Service life and life cycle of building structures.

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Abstract:
A short overview of the main aspects which influence the life of a building structure is given. The requirements of building structures are likely to change during its functional working life. Therefore designers of building structures should strive for the best possible match between design working life, technical service life and functional working life. The design process should also concern the whole life cycle of structures and their components in order to minimise negative environmental impacts.

Industrial, Flexible and Demountable (IFD) building is defined and presented as a concept of building which deals with these subjects.

1 INTRODUCTION

The service life of a given building structure is affected by:

- Design of the building, its structure, joints and components
- Quality of the individual materials and components
- Standard of construction
- Actions on the structures during life
- Environmental effects on the structure
- The use and changes in use of the building during its service life
- The decision processes regarding maintenance, repair, adaptation and finally demolishing of the structure.

For a good understanding, the following terms regarding the life of structure are defined:

**Design working life**
The design working life is the assumed period for which a structure is to be used for its intended purpose (with anticipated maintenance but without major repair).

**Technical service life**
The technical service life is the period for which a structure can actually perform according to the structural requirements based on its intended purpose (possibly with necessary maintenance but without major repair).

**Functional working life**
The functional working life is the period for which a structure can still meet the demands of its (possibly changing) users (may be with repairs and or adaptations).

**Technical durability:**
The ability / capacity of a structure in its environment to remain structurally fit for its intended use during its technical service life (with anticipated maintenance but without major repair).

**Functional durability:**
The ability / capacity of a structure to fit the requirements for use despite changes in use.

2 STRUCTURAL REQUIREMENTS

A structure in use will have to meet with the following criteria during its life.

**Technical service life (a):**
Safety (including loss of equilibrium):
Structural Resistance $t >$ Solicitation $t$
Serviceability:
Structural Serviceability $t >$ Min. Serviceability $t$

**Functional working life (b):**
Structural Functionality:
a. Technical service life:
During its technical service life a building structure has to meet with minimum required levels of structural safety and, at the same time, has to meet with minimum levels of serviceability.

Structural safety during the technical service life of a building structure

The structural safety of a structure depends on the resistance and the solicitation of the structure. Both can be subject to seen or unforeseen changes in time. The resistance of a building structure is likely to change in time. Structural materials can be affected by deterioration, for instance depending on the moisture content of the materials. Sometimes the expected life of a structure can be predicted more or less accurate, for instance in the case of the estimation of fatigue life. Failure can be predicted in relation to the number of loading cycles. In the case of time dependent (strength) properties of materials, different models to predict the life of a structural element with a minimum level of safety are available.

Structural Integrity under exceptional loadings is an important subject dealt with in WG 2.

Serviceability during the technical service life of a building structure.

Apart from structural safety the serviceability of the building and its structure play an important role in the life of a building structure.

b. Functional working life

The functional working life depends on the minimum user defined functionality on the one hand and the functionality of the structure on the other hand, combined with the ability of the structure to be adapted in such a way that the user criteria are met.

With changing societies the demands of building occupants become more and more dynamic. An investigation carried out under companies in the Netherlands showed the following figures:

15 – 22 % of the companies want to move
10 – 15 % of the companies want to alter / rebuild
(Source:NVB 1998)

(Profit and Non-profit organisations in Holland move with an average of once every five years).

If the functionality of a given structure meets the (new) users demands, no adaptations to the structure will be necessary. The functionality of a structure depends largely on aspects determined at the design stage. For instance:

- The location of the structure (and building)
- Positions of bearing walls
- Column free area of floors
- Bearing capacity of the structural elements to accommodate functions with higher imposed loads
- Height between floors to accommodate e.g. service ducts

If the users functional demands are not met by the functional quality of the structure the functional working life depends on the capability of the structure to be adapted or else the functional working life of the structure will end.

With regard to the adaptability of the structure we can distinguish the following influential aspects:

- Bearing capacity of structural elements to accommodate adaptations elsewhere.
- Characteristics of the existing structure with regards to possible strengthening or making new voids for ducts or stairs
· The possibility to exchange structural elements (con-
nexions etc.)
· Other building aspects which influence the possibilities
  for strengthening or exchange.
· Possibility to disassemble and relocate the structure

The relation between the functional working life and the
technical service life can be shown graphical:

![Diagram showing potential functional working life versus technical service life](image)

Fig. Potential Functional Working Life versus Potential Technical Service Life.

Structures for which the functional working life is smaller
than the technical service life need to be taken out of the
market. (Their functional life can be extended by finding
new users with lower demands on structural functionality
or by improving the level of functionality: adapting the
structure).

Structures for which the functional life (in terms of
years) is bigger than the technical service life should be
repaired, upgraded or also dismantled because they
don’t meet the safety or serviceability requirements.

Because of the large expenses often involved in adapting
building structures it can be advantageous to strive for a
functional working life equal to the technical service life:
the diagonal in the diagram above.

An example of a project that strives for “the diagonal” is
the XX-office Building in Delft, Netherlands. F. VAN
HERWIJNEN discusses the design of the structure for
this project in his paper “THE LOAD BEARING
STRUCTURE OF THE XX-OFFICE BUILDING IN
DELFT”.

Several aspects are important in connection to the deci-
sion process to maintain, repair, adapt or demolish a
building structure. Perhaps the most important aspect in
achieving an optimal management strategy for new and
existing buildings is economy.

SZCZEPAN WOLINSKI discusses optimization of to-
tal expected life-cycle cost subject to minimum reliability
requirements, optimization of the whole building
management, and also, evaluation of the remaining life-
time of existing structures in his paper “ECONOMY
AND LIFE-CYCLE ASSESSMENT”

Building diagnostics
In order to obtain the right information to support man-
agement decision processes, for instance whether and
when maintenance and / or repair are needed, it be-
comes necessary to evaluate the performance of the
structure. Several techniques to monitor, test and evalu-
ate existing structures are available, and are still being
improved and further developed. Building diagnostic
play an important role in predicting the life of existing
structures. The numbers of buildings built prior to the
application of limit state design outnumber the ones that
are built to latest views. Therefore building diagnostics
play an important role in the decision process to main-
tain, repair, adapt or demolish the structure.

The Life Cycle of structures
Before, the Design working life, the Technical service life
and Functional working life of structures have been dis-
cussed. However it is necessary to look beyond the life
of existing and future building structures. The effects that
building construction has on the environment plays an
important role in our well-being. The effects of the ex-
traction of raw materials, the production of materials
with possible waste or toxic emissions but also the use
of the products itself (with possible negative impacts)
and the possible re-use should be considered. In short:
the whole life cycle of the building structure.

Sustainable Development implies that aspects concern-
ing the environment, the vulnerability of the earth, ex-
haustible resources, and the quality of life are all to be
taken into account. Sustainable Development is viewed
as a major requirement for future technology. It is often
referred to as consisting of three main points:

1. Integrated cycle management: the closing of the mate-
rial cycle from raw material to waste material and emis-
sions.
2. Reducing energy-consumption and the use of sustain-
able natural energy sources.
3. Quality improvement: Raising the quality of the prod-
ucts, the fabrication processes, minimising waste
production and negative impacts on environment all
aiming for a longer use of our available natural re-
sources.

Building waste
Waste as a result of building construction makes a large
contribution to the total production of waste, therefore is
an important issue to be dealt with.
### Waste Categories

<table>
<thead>
<tr>
<th></th>
<th>1999 total</th>
<th>2000* total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re-use</td>
<td>Incineration</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>X 1000 Ton</td>
<td>X 1000 Ton</td>
</tr>
<tr>
<td><strong>Household garbage</