structural analysis methods were improved. For that reason the amount of scientific knowledge necessary to apply them increased considerably so that specialization in engineering continued. The division of the building craft into structural engineering and architecture which began in the 18th century progressed rapidly. At first the consequences were not too bad: In classicism even rational and mathematically minded master builders and typical engineers were able to design decent and tasteful buildings. The literature on engineering still contained suitable rules. As industry expanded and the capitalistic economy developed with private entrepreneurs and stock companies replacing the government as client, economy became the main characteristic of the new industrial buildings. Structural analysis and engineering craftsmanship had to serve this purpose.

Larger buildings were erected according to two principles: either following statical, calculatory and engineering rules which was generally the case with the so-called functional buildings, or with artistic and architectural ambition as done especially with, say, monumental projects. Iron, steel and reinforced concrete made it possible for the civil engineer to create numerous new structural forms which he could design, calculate and dimension on a scientific basis applying stress and strength analysis. In doing so he influenced the shape decisively. For this reason works of structural engineering, large structures of iron and steel and by 1890 also of reinforced concrete, were created usually without the help of architects: bridges, weirs, dams, halls, drilling towers, cooling towers, gasometers and others.

A conflict arose regarding buildings planned with more attention paid to artistic and architectural aspects: From the architect's point of view iron, steel and early reinforced concrete were to be used more as structural materials than in the sense of architecture and plastic art. The structures statically calculated by engineers had become indispensable to the architect and so he used them to span, to transfer loads, to create rooms, but he hid them under Neo-Gothic, Neo-Romanic and Neo-Renaissance, underneath the external imitation of old kinds of styles and element forms. On the whole, harmony between shape and structure was not achieved. Early exceptions such as the reading rooms of public libraries in Paris, the Crystal Palace in London, the Eiffel Tower confirmed the rule more than contradicting it because of the particularity of these buildings.

At the end of the 19th century the division of building art into structural engineering and architecture was in an advanced stage, the same with the separation of the profession of master builder into those of the architect and civil engineer. With the exception of housing the architect's field of work was relatively small compared to the whole building activity. It was often reduced to the aesthetical, history-orientated facade designing.

4. ARCHITECTS AND STRUCTURE

Yet it was the architect and not the engineer who noticed gradually that even simple technical functional buildings could have aesthetic qualities. The architect began to study the characteristics and application possibilities of the new building materials to such an extent that he was able to use and to show them more and more as means of structuring architecture. A process of fruitful interaction between technical and structural skills on the one hand and the search for new forms on the other was set in motion by the attempts of engineers to achieve a maximum of performance with the least possible expenditure and the interest of architects in the potentials of structural engineering. The masonry building style concerned with historic formal elements came to an end - at least for a while considering todays post-modern escapades.

To discover and acknowledge the design qualities in building forms of technical origin for their aesthetic values was not alone responsible for the tremendous shift in architecture towards modern structure. The stronger impulse came from the intellectual and political trends of the day and from the new designing theories deriving from them. Just think of cubism or de Stijl and constructivism: Their aesthetics of stereometrical forms, their demands for elements free of any associative qualities, for abstract forms and the use of new materials met with the character of technology. Interaction developed between both of them. Both stood sponsor to a new architecture, both were integrated by architects such as Le Corbusier or the teachers at the Bauhaus to achieve a synthesis of artistic design and structural expediency which was adequate for the material.

It is surely justified to call this a turning-point in the history of building culture. It would be wrong, though, to believe that in intergrating modern structure into his repertoire the architect began studying scientific engineering. Some may have gone to more detailed studies wishing to comprehend questions in their entirety, or just to be able to understand certain problems and solve them better. On the whole, there were limits to and dangers in the architect's involvement in technology: The Bauhaus, which at first was concerned with the intergration of art and techniques of craftsmanship, later did include the engineering technology but it remained devoted to small-scale items such as furniture and product design, larger engineering structures were excluded. Some architects let the form again become independent and develop apart from its origin within structure. Others went to imitation and followed mere fashions. That happened at all times.

Actually architects - beside engineers - did not get down to a basic examination of new structures until after the last world war. In the field of large span membrane structures I would like to mention Frei Otto. But they are few and they are not all in search of solutions to technical problems but are interested in the opportunities structures offer: What can architecture achieve with the assistance of structure? The majority of architects engaged in the actual designing are not as interested in the basics of structure as in its dependence on form, function and costs. This is not wrong and we will have to discuss this later.

If you were to take a survey of the results of trying to intergrate the structure into the overall design you would probably receive a slightly unbalanced Gauss normal distribution: few excellent examples, some acceptable ones, a lot of mediocrity, quite a number of unfortunate examples and some downright failures. Of the latter I would like to mention the Berlin convention hall which collapsed because the structure had been manipulated to get the appearance of a free-spanned form and so to actually fool the people.

