

FROM MASSIVE CONSTRUCTION TO DECOMPOSITION OF HOUSING -a way to support further industrialization and customization of housing-

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ABSTRACT

Traditionally design of housing has concentrated on the construction phase optimizing the construction costs and short term performance. Such approach does not take into consideration bought adaptability of built structure to the new requirements and technical, environmental and economical consequences that are related to its physical transformations. Therefore most of conventional buildings are not designed for change and their components are not designed for disassembly.

However due to the ever-changing nature of our society the sequences in building use are becoming much shorter than before. Clearly buildings frequently undergo adaptations due to the degradation of more technology dependent components and frequent changes of the users requirements. Ultimately the inability to remove and exchange building systems and their components results in significant energy inputs and large quantities of waste. Therefore the improvement of buildings capacity to adapt to the new requirements and consequently extend the service life of the building and its systems can be seen as a key issue of sustainable development in the future.

This articulates the concern for assembly, which determines the interface between building components. The overall relationship between these components should assume primary importance in design of sustainable building. Therefore, more systematic approach to the design is needed. In other words an approach that will focus on building assembly and combination of materials and their functions at joints.

The study of these aspects has been a subject of the Ph.D. study at Delft's University of Technology "Design for Disassembly" where the main aspects of design for change were discussed and their application will be presented in this paper.

Key words: *sustainability, adaptability; flexibility, structural transformation, disassembly, environmental efficiency, service life*

1. INTRODUCTION

Observers of current and future trends predict that the nature of working and living will change so drastically, and the scope expand so greatly that we will soon be faced with completely new structures. We are at the beginning of the era that will be defined by temporary, combined and virtual organizations. The dynamical organizational structures developing in response to these changes, need an environment that will provide necessary flexibility. Today the whole cities rapidly rise and fall, buildings are taken down and new ones go up, the site is permanently subject to transformation.

On the other side the environmentalists are warning that if we do not reduce consumption of natural resources and pollution we will not leave much hope to the future generations.

Consequently the main question of sustainable development is how to find the balance between consumer-oriented society and the key principles of environmental ecology such as to: conceive natural resources, save energy, reduce waste etc.

To be able to understand and approach these significant issues, we must change our perception concerning the building life cycle and construction issues.

One of crucial problems of today's building construction is that buildings are made in such a way that every transformation (if possible) is linked with demolition of building parts or whole building structure.

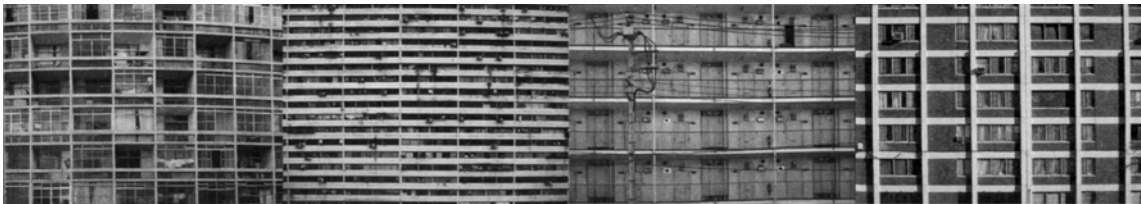


Figure 1: way of building today



Figure 2: the consequences of today's construction practice

Generally the main problem facing transformation and deconstruction today is the fact that developers, architects and builders of the past visualized their creations as being permanent and did not make provisions for their future changes and disassembly. (CC GIL 00) While assembly may be seen today a complex sequence of connecting carefully designed components and materials, a process that may involve thousands of people and fleets of machines, disassembly, in the building industry usually involves a few bulldozers or a fist full of explosive. Such practice has enormous environmental consequences.

For that reason the design of sustainable building runs the danger of being carried out on ad-hoc bases without disintegration aspects of building structure being an integral part of the design process. That means that 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.

2. TOWARDS BUILDING DECONSTRUCTION

The key aspect of sustainable construction is in buildings ability to be transformed where the decomposability of the structure has the key roll. The three main reasons for that are: (i) market requirements (dealing with changing demands); (ii) environmental impact of the building (iii) building construction (stimulating longer service life of the building and its products).

2.1 Changing demands

The rate of recent changes in technologies and society which is coupled with the changes taking place in the lives of users and in the conditions stimulating market activity justify new planning approaches which are dynamic and flexible.

