TOWARDS DYNAMIC BUILDING STRUCTURES
-BUILDING WITH SYSTEMS-

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Abstract
Technology innovations, population growth, evolving ecology problems and changing economics are imposing new requirements on a built environment. This influence considerably the way we are to design and built in the future.

The most important issue regarding the building today is related to the increase of it's environmental efficiency which can be achieved by creating the potentials for closed loop material cycling of building products. Accordingly the main aim of the construction industry is to contribute towards global sustainability by using energy saving processes, reducing the use of natural resources and reducing the waste production.

Further more buildings frequently undergo adaptations due to the degradation of more technology dependent components and frequent changes of the user's requirements. Ultimately the inability to remove and exchange building systems and their components results in significant energy inputs and large quantities of waste.
Most of the modern building structures today using pre-manufactured elements are designed to be mountable but not de-mountable. The main reason for that is in a fact that different functions and materials comprising system building are integrated in one closed and dependent structure which does not allow easy transformations. This is one of the biggest reasons for huge amount of waste.

If sustainability is to be achieved than the buildings should be constructed with systems that will provide dynamic building structures which could be easily adapted to the changing requirements and whose parts could be reused or recycled. Therefore the accent in the future development should be on systematization of building into independent systems which will take into account that different parts of the building have different life cycle and functional expectants as well as different assembly procedures. Systematization of this kind would provide precondition for change-ability of spatial as well as technical systems of one building.

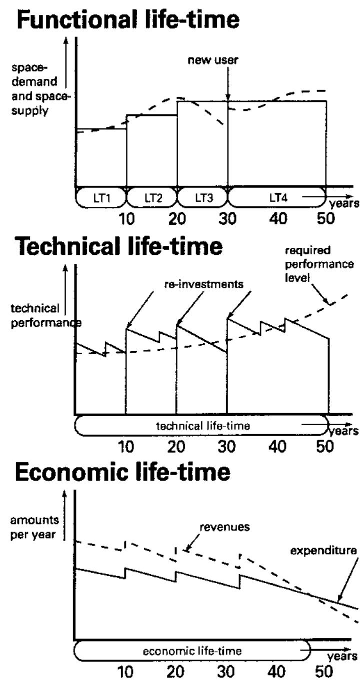
Statement
The key aspect of sustainable construction is in building's ability to be dismantled where the systematization and the hierarchy play a crucial roll.

Key words: systematization, hierarchy, systems building, open system, disassembly, variation, reuse, recycling

INTRODUCTION

Today's worlds greatest concern regarding built environment is how to design sustainable in a seance of: increasing spatial flexibility, extending the life span of building components and promoting the recycling of materials and products.[Durmisevic98] In other words buildings and their components should get a chance to have a multiple lives. The implementation of such concept would have economical and ecological benefits.

Table 1: life-time coordination



Technical and functional service life of modern building is approximately 50 years. Yet, today it happens that the buildings with an age of 15 years are demolished to give way to new construction. The average functional service life is becoming shorter and forces the return on investments to come quicker. Generally speaking the economical duration of one phase in the use of the building is shorter than the technical life span of most of its components. Eventually the reduction of the technical life cycle is no option because this would be destruction of capital investment. This means that the natural resources and energy used in production and assembly of the components would be lost with demolition and waste disposal.

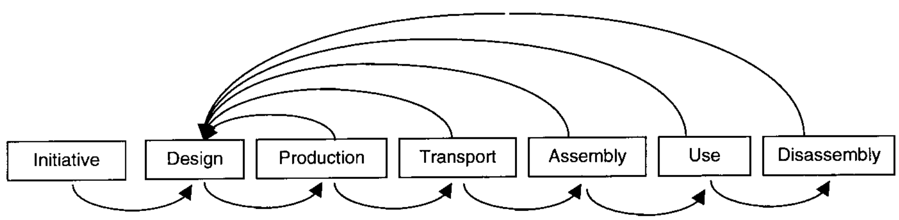
Rather than destroying structures and systems while adopting the building to fit new requirements, it should be possible to disassemble sections back into components and to reassemble them in the new combination. At the moment that the act of demolition is replaced with disassembly building components would get a chance to have multiple lives which would drastically extend their life cycle.

This means that the design of sustainable building would run the danger of being carried out on ad-hoc bases without disintegration aspects of building structure being an integral part of the design process. Therefore we must consider how we can access and replace parts of existing building systems and components, and accordingly how we can design and integrate building systems and components in order to be able to replace them later on.

INTEGRATED LIFE CYCLE DESIGN

The problem of over-consumption of resources includes all aspects of planning and constructing of building. Sustainable design highlights the fact that apart from optimization of function and construction costs in relation to the design requirements, building design must meet demands from all life cycle phases (initiative, design, production, transport, assembly, use, disassembly).