Speaking of unfortunate objects - enough of those were produced in the last 20 years: perverting the style of technology to a complete negligence of shape and appearance, reducing the structure to a necessary minimum or even less. Of course, architects were involved and engineers as well but first and foremost the clients, I would say: firms and builder's syndicates interested in high profits. That has less to do with a lack of grasp of technology by architects than with a lack of feeling of responsibility towards society and this not only among architects.

What about today's architect's involvement with structure? That's where I stumble first: What architect am I referring to? Fritz Haller of Switzerland? Günther Behnisch of Germany? James Stirling of England?
These names represent a wide range of philosophies of design which make use of structure differently - as to organize, to participate or actually to recede. Nevertheless, judging from their buildings, the knowledge and understanding of structure these architects have is all but superficial. This is probably even more a question of skill than of philosophy.

5. WHAT MUST THE ARCHITECT KNOW ABOUT STRUCTURE?

Considering that structural engineering is a discipline of its own within the faculties of civil engineering, it again being split up into several branches of studies, if you see that the engineering sciences are getting more and more involved with building physics - just think of thermal insulation - and if you see the expansion of theory and calculating we are experiencing due to the use of computers - we actually have too much data to work with, not too little. Well then, it is perfectly clear, that the architect can hardly keep pace, just think of the time he would need. In addition to these developments the field of architectural studies has expanded greatly itself, now including aspects of society and social politics that have become part of preliminary analyses for designing. No, I would say that it is not possible to add more engineering science to the architect's curriculum, and in practice he will not have time for it anyway.

Looking deeper into theoretical engineering is not what would help the architect to work with structure. Much of what he would find would be methods of calculation leading to such scientific detail as is beyond application to practice - we will hear more on that. Static and physical calculation and dimensioning is not the problem today, in the computer age, and especially not for the architect. Basic physical principles for better understanding and just a few rules for estimating would do. Knowledge of structural systems - of descriptive or qualitative nature - is of more importance to him to point out where advantages and disadvantages are, where opportunities and limits lie and what design is adequate for the given material. In the past a whole variety of different solutions have been developed and this variety is what is confusing the architect. He lacks knowledge and skill to compare, value and choose among various structures the one that suits his whole design best. Instead, he settles too quickly for stuctures he already knows, thinking the engineer will certainly be able to calculate them to make them fit.

The architect needs a knowledge of structures permitting him to design and not to calculate. He must understand the nature and characteristics of structures. Designing the structure is just part of the whole design process. The optimum overall design of a building should be the result of integrating elegance, functional and structural efficiency and economy. That means the architect should be at ease with structures, should be able to "play" with them, he should know alternative structures. Even if the architect consults engineers at a very early stage he will always remain ahead in day to day work with his basic and original part of the design which cannot be added at the end. Form also cannot be put into a building later nor the function be thought of when the design is practically completed; neither can economy be achieved afterwards. The objective is to consider form, function, structure and economy together, its to conceive planning in its nature as entirety, to design a building and its structure at the same time. This is what the architect needs knowledge about structures for. Moreover, he needs it for the constructional operations where the plans are to be carried out to detail, and he also needs it as building historian working with historic buildings and construction methods.

The architect should also have knowledge of structure to be able to work with engineers in teams throughout design and execution, to understand the engineer so that both know what they are talking about. The engineer will speak more of the structure itself, about dimensions and details, the architect more of its integration and form. What the architect will have on his mind are the modula and proportion of the building, which are influenced by the structure, rather than proof of stability which is the engineer's concern. To work in a team there must be a certain amount of mutual knowledge and skills, an overlapping area in which both architect and engineer have expertise, where, depending on the object or task, both must stake out their claim to work.

6. CIVIL ENGINEERS AND STRUCTURE

What about the relation between civil engineers and structure? How did it develop? What is it like today? The engineering sciences, technology of constructing materials, the material examination, the practice of calculating and structural detailing, site organisation and other areas have developed to such an extent that not only progress was made but also quite a bit of specializing has occurred. The variety of opportunities made it difficult for engineers, too, so that they gradually left the field of designing to architects even where it concerned functional buildings.

No doubt there have always been engineers who were not only able to calculate and dimension structures but who could also shape them. For instance Nervi, Torroja, Candela, Freyssinet, also Isler, Leonhardt, to mention a few. But it's Leònhardt, too, who complains about the increase in theory in civil engineering education, about the receding or complete absence of any design instrucion. He also points out the lack of understanding engineers have of aesthetics and beauty.

The civil engineer really does often leave selection and design of structure up to the architect and confines himself to calculating and dimensioning what the architect presents to him. He accepts being consulted too late by the architect, which happens very often if not as a rule. To many engineers it is the subject of their work and at times is of great satisfaction to calcualte for the architect and help him fulfil what he has designed although the architect did it with a restricted conception of structure and by committing himself to the wrong structure too soon. This description of engineers who know too little about function and appearance of buildings being uncritically dependent on architects who do not know enough of structure is the dismal picture of our everyday practice.