Recent trends in housing show that the recurrence of changing sequences is more frequent than before. Eventually every new phase in the life of one individual brings a set of new requirements on the built environment. If these requirements can not be met within the context of inhabited space, the space will be abandoned. This is exactly the problem that many housing corporations are facing today. The technical characteristics of dwellings from 50's and 60's do not facilitate easy adaptations. That is why most of them are facing fundamental questions regarding their future use. Ultimately the choice has to be made between two inconvenient possibilities, demolition or costly reconstruction.



Figure 3: analyses of different scenarios for spatial organization of dwelling from 70's(left existing situation , last right the most wanted situation)

Research which was done by one of the biggest housing corporations in Amsterdam indicates that 30% of people living in dwellings would like to move because of the fact that they can not adjust the existing dwellings to their needs. Another 45% would like to stay if they can adjust the dwellings to the different live phases in the future. These figures send a clear message to the housing corporations. In order to stimulate the

tenants to stay in their dwellings the character of the dwellings has to be changed. The tables 1 and tables 2 below gives an overview in percentages of the need for change and the need for use of flexible infill system among the inhabitants.

m2	%yes
more than 49m2	22%
49-62 m2	24%
more than 62 m2	42%

Table 1: Relation between the percentage of families which would like to transform their dwellings and the size of the dwelling (Rigo99)

This research accentuated that there is a grooving interest among the tenants to use flexible systems in order to adopt their dwellings to their needs. The interest in flexible infill systems differs from one type of family to another. For example 64% of families without children are interested in application of flexible systems while the percentage of families with children interested in flexible systems is between 76-80%.

age	yes	maybe	no
Until 31 year	86%	0%	14%
31-45 year	77%	16%	4%
45-55 year	73%	7%	20%
55-65 year	63%	25%	13%
more than 65 year	33%	42%	25%
Total	73%	0%	14%

Table 2: Interest of different age groups in application of flexible infill systems in their dwellings(Rigo99)

Finally the resent market analyses fig.4(Rigo99) have shown that one dwelling is completely changed in a period of 24 years. It is expected that the pulse of change will be accelerating very fast in a near future fig.4. Further more following the know-day's trends of fast cycling market changes it becomes very difficult to predict the future scenarios for the use of dwellings. The uncertainty spreads not only to the question of how the dwelling will be functionally organized in a future but is it going to be a dwelling or something ales after 8 years or more. For that reason some housing corporation are even thinking about the concepts of "destination free spaces" which could be easily transformed form apartments into offices and other way around.

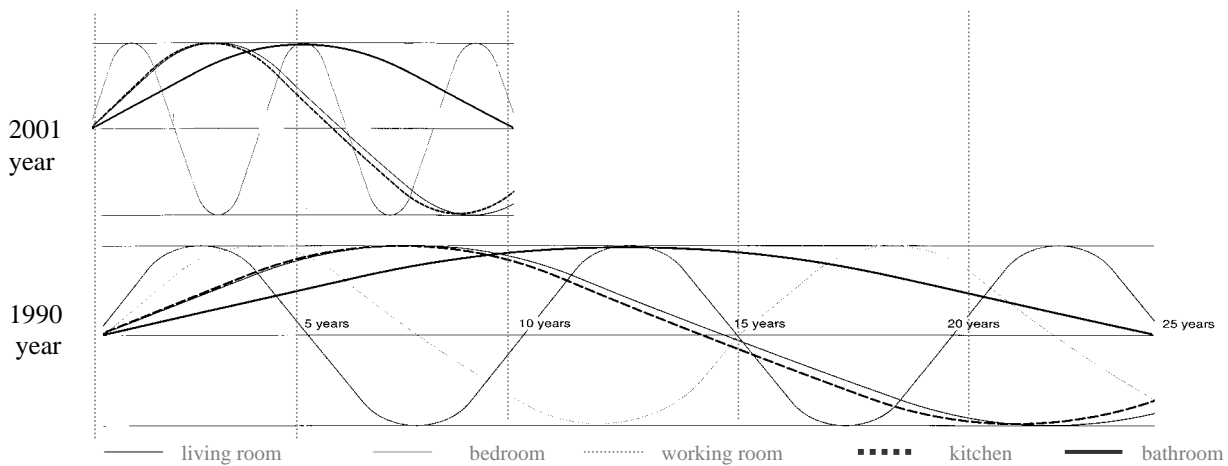


Figure 4: the pulse of change in dwellings

According to the above mentioned figures it is clear that in about 70% cases the initial spatial organization of a building does not meet later needs during the total life cycle of the building. Nevertheless, the design and construction of modern housing (whether the traditional or system buildings) is still focused on the traditional concepts and does not facilitate easy transformations.