Table 1: Life cycle phases of the building



During design phase (one of the first phases) the greatest potential exists to influence the building properties in all life cycle phases. Such concept provides a framework for the multidisciplinary team-work that can influence the building design for cost effective and high performance buildings.(table 1)

Table 2: Strategies for sustainable design

Life cycle phase	Strategy per L.C. phase	Relevance
Design	• Development of scenarios for building use • Optimization of the building in each of its life cycle phases • Concurrent engineering	Flexible building Environmental burdens Timely and correct decision making Construction time
Manufacturing	• Use of material saving process • Use of recyclable or reusable materials • Use of low weight materials • Use of less energy intensive materials	Resource depletion Energy use Environmental burdens Resource depletion
Transport	• Low weight / volume	Environmental burdens
Assembly	• Dry assembly • Parallel assembly	Construction process Resource depletion Environmental burdens
Exploitation	• Low energy use • Design for maintenance/long life	Resource depletion Environmental burdens Resource depletion
Demolition	• Design for disassembly	Resource depletion Environmental burdens

The strategy for integrated life cycle design and its relevance per life cycle phase has been defined in the table 2. In the further text the aspects of system building will be evaluated according to the strategy and relevance described above.

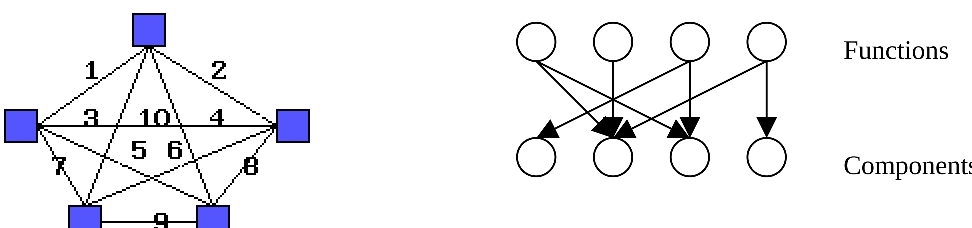
SYSTEMS BUILDING

If we look at the system building in a context of the sustainability aspects that were presented per life cycle phase in table 2, than we must conclude that conventional system building can hardly comply with these aspects. For example the flexibility which comprises diversity and demountability are essential in the design phase. On contrary system building preferably uses larger component sizes and often ends up with identical products when combined with mass production. If diversity is to be priority than prefabrication of large stiff components can't be directly connected to mass production.

Figure 1: left (component assembly of one closed system), right (connection between components within the closed system)

Further more although their construction is associated with careful assembly on the construction site they are usually inflexible in exploitation and demolition phase. This has to do with integration of different functions and materials into fixed connections and luck of accessibility to the components with shorter life cycles. (Figure 1,2)

Figure 2: characteristics of conventional system buildings



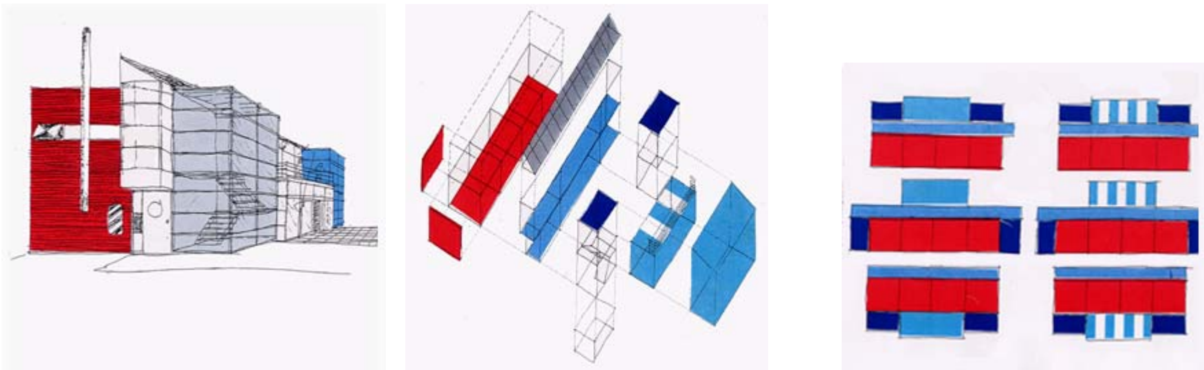
Dependence

To summarize, conventional building systems are often developed in the form of closed systems operating independently from other industry and usually for a single building type such as schools, offices or housing. Such building systems are designed to make use of mainly one material such as concrete in concrete panel systems or timber in timber-framed systems. A

limited rang of parts is designed and produced to simplify the control of all operations and to ensure total control of the building program.
Further more the aspects such as adaptability, independence, exchangeability of building components and diversity in form are hardly to be found in such systems.
They are mostly characterized by: high level of uniformity, pure architectural language, fixed integration of different functions in one component (figure 2) and closed life cycle.

Sustainable form of construction on the other hand should opt to the dynamic building structures which are made of independent systems and whose parts could be easily replaced and reused or recycled. Such buildings could be recognized as systems buildings where different components manufactured by different suppliers could be compatible.
”Systems building is used to define a method of construction in which use is made of integrated structural, mechanical, electrical, envelop and partitioning systems. The ultimate goal is integration of planning, designing, manufacturing, site operation management and financing into a method for cost effective and high quality industrialized buildings.
The most important aspect of such dynamic systems building is separation and decupling of levels that have different functional and life cycle expectance. Such decomposition is a top-down process which should be developed following the criteria that will help us to recognize and decompose the systems from the whole.
Therefore the accent in the future development should be on systematization of building components into independent subsystems which are assembled in hierarchical order that is suitable for maintenance and repleaceability of frequently changed parts.

Figure 4: one proposal for building systematization according to the different functions

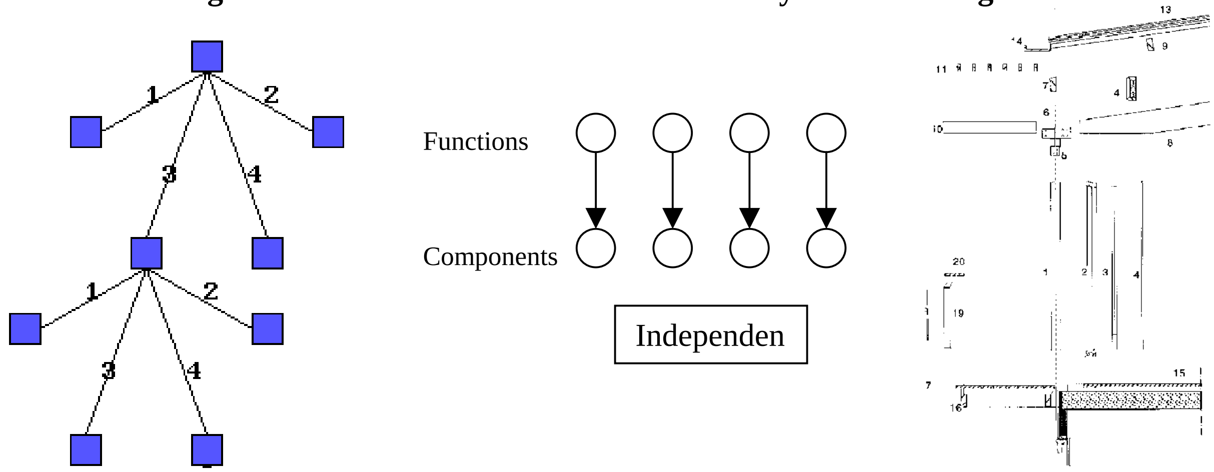


Such concept would allow for future alterations to external screening and to internal partitioning. It would allow for services to be independent of the fabric to provide for accessibility, servicing and alteration, it would create the precondition for reuse and recycling and finally the way is open for designs of great diversity and richness.(figure 4)

Each building can be defined as a hierarchical arrangement of all elements in the building. This internal hierarchy determines the structure of the building and, therefore the easiness or difficulty of the buildings future dismantling or reconstruction.
Unlike the conventional system building where all building elements were joined together creating maximum integration at the joints the main characteristic of systems building is in separation of different building’s functions and altering them from fixed to less dependent conditions.(figure 5)

Such development stimulates system development and further industrialization of building wherein systematization is derived from the fact that different parts of the building have different lifecycle and functional expectancy and therefore should act as independent parts of the structure.

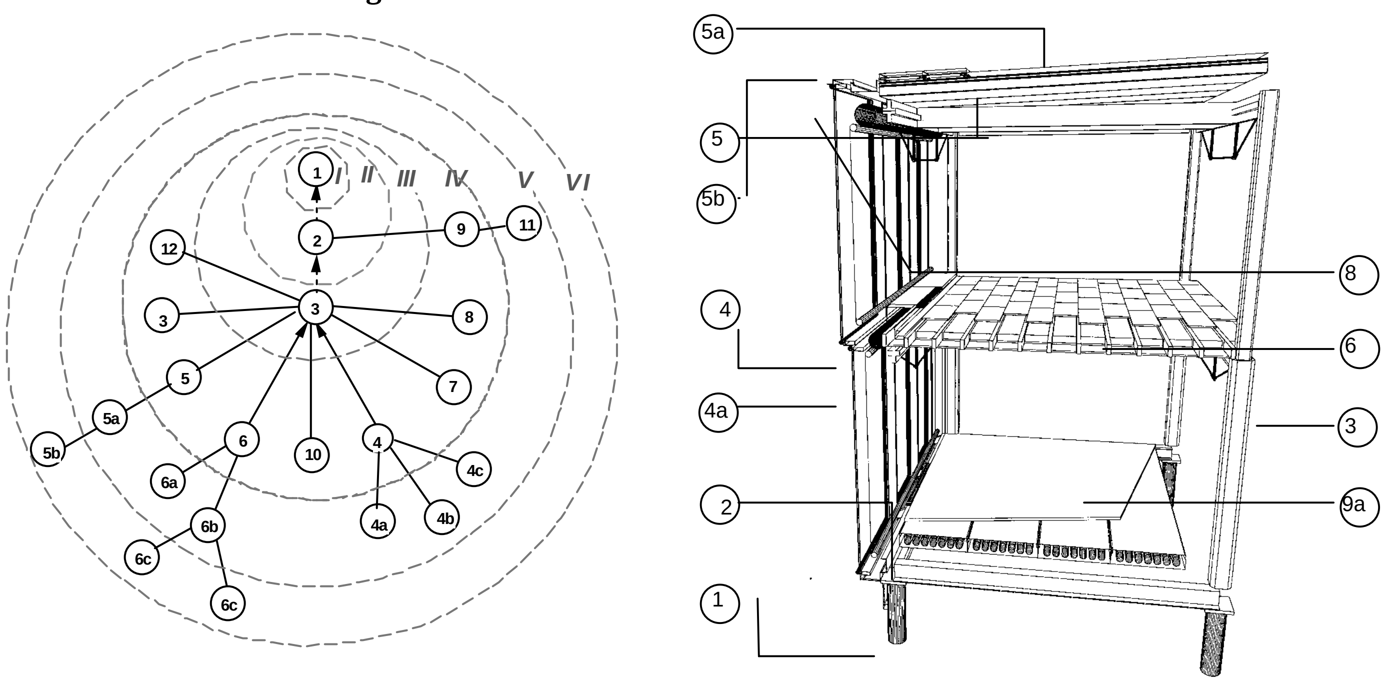
Figure 5: characteristics of the sustainable systems building



THE CASE "XX"

The structure of the "office XX" in Delft is characterized by such systematization where load bearing frame, façade, floor panels, roof panels, were pre-made and assembled independently on the site.

Figure 6: Relations between subassemblies in XX



The diagram in figure 6 presents the relations between the main subsystems in the XX building and their hierarchical dependencies. The elements of the load-bearing frame , are assembled in the first three sequences. They have further relations with "base" elements belonging to different subsystems, which were assembled in fourth sequence. The "base" elements of different subsystems have further relations with elements that belong to the particular subsystems and perform as finishing or servicing elements. These elements are assembled in sequences five, six etc. The most dependent elements in the XX structure are the load bearing elements since they are assembled first and they have relations with all other parts of the structure. On the other hand those elements would be the last ones to be disassembled in the disassembly phase because of their load bearing function and long life cycle. All other parts of the building have high level of independence since they are independent from each other and only connected to the main structural frame.

Figure 7: independence of subsystems in the "XX" building

The main characteristic of the XX structure is that most of its parts are demountable and assembled in a systematical order, which is suitable for maintenance and replaceability. This was achieved through two aspects. First the building was subdivided into the independent units – subsystems which could be independently produced and assembled. Each subsystem has a specific function within the building and answers specific requirements. This means that with the change of one requirement only one subsystem should be replaced. Secondly, the replaceability of the subsystems was achieved through the coordination of relations between subassemblies and, the design of connections, which are suitable for disassembly.
The "XX" building is a typical example of the open systems building. It has been constructed out of fifteen different subsystems. Each of these subsystems has kept a high level of independence for the future alterations. In such way the XX building forms the transformable structure whose parts could be easily replaced and reused or recycled.

CONCLUSIONS

Sustainable development emphasizes lifetime extension as well as alternative combination and treatments of building and its systems. In that respect independence and exchangeability of building components are the key criteria for systems development. Unlike the building systems which are made with large-scale elements, comprising one set of components designed to integrate exclusively with each other, "systems" building can be seen in a form of an open structure which is a result of disciplined integration of independent subsystems. Such structures have a form of an open system that permits continuous changes and additions. Dynamic structures of this kind whose systematization is suitable for exchangeability of its parts could be seen as a solution to de demands for sustainability.

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