I remember that during my own engineering studies at university the structural systems were given and it was important to be able to apply the methods of calculating and not so much of structural detailing. The latter could be learned in practice, so I was told, and this was why there was no room for it in a scientific discipline. There weren't any joint projects for both engineers and architects, not even to find out if and how both would have to work together as partners later. This was the case at most universities up to the present day.

A student of civil engineering leaving for practice with a diploma, full of theory, unfamiliar with structural design, let alone in designing, lacks the ability for dialogue, for questioning the quality of an architect's design. In relation to the design proposals of an architect the engineer remains on the defensive, the only argument he can use is what he learned best: calculating. In most cases you can calculate to make everything fit. The less the design has to be altered the more satisfied the architect is with the engineer, whom we shouldn't call "engineer" or "constructor" if it is enough for him to be the uncritical assistant but with the german word "Statiker".

In civil engineering, or, to be specific, in structural engineering, theory and practice have drifted too far apart. The methods and procedures have become independent and an almost childish faith in these methods and procedures has developed although they are only aids and remain that way. Precision and improvement of calculating is of no importance to practice anymore. Spectacular construction accidents in recent history show that calculation at the desk and standardisation have gone too far. The conditions and opportunities that lie in construcion execution have been forgotten or have not been assessed adequately. Complicated dimensioning procedures and standards have made us believe we have achieved levels of security and control over technology that don't exist in reality.

From practice calls have become louder to turn away from too complicated calculation and standardization and to get involved with design and structure. Instruction and research at the universities have responded rather hesitantly.

7. SUMMARIZING THE DIFFICULTIES WITH THE STRUCTURE

Many architects dealing with design and structure have trouble with the great variety of possible structural systems. They lack knowledge and skills to establish, compare and choose from different alternatives to find the optimal structure in view of the overall design. Instead, they settle for a certain structure too soon and consult the engineer too late. They haven't learnt to cooperate with him in a team effort.

Many engineers also have difficulties with the many structural possibilities and with comparing and selecting. They are too concerned with calculation and standards, with theoretical and calculatory handling which has drifted too far away from reality considering the apparent perfection achievable. Civil engineers know too little about design and form, about integration and appearance of the structure within the overall design, they have left this to the architects. Not able to communicate they accept and complete the structural proposals - whether good or bad - as uncritically as they - or at least many of them - did at university.

8. WHAT MUST BE DONE TO IMPROVE THE SITUATION

We must bring the education programs of architects and civil engineers closer together and let them overlap. I am perfectly sure of the problems that lie within this task. Fritz Leonhardt once said: "I have tried my whole life long to fill the gap between architects and engineers; I didn't have much success doing so." We must try it anyway. The establishment of chairs for structural design at the faculties of architecture in Germany 20 years ago, which were occupied by civil engineers, can be regarded as a first step in the right direction. First steps have also been made in the opposite way: There is not only a civil engineer among the teaching staff of the architects at the University of Stuttgart but also a professor of architecture at the faculty of civil engineering teaching students the basics of architectural design.

At the University of Dortmund the study programs of architecture and structural engineering are connected. There are mutual lectures, exercises and design projects in which students of architecture and civil engineering are cooperating. Establishing this Dormund model program, though, was only possible in a newly-founded university. This is due especially to the fact that hydraulic engineering and transportation were excluded from the civil engineering program (both are important fields at other universities) to the benefit of cooperation with architects. Such a radical step is hard to imagine at older German universities.

What is feasible within a traditional university system? What can be done through personal initiative, or be tried out before being made the rule? To some extnt joint lectures, exercises and excursions on construction material, building-related physics, basics of structures during the first stage of studies because it is necessary to have common technical knowledge and skills, to get to know one another, to meet during studies. Then, in the final part of studies, structural design as a joint optional course and at least one mutual design project of different intensity, just as well on a voluntary basis, for which the introduction, correcting and final discussion could be done together. Called to help the architect choose the appropriate structure at an early stage, the student of civil engineering will also learn of the complexity of designing, of what origin his profession and tasks are, what interplay his structure will be exposed to and what demands it will have to meet. Common seminars and lectures would be a further step to exchange ideas and experience between both faculties, and another subject that seems to be necessary and that could be offered as an optional course is "history of structures and technology". Also, it should be fairly easy to open existing optional courses to members of both faculties.

9. CONCLUSIONS

The education of architects and civil engineers needs areas of overlapping, not to revive the medieval profession of master builder, that would not be possible because of the expansion of needed knowledge in the building sector. But by separating both we create narrow-mindedness which itself causes smiles of pity and ignorance of architectural students towards students of civil engineering and vice versa. We create prejudice, inferiority complexes and compensating arrogance which accompany the students throughout their career, which depress them and which many cannot discard. The ability to work in a team is destroyed instead of being encouraged. The future cooperation between architects and civil engineers in the field of design and structure is made more difficult instead of being made easier. The total separation during education, which does not match the demands of practice, is damaging society as well: it creates needless costs and leads to poorer design and construction quality. That is why architects and civil engineers ought to talk more with each other during their studies.

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