Such a situation is urging for new concepts and methods of construction that will allow faster and less dramatic transformations of built structures. The transformable building is therefore becoming the primary goal, as traditional forms of buildings are no longer able to cope with problems of modern living.

Another aspect which is urging for new design and construction concept is related to the environmental impact of the building.

2.2 Environmental impact

Although buildings are frequently exposed to change most of them are still being built in a way which ignores the necessity for their adaptability in the future. As a result of this the number of buildings that are facing fundamental questions (demolition or costly reconstruction) is increasing.

The demolition of building structures produces enormous amounts of materials that in most countries results in a significant waste streams. In the U.S. demolition waste amounts to 92% of the total construction and demolition waste stream of 136 million tones annually. That is 125 million tones of demolition that is for the most part land-filled. (C.Kibert00)

In the Netherlands the construction and demolition waste amounts to 15 million tones per year.

The changes of the built structures have negative impact on the environment which is expressed through the volumes of waste going to landfills and incineration, as well as through the energy, dust and noise which are related to the demolition activities.

Higher ecological efficiency could be achieved by prolonging the lifecycle of the building and its components.

Therefore the key issue of the sustainability is development of the design strategy that will transform the inflexible building structures into dynamic and flexible structures whose parts could be easily disassembled and later on reused or recycled. This would drastically improve capacity of building structure to be transformed with minimal environmental stress.

Therefore the future development in general should be directed towards reusing, recycling and waste reduction (3 R's). Re-assembly is the first precondition for the 3 R's. Looking at the last phase of the building it becomes very clear that if the act of demolition would be replaced by disassembly materials and components could be reused and finally recycled.

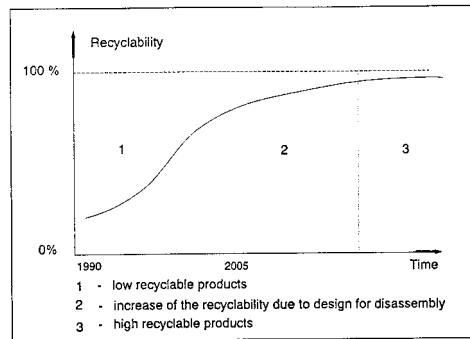


Figure 5: increase the sustainability due to the design for disassembly

The advantages of such demountable buildings upon the conventional ones would be that:

1. The built structures could last longer because of the fact that their parts could be easily exchanged; thus buildings could be easily adapted to new requirements.
2. The building components and materials could last longer by virtue of the fact that they could be reused in new situations, or recycled.

2.3 Building construction

Buildings frequently undergo transformation due to the degradation of materials and more technology dependent components, frequent changes of user requirements and changes of regulations.

No matter what the nature of change is, the reality shows that transformation within buildings always involves demolition and waste disposal.

Unlike other industries where the transformation on a product level has been upgraded in last twenty years providing a tools for disassembly, recovery and repair of used components, building industry is still very dependent on traditional building methods and processes. The construction of conventional building is associated with careful assembly on the construction site. On the other hand they are usually inflexible in exploitation phase because of inflexible load bearing construction, fixed connections and lack of accessibility to the components with shorter life cycle. For that reason the transformation on the building level is related to the time consuming construction processes, significant energy and material use and enormous waste production.

Although the design life of modern buildings is typically 50 – 100 years, their service lives are unpredictable because their major component parts wear out at different rates complicating replacement and repair schedules. It is quite usual for example for part with short durability to be fixed in permanently, preventing easy disassembly. Therefore at the end of components service life there is usually little option but for demolition with associated waste disposal. Stewart Brand describes these variable decay rates as “shearing layers of change” that create a constant temporal tension in buildings. Faster cycling components such as space plan elements are in conflict with slower materials such as structure and cite because of maximal integration of all building components into a single mass. Therefore the first step towards managing the temporal tension in building is through decoupling of slow and fast components (Kibert00).

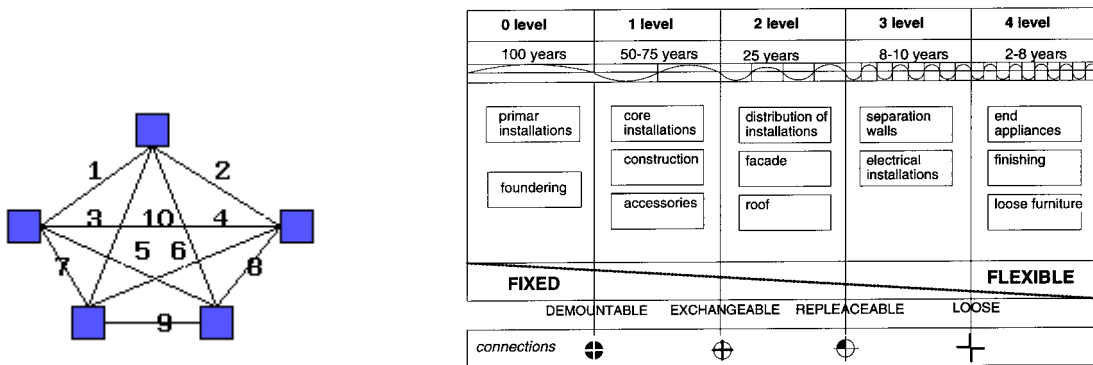


Figure6:left: relations between building elements creating a single mass

According to the life cycle analyses of materials and products buildings are made of materials and products with different life span (from 5-75 years). Still most of the materials are being put together in rather stiff conditions with little respect to different life spans and different function they have.(Fig.5) While the structure of the building may have the service life of up to 75 years, the cladding of the building may only be suitable for 20 years. Similarly, services may only be adequate for 15 years, and the interior fit out may be changed as frequently as every three years. On the other hand the reason for replaceability of building components is not always related to the technical durability of components but more often to the short phases in the use of the space.

It is well know that each building present an integration of spatial and technical systems, and one can not exist without another. Therefor in order to facilitate easy transformations of the building bought aspects of spatial and technical transformation have to be considered. Aspects of spatial transformation are extendibility of disposition free partitioning of the space, replace-ability of the functions, change of functions. Aspects of technical transformation are accessibility, extendibility of systems, disassembly and independence

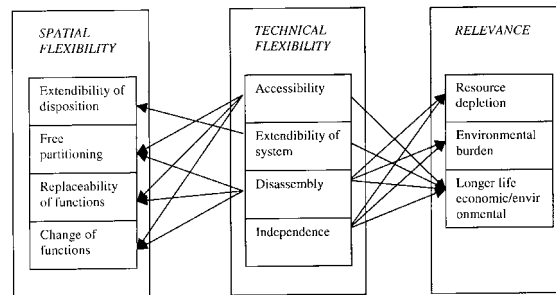


Figure7: Relations between technical and spatial systems

In most cases viability of spatial transformation depend form the technical transformability since the way that building is structured can influence the process of transformation form the whole building to the material. (Fig7)

3. FROM MASSIVE TO DECOMPOSABLE STRUCTURES

Having in mind the level of dependence between spatial and technical systems within buildings all building structures could be divided into three basic groups such as fixed structures, partly decomposable structures and totally decomposable structures. Fig.8

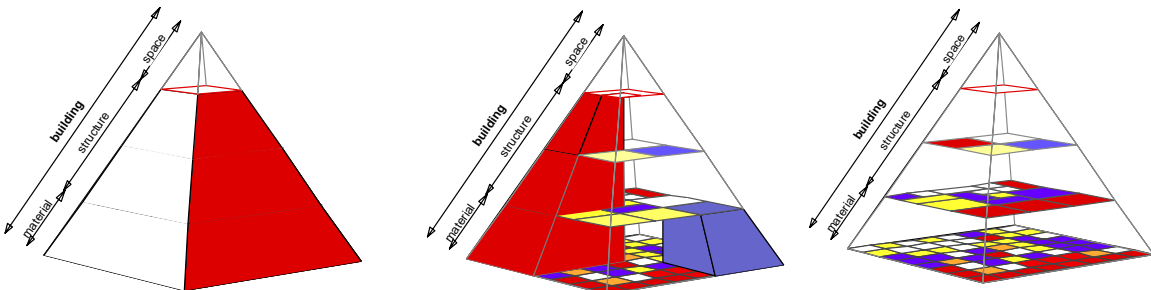


Figure 8: left: fixed structure, middle: partly decomposable structures, right: totally decomposable structures

The process of transformation from massive to decomposable structures symbolizes the process of separation of the building's functions such as support, enclosure, fittings and partitioning and altering them from fixed to less dependent conditions as well as further systematization and industrialization of the building.

Fixed structures could be characterized by fixed integration of all building components at connections.(fig.9) In such buildings elements are very dependent from each other since they are assembled with no regard to different lifetime expectance and different functional purposes they have at the connections. Consequently in order to replace one component the relations with other components have to be demolished. For that reasons other components are often damaged as well.

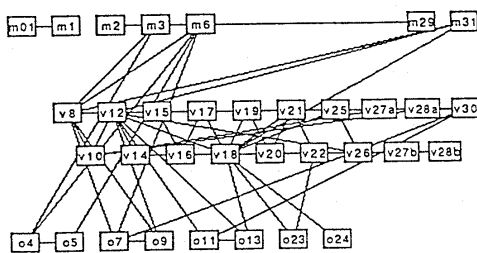


Figure 9:

Partly decomposable structures are the once where separation has been made between fixed and flexible parts of the building. The fixed elements are the elements with high level of flexibility towards spatial and functional changes and high durability. The

flexible elements are the elements, which are frequently exposed to change, and which have shorter life cycle.

The flexibility of such structures is restricted to the designed capacity of the fixed elements and type of flexibility which was strategically chosen. (fig 10).

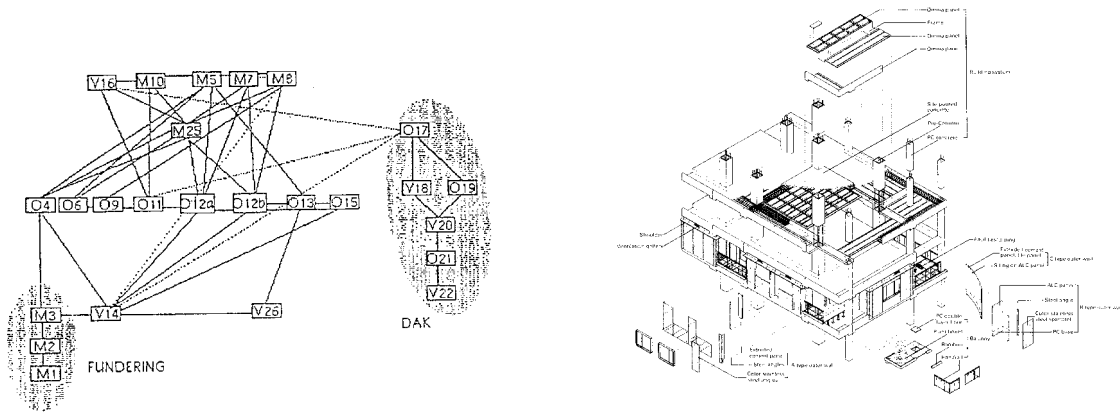


Figure 10 :

Totally decomposable structures are the structures, which could be totally dismantled at the end of their service life. That means that they could be relocated or that their parts could be reused in other combinations or recycled. (fig.11) This group represents the structures which provide clear separation between all building components. They are composed of system of modular parts that are easily transportable and usually dry assembled on the site. Decomposable structures define a method of construction in which use is made of integrated structural, mechanical, electrical, envelop and partitioning systems in a way that will stimulate their independence and exchangeability. The most important aspect of such buildings is decoupling 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 building and its products from the whole.

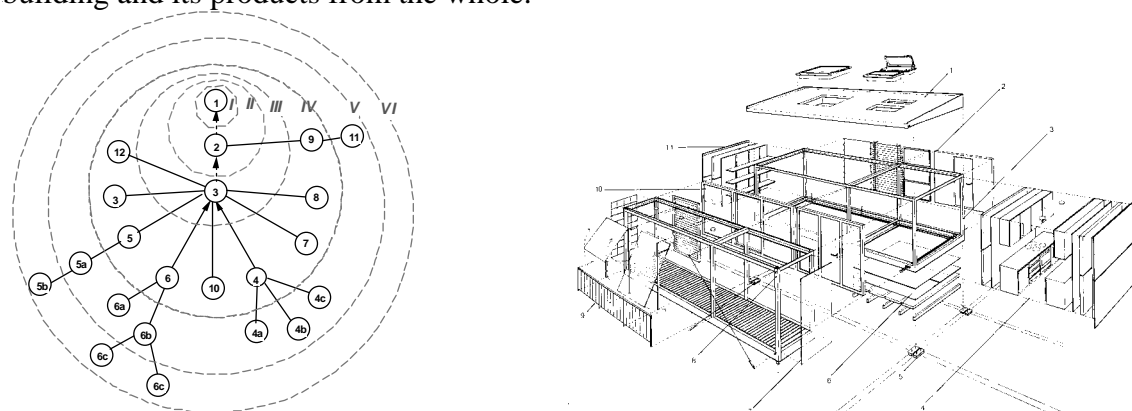


Figure 11: hierarchical organization of building components within decomposable structures

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 (fig.9) the main characteristic of totally decomposable building is in separation of different building's functions and altering them from fixed to less dependent conditions.(figure 10,11) 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.

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

3.1 Key aspects of building decomposition

Two basic criteria of building decomposition are independence and exchangeability of building products. In other words one building product can be dismantled if it is defined as an independence part of a building structure and if the interfaces with other parts are demountable. Independence of building products can be defined through the structural features, while exchangeability can be optimized through product and connection features as it is presented in the table 3.

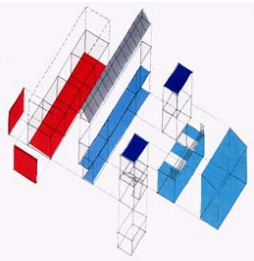
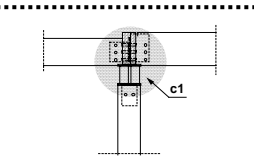
Aspects of building decomposition				VARIABLES
<p>Independence ← <i>Criteria</i></p> <ul style="list-style-type: none"> <input type="checkbox"/> Structural order (building structuring) 	Structural features		I N D E P E N D E N T	
<p>Exchangeability ← <i>Criteria</i></p> <ul style="list-style-type: none"> <input type="checkbox"/> Integration of materials and functions at connections 				Product features
<ul style="list-style-type: none"> <input type="checkbox"/> Characteristics of connections 	Connection features		D E P E N D E N T	

Table 3 aspects of building decomposition

Factors that determine independence of building components are systematization, hierarchy and relations. These factors determine the structuring of the building and have direct relation with spatial system of the building. The factors that determine exchangeability of the building products are related to the product and the connection features. Those factors are: type, function and life cycle of products and assembly sequences, typology and hierarchy of connections. Optimization of these factors depends on structural features and spatial systems of the building. The optimization of product features should be focused on application of right combinations of materials their functions and life cycle at connections. The optimization of the connection features should be focused on application of proper connection techniques having in mind the hierarchy of connections and aspects of product features.

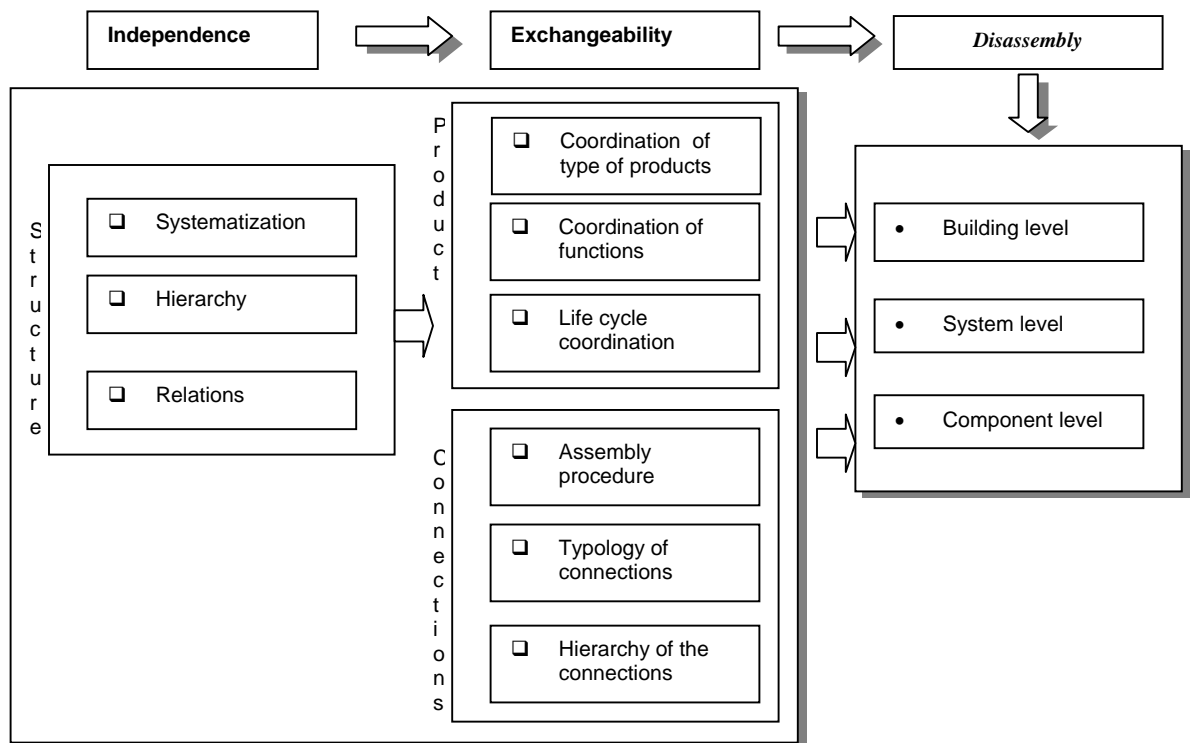


Table 4

Once the scenarios have been defined on spatial level the focus can be switched to the technical level where interfaces play an important role. It is that here the final efforts to achieve flexibility often fail.

Following relations have an impact on flexible interfaces:

- Relation between subsystems which have different life cycle
This relation is related to the sequences in assembly (first in –last out principle), level of independence which has to do with hierarchical position of the components in the building and type of connections
- Relation between subsystems which have different assembly processes

This relation has to do with process of making and number of parties which are involved in the process. There are three principle solutions for this relation.

- a./two different subsystems are assembled by one contractor,
- b./two different subsystems interfere into each other processes which is often the case with installations and load bearing structure or finishing
- c./two completely independent systems are assembled in independent time sequences.

- The relation between subsystems which perform different functions

These relations will occur at the connections between the two systems. The major problem here is continuity of the systems. Therefore indirect connection could be more suitable from direct connections.

- Relations between the systems which are project independent

The most important aspect in these relations are agreements about position, dimension (Age van Randen)

Having in mind above mentioned aspects which have impact on design of building connections five principle guidelines for design of decomposable structures could be defined :

- a. create separation between the elements with different functional and life cycle expectancies by using separate construction systems
- b. parallel assembly should replace sequential assembly in order to allow disassembly of single part without disruption to other parts
- c. keep all components separated avoiding penetration into other component or system
- d. provide accessibility to the components with shorter life cycle
- e. mechanical connections should replace chemical connections

4. DESIGN FOR DISASSEMBLY

In the past decade the technical and functional service life of the building was approximately 50 years. Today it happens that 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 a return-on-investments to come quicker. Within this context the reduction of the technical service life is no option, because this would in fact be destruction of capital investment. At the same time the natural resources and energy put in processing of materials into components and their assembly would be lost through the demolition and waste disposal.

Due to the ever-changing nature of our society the sequences in building use are becoming much shorter than before.

Consequently every new phase in the use of a building implies changes, which cause extra load on the environment due to energy use, dust and noise from demolition activities and building waste. Furthermore, if there is no justifiable technical solution for a new requirement, the building reaches the end of its life cycle. In order to facilitate the new phases in use of the building the design process has to be switched from the process of optimization of construction cost and short-term exploitation to the strategic planning. (fig.12)

This design concept besides focus on the scenarios for the spatial exploitation has to focus on the design for disassembly to facilitate the new stapes in exploration of the building and encourage the reuse and recycling of materials and components.

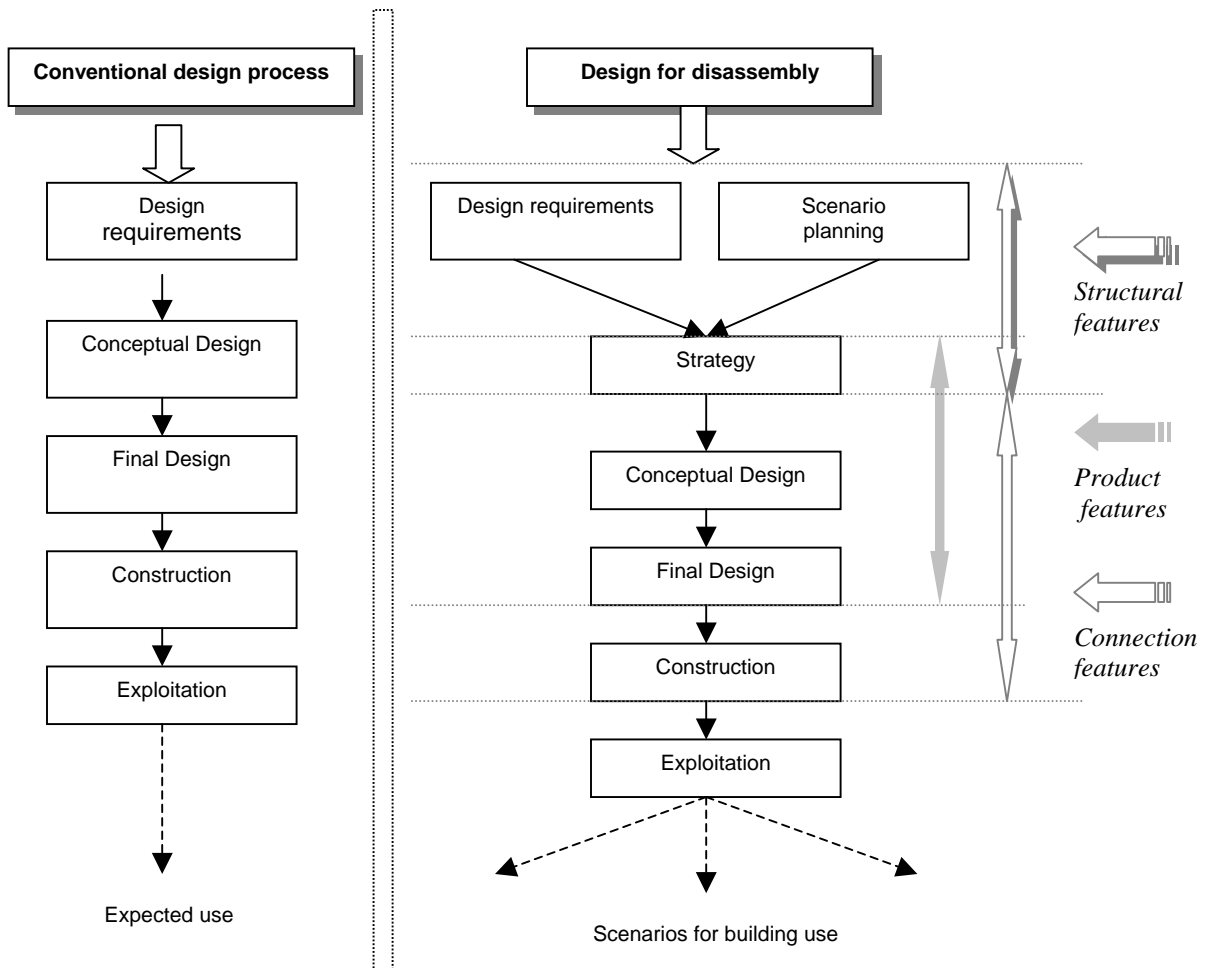


Figure 12

In order to make timely and correct decisions taking into account the scenarios for future use of building space and materials every phase of the design process needs different inputs. That means that the aspects of building decomposition have to be integrated and optimized from the beginning of the design process. In such way the design can meet demands from all life cycle phases of the building from design to disassembly.

5 CONCLUSIONS

The dominant life cycle of building its materials and components is a linear system, which end in demolition and waste disposal. If however the act of demolition would be replaced by the act of disassembly more materials and components can be reused and recycled.

When considering the potential for closed loop materials cycle for the built environment it becomes clear that the main problem lays in dependent integration of components with different lifetime and functional expectances at connections. To achieve extended service life designers must design buildings for disassembly to facilitate the new stapes in exploration of the building and encourage the reuse and recycling of materials and components.

Therefore the accent in the future development should be on systematization of building components into independent sub assemblies which are assembled in hierarchical order that is suitable for maintenance and replace-ability of single components. That means that the design has to move further from purely conceptual aspects to an more analytical approach with greater focus on technology and building methods.

6. REFERENCES

- (Kibert00) : C.Kibert, Construction ecology and metabolism. Conference proceedings "Integrated life cycle design" Helsinki 2000
- (Delsing89): Industrialisering van de woningbouw, Het Ontwikkelen van aanpasbare en industriële woningbouwsystemen, toegelicht met de toepassing van staal in de woningbouw, Eindhoven 1989
- (Durmisevic99): E.Durmisevic, Transformation possibilities on infill level in dwelling, Implementation of flexible wall system, Delft 2000
- (Rigo99): Rigo Research and advies BV, Een woning altijd op maat, 1999
- (Kaptejns92): J.Kaptejns, Verslag van het onderzoek het informatiseren van het ontwerpen van bouwknopen, Delft 1992
- (Durmisevic00): Towards dynamic building structures, Conference proceedings Beyond Sustainability, Eindhoven 2000
- (Kibert00): C.Kibert, Deconstruction as an essential component of sustainable construction , Conference proceedings, Sustainable building 2000, Maastricht 2000
- (CC GIL 00): Sustainable building research group, The impact of the facilities/maintenance management on the long term sustainability of the built environment, performance indicators at post-construction stage of building life cycle, Conference proceedings SB2000, Maastricht 2000