30 PROGRAMMING BUILDING CONSTRUCTION

MICK EEKHOUT
YPE CUPERUS

Planning the construction of a building includes specification of its technical performance. In the perspective of preceding Chapters on urban planning and planning of buildings, a conceptual range based on sizes from large to small is suggested for the benefit of the overall picture in this book. This will not occur in reality, however, as the time cycles of these scales are quite different. Although the scale range from urban design, architecture to interior design may be suitable in terms of scale and dimension from the point of view of the architect, the range urban design, architecture, and building construction is more suitable in terms of technical function. It defines the phases in terms of time rather than of significance: after the functional and spatial design concept the construction concept is made and developed towards a mature composition which is the construction of the building, as a totality of systems, sub-systems and building parts, components and elements. Materialising a design concept is as significant as the previous conceptual design activities. Building technical design is the subject of this Chapter. Hence, it does not include areas of urban technology like civil engineering: road and water works and infrastructure: like pipes and cabling that make a city function.

30.1 CONSTRUCTION PLANNING ON FOUR DIFFERENT SCALES

Construction planning can occur on four major levels. In the case of specifications for a highway it can be required that a bridge has to be realised crossing a waterway. The specifications will describe the frequency and loads of the traffic, the free spans and the free height underneath for nautical traffic. In case of the second level of a building the planning description will depart from the spatial design concept and the zones in which the construction has to be fitted in in order to form the materialised concept of the building. On the third level, the construction components, of which a lot of different versions have to be developed within one single building, are planned, departing from the function of the desired component within the whole of the building or one of the composing building parts. On the fourth level, the choice of material and production method is made in order to form, out of material or half products, new elements with distinct desired characteristics.

Imagine a building where the load bearing structure has the form of a skeleton and the façade is planned to be produced independently in an off-site factory. In order to keep options open to cater for future decisions; the façade construction could be connected to the supporting main construction with steel angle brackets. Once the façade design is ready and the weight and loadings on the façade are known, the dimensions of the elements of the façade can be developed and engineered and the optimum connection fixed, keeping in mind the mode of elevations and installation. This connection detail might contain steel clad plates and sliding provisions and fixing elements as M16 bolts, which have to be detailed at a scale of 1:1.

30.2 HIERARCHY

These examples illustrate that construction planning is not related to one particular scale. Rather the subject, in the order of given function and 3D form from the previous higher level, like the form of the building has been derived from the town planning design, the form of the construction design of the building is derived from the architectural design of the building. It involves analysis of the technical functions of the higher entity as the higher level into its composing parts. After analysis the appropriate structural scheme has to be chosen, the proper materials, the form of components and elements in conjunction with production and the final detailing fit for installation, each at its own level. The complexity of the building is usually greater than that of infrastructural works. The speciality of bridge design usually refers to civil technology designers and engineers. Infrastructure design, building design, component design and material design are the four basic levels of construction design a planning can be made for.

Decisions about infrastructure belong to a level, different from decisions about the load-bearing construction of a building. However, while there is a separate relationship between the two, it is a relationship of hierarchy. The position of the building depends on infrastructure; not the other way around. The load-bearing construction, in turn, creates the condition for possible claddings. In addition, the cladding component determines the parameters for developing a new material in order to cope with new requirements. This hierarchy of entity and parts co-incides in general with corresponding levels of decision making.

There is also a relationship with life-span. The position of the street, part of the infra-structure and town planning, is fixed for hundreds of years. The building is written off in an economical life of some thirty years and has an average technical life span of fifty to hundred years. The cladding has a technical life span of twenty to thirty years and a market lifespan possibly shorter. Dwellers move every 7 to 10 years and office buildings are re-furbished every 5 to 10 years; shop interiors every 3 years.

The hierarchy of building parts reflects the ease with which elements can be moved. A user can move furniture immediately, since it can be lifted, not being connected to other parts. However, designing furniture is not regarded as belonging to the architecture domain. Doors and windows can be swayed instantly; internal partitions as well, if necessary. This is technically more complicated, but a professional craftsman can remount an internal wall within one single day. Alterations to the load bearing structure are technically major changes that are hardly done within a period of one generation of habitation (10-20 years for offices and 30 years for housing). Altering the position of a street is beyond consideration; planning new roads takes decades. Understanding different levels of building parts, and their consequent levels of decision making (reflected in life spans and mobility) is important in determining the technical performance specification.[a]

30.3 DISCIPLINES

If we look at a building as a system, 'a group or combination of inter-related, inter-dependent, or inter-acting elements, forming a collective entity'[b], we can also define the sub-systems. The load bearing structure is a sub-system to the building that received external loadings and sustains dead weight and directs them as internal forces to the foundation and the soil. The plumbing sub-system takes care of distribution of water throughout the building. The building façade sub-system provides the climate barrier between inside and outside. Many more sub-systems can be identified this way. These sub-systems are called building parts. These technical sub-systems may co-incide with one level of decision-making. The sub-system 'furniture' co-incides with the authority of the space user while the sub-system 'internal-partitions' with the authority of the tenant. In contrast, the plumbing sub-system depends on decision-making at all levels. This requires an integrated and coherent chain of decision making from source to tap.

A much more strongly relationship is seen between sub-systems/building parts and the building disciplines concerned. The main contractor sub-contracts laying the foundation to a third party, specialising in driving piles. Another sub-contractor builds the ground floor, while yet another party builds the steel or pre-fabricated reinforced concrete load-bearing structure. When planning the construction process, all specialised producers working off-site and all disciplines on the site need to be considered. They should not interfere with one another, nor should they damage each other's work and they should be able to finish their job, if possible, in one un-interrupted working period. A building built and completed on the site through a

a Habraken, N.J. (1982) *Transformations of the site*.
b Hanks, P. (1988) *The Collins concise dictionary of the English language*.

well co-ordinated building process has the potential to be built and maintained by independent disciplines and to adapt to new demands. Consequently knowledge of the construction process is essential when writing the technical brief.

30.4 BUILDING AND MANUFACTURING

Building is an on-site assembly and installation process as productions and manufacturing are factory-based pre-processes. On-site building processes exposed to the outdoor climate, are usually unique and quality can be controlled mainly on-site during construction. The elements and components produced off-site an be controlled in quality as end products in the respective factories, or as a result of a continuous and total quality assurance process. On site only the installation aspect is controlled. Building elements and components of diverse natures and their mutual (i.e. external) and their internal sub-system connections are subject to ever increasing quality demands. The two contemporary examples of a traditional timber window frame in a dual brick wall in a rural type building with a triple-glazed, climate-controlled façade integrated with an air-conditioning system in a high-tech office building illustrates the way in which an increasing part of the building energy is transferred into production environments. The development costs of high-tech systems for the said triple glazed façades cannot be justified for a single building. Manufacturers who intend to recover their investment over a period of time incur such costs. The shift from 'building' to 'production' and 'manufacturing' creates an appropriate environment for development of project-independent designed, but project-pre-fabricated sub-system elements and components. At one extreme the whole building could be pre-fabricated in different factories of co-makers and finally assembled and completed in a single end-line factory. The leading example of this is the Japanese Sekisui Heim house.

293 Sekisui Heim, housing factory in Japan

From a limited catalogue range of components, the client can design his house, as he would purchase a modern kitchen. All parts are assembled in the end-line factory into three-dimensional elements designed to fit onto the back of a truck. These are then transported in the right order to the building site, where they are post-assembled to form the final house.[a] An on-site assembly process replaces the traditional construction process, however, since building is by its nature always site related – unlike cars and other consumer products – it will keep to some extent the properties of an on-site 'building' process. (In the fourties one of Jean Prouvé's very mobile and light-weight houses was stolen from the site!) Understanding the turning point in balance between building and productions & manufacturing is a very important factor in planning construction.

30.5 BUILDING CONSTRUCTION PLANNING

The specifications of the technical composition of a building are described by the architect in the project specifications. These specifications contain:

- an administrative part;
- a technical description part;
- and a building execution part.

This type of project specification stems from the traditional habit in the building industry to describe and understand traditional methods of building using traditional materials. Both designer, the architect, as well as building contractor mastered these techniques and materials. Communication was simple; quality assurance based on the fact that many influences on quality could be managed and checked on the site itself.

However, with the introduction of pre-fabrication and industrialisation in the building process, with their inherent specialised production techniques by the producer, not to be influenced by consumers, it has no sense to prescribe to the specialist, who knows better than the consumer how to make his products. There are only two ways out: to prescribe in global

a Cuperus, Y.J. (2000) *Industrialisatie van de Japanse woningbouw.*

terms the requirements posed to the specific building products, building system; to opt for special components, so that the proposing sub-contractor / producer can detail his proposition and price it. The second possibility is to use the product description of the specialised producer directly in specifications. This is a pure case of ignorance of the prescribing parties compared with the tendering parties; and will happen as long as producers are ahead of architects. In fact, these producers are treated as co-designers and co-producers; and just to fit them in the conventional building and contracting process these specialised specifications are used to enlarge the project specifications.

The project specifications are usually described in the old fashioned manner of collections of materials. It goes far beyond the goal of the site contractor to divide the total job of productions off-site and building on-site and its respective technical description into workable parts, i.e. building parts that are clusters of coherent products, with its own administative, production and site assembly conditions. Sub-division of the main contractor's job into 20 to 60 sub-contractors per project contract is a tedious job, with many risks of non-description of the mutual border zones between contractors and mis-understanding of the specialities of these sub-contractors / specialised installing producers. With an increasing amount of specialised contractors in contemporary projects, specialised sub-contracts have to be drafted in order to maintain the quality of the offered sub-contracts. The other *modus operandi* is to pick the brains of these specialists and to describe the specifications from the perspective of the prescribing architect.

30.6 THREE MAJOR TYPES OF BUILDING PRODUCTS

For manufactured products a scale of project independence can be identified in three major types of building products:

- Special building components, are designed and produced for one specific project (designed and produced project–dependent);
- System products or building systems (semi- dependent: designed project independent, yet produced project- related);
- Standard building products (designed and produced project–independent).

30.7 SPECIAL BUILDING COMPONENTS

These are products specially developed for a single building. The building designer or architect designs the global conditions of function, size and spacing and writes their specifications. These have to fit within the entire technical composition of the building and have to give the building that extra flavour or dimension that makes all the special effort necessary. The architect can select a component developer in his own office to work out the special product or select a producer with an experienced precomponent designer/developer in his service. Usually the architect acts as principal, within the budget limits of his client, towards the component designer to fully develop the design of the speciual components, to have a prototype made and after satisfactorally development to have them produced. The entire development process of special building components knows three major phases:

- concept design
- protoytype & testing
- production and installation

30.8 SYSTEM PRODUCTS OR BUILDING SYSTEMS

The brief is not limited to one component; rather it covers a family of related elements and components of a building system or sub-system. This can be developed from a special commission related to one specific building originating from the specific requirements of an architect, desiring a project-related sub-system. But, it can also be developed project- independent by a producer as the largest common denominator of a great many different applications with similar or slightly different requirements, which cannot be fulfilled by an existing system, unless the development is started because of a ‘me too’ attitude. In the latter case of a market (sub)system it makes sense to start with market research in order to determine the gross list of demand requirements and market opportunities corresponding with them. From this analysis a development brief can be drafted and the desired performance of the new (sub-)system specified. The preliminary design of the new system can then be checked against this initial specified performance.

Project-dependent systems are developed between an architect and a producer or system developer for use in one project only. Project-independent systems need to be marketed and sold as applications to the clients: the set of all architect / contractor combinations of the different application projects.

Once a detailed and final brief has been developed by the architect, the system developing and producing manufacturer can price his special sub-system for the project at hand. The phasing of the development of system products happens esentially on two different levels: initially, on the system level, afterwards on the application level:

- system design concept
- preliminary marketing investigation
- prototype and testing of system

and

- application design
- prototype & testing of application
- production of application.

30.9 STANDARD BUILDING PRODUCTS

In this case the producer takes the initiative to develop a standard product, totally project independent. It is made for the market, not for specific building projects. Five main phases of development activities can be identified after the initiative or basis for a product idea, initiated either by the marketing department of the producer or by the board:

- concept design
- preliminary market investigation
- prototype and testing
- final marketing investigation
- market introduction & production.

Between, or better still, parallel to the technical phases, the market demand for the developing product is monitored. During the preliminary market research the product concept is presented, the feedback evaluated, and used to modify the design of the final product. During the final market investigation the same is done with the real size prototype. The reactions of the chosen clients (representing the entire market in all of its expected facets) will influence the final composition and appearance of this standard product. One of their characteristics as compared to system products is that they are developed and produced before sales.[a]

30.10 NEW MATERIAL PLANNING: ZAPPI

Zappi represents the ultimate in the new and unknown. The term Zappi was invented by the former town architect of Haarlem, Thijs Asselbergs, at a forum discussion in January 1992. We were asked to describe an ideal building material as yet unknown to either of us. After discussion the term Zappi lived on as special epithet. Originally launched as a term for a new building material with superior qualities yet to be developed, it symbolises the adventurous quest. It represents what is unknown, mysterious, challenging! It is both a material and an

a Eekhout, A.C.J.M. (1997) *POPO of ontwerpen voor bouwproducten en bouwcomponenten*.

idea, simultaneously tangible and abstract. It is a mental construct that cares little about the apparent senselessness of ideas, or practicality of invention.

Firstly: Zappi as it began: a long-term fundamental research project with the objective of the development of a strong, stiff and tough glass-like engineering material that does not fail suddenly on overloading; being carried out in conjunction with the Faculties of Aerospace Engineering and Applied Sciences (materials science programme).

Secondly: Zappi represents not only objectives, but also a mentality. Zappi is a friendly and rather comical bulldog, with a character combining intelligence and perseverance. This mentality is needed to generate the motivation needed to maintain the process of design research, evaluation and development. And who is best suited to the research for this new product? An individual has as many disadvantages as a team. An individual needs a soundboard and subservient assistence; a team can choke creativity of its members.

Looking for Zappi may take a lifetime. The process of design, manufacture and construction usually gives more satisfaction than the void experienced after a building has been completed or a new product has been manufactured and launched. The ultimate goal represented by Zappi may, like the horizon, always remain just one day ahead; but it is, nonetheless, just as noble a goal as the Holy Grail to King Arthur's Knights of the Round Table.

Thirdly: Zappi is always near by. Each step towards Zappi is also Zappi itself, simply because of the pleasure one can derive from achieving a definitive step on the road towards Zappi. An example of such a step forward is the frameless glazing of the early nineties. Each further development towards a perfect structural glass material is also part of Zappi. Each result is achieved because Zappi takes immediate advantage of every new opportunity, although at the same time it never forgets that achievement of the ultimate objectives involves a number of discrete steps. That is the reason why this paragraph contains Zappi in its title: its publication marks one step that has been taken, to be followed, hopefully, by many other equally successful steps.

Fourthly: Zappi represents the infectiousness inherent to development of new products for the building industry. Zappi wants to see the entire audience laughing with it at its jokes, to win applause with its clever feats, and to stimulate the larger circle of parties actually involved – all those who, in one way or another, are engaged in product development for the building industry. This is achieved by disseminating new ideas and products among professionals with the motivation to upgrade the technology of materials and products for architecture and the builing industry. Zappi's answer to the question *"Would you ever do it again?"* would always be *"Yes!"*.

A proposal has been drawn up now for the fundamental materials research required for Zappi, one of Zappi's objectives. However, information about the initiative has already been published – and the pull effect of marketing has resulted in the first collaborations.

Zappi, designing a material

The concept of designed materials is new to materials science. Traditionally, a new material was developed, and then it was up to designers and engineers to find ways to use it. The modern discipline of materials science has made it possible to design materials that are tailored to the demands of designers and engineers. The materials science research constituent of Zappi is an experiment in the design of a material that satisfies the requirements of the architect needing a combination of the mechanical properties of steel and the transparancy of glass.

Glass in architecture

For centuries glass has been used as a transparent barrier to preserve the interior climate of a building whilst allowing daylight in its interior. Experience has shown that it is the most stable transparent façade material available. However, glass has poor mechanical properties. This has resulted in a material conflict. The glass window, essential for the inhabitation of interior spaces, is, in structural terms, just a hole in a wall. From the beginning of this century onwards large glazed openings played a major rôle in the development of Modern Architecture. Glass was used in the construction of tall buildings as a façade cladding for steel or concrete framework structures. Increasingly stringent requirements from the sixties onwards created a need for the enhanced performance provided by the use of coatings and advanced double-glazing systems. In the last decade the use of ultra-transparent glass façades and roofs to contrast with closed walls has become an accepted architectural practice. Yet, glass remains mechanically unreliable. In modern applications glass panels are fully pre-stressed to allow them to bear greater stresses. Although special laminates are available, they do not offer significant improvement on glass as a structural material.

The design of the Zappi material

In essence Zappi should combine the following properties:

- The mechanical properties of steel
- The transparency of glass

In physical terms, an impossible combination in one single material; the first property requires the dense metallic crystalline structure of a metal, whilst the second property requires the microstructure of an amorphous solid mutually exclusive structures.

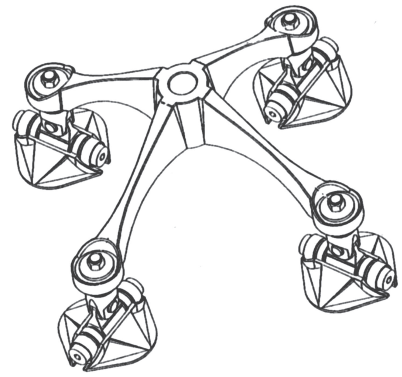
Some answers to the problem can be obtained by combining existing materials and techniques in novel ways. What we have at our disposal are transparent materials like glass and polymers. Pre-stressed glass possesses the required strength and E-modulus, whilst polymers like polycarbonates have the required ductility. The combination of these materials in a composite should provide us with a structural material with enhanced properties in comparison with its components. Obstacles remain:

- Pre-stressed glass fails as a result of extensive unstable crack growth with multi-directional crack branching, leading to total de-cohesion of the material after global or local overloading.
- Amorphous polymers like polycarbonates have very low surface energy values, rendering them highly unsuitable for conventional laminating processes.

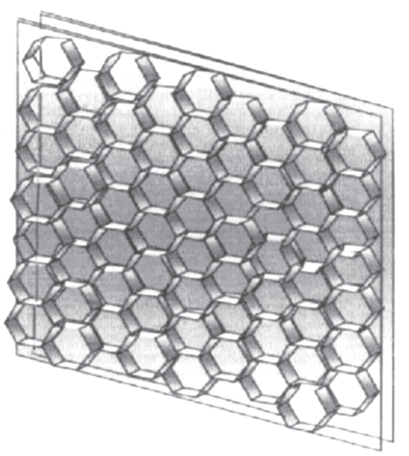
If we are to make a suitable composite then, the cracking behaviour of glass will first need to be modified in such a way that the glass will fail in a controlled manner. Next, we have to bond this modified glass to a suitable polymer.

There are several possible approaches that can be used to modify glass. The most logical approach would be to develop a new glass 'alloy' with the required properties. However, development of a new type of glass is a complicated process, requiring extensive technical facilities. Another approach is to modify the fracture behaviour of existing types of glass, to be achieved with exisiting surface modification techniques. The further development of these techniques for standard glass may not provide an optimum solution, but will result in a demonstration of the technology. Two years of preliminary research have resulted in a scientifically-verified concept for a material that combines transparancy of glass with mechanical properties of aluminium.

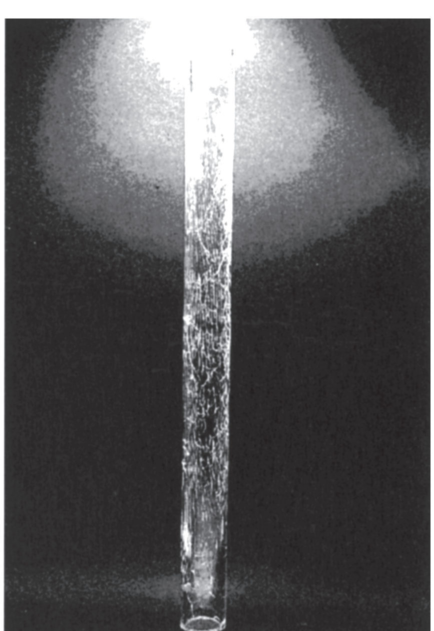
Although Zappi is still a long way off, the research and development programme is an exciting and convincing process. What is so stimulating is that the various projects make it possible to achieve *incremental* results. Factors of major importance for each incremental result are its orientation to constructional value and its practical application. Zappi prefers its high-tech product to be used in good buildings – which makes it even better. This means that the significance of the development of a new product cannot be assessed on its own. As always



294 Hinged nodal bond



295 Design of material with a high acoustic impedance



296 The transparent column after the trial

in research and development, real satisfaction is derived from victories you win by the skin of your teeth. Perhaps, the best remedy for the disease of sterile architecture is joy in design, joy in performance, vigour and wit.

The nodal bond, Barbara van Gelder

Connections between glass and metal have always been a problem. One possibility is to drill holes in the glass, then harden it. Subsequently, bolts are passed through the holes to attach the glass. However, this is not always desirable with modern double glazing panels as it may cause leakages in the air cavity, with all the concomitant problems. One alternative is to bond the double glazing panels to the metal: a new technology, about which relatively little is known at present. Barbara van Gelder carried out research into glass-metal bonded joints, and came to the conclusion that one of the greatest problems involved is the rigidity of the joint, that caused substantial localised forces in the glass and ultimately fractures adjacent to the bond. In order to solve the problem she designed a hinged nodal bond preventing the build-up of excessive forces in the glass. That results in a safer construction. A patent application has been submitted.

The sound-absorbent panel, Kees van Kranenburg

Existing glass structures often exhibit major deficiencies in terms of building physics. The glass construction increases the architectural expression of the building at the expense of the comfort it provides. One problem is noise. A large glass façade possesses only limited sound-absorbent properties which is not beneficial for the comfort in the rooms behind it. Kees van Kranenburg accepted the challenge to design a panel that had good structural properties and was transparent, but possessed much improved sound-absorbent properties. A long period of research into the acoustic poperties of the Zappi panel was required, followed by a series of designs and construction and testing of the prototypes.

The transparent column, Joost Pastunink

The column is a basic element in framework structures. In the past, glass columns were used only extremely rarely, as their inherent brittleness makes them unsuitable for construction purposes. A transparent column capable of transferring invisible vertical forces would offer unprecedented opportunities. Joost Pastunink laid the foundations for this type of column: by designing a process to make a laminate using two concentric glass cylinders he was able to manufacture a prototype that did not fail spontaneously when subjected to an overload, but gradually crumbled in safety under the load imposed. Even after a considerable amount of fracturing the column still exhibited a substantial residual load-bearing capacity. The total load-bearing capacity of a column 40 mm in diametre and with a wall thickness of 3 mm is 10 tonnes – equivalent to a roof surface of 100 m^2, including its own weight and the useful load. A patent application has been submitted.

30.11 BUILDING TECHNICAL PROGRAMMING

Planning the production of building components may be characterised as an ex ante activity; it precedes the conception of a building design. However, even while a component is being planned, performance and market assessments are continuously evaluated, independent of construction activity. This is very much ex post, measuring product performance in its designed environment.

In the final analysis, construction of buildings can only be planned with full appreciation of construction processes and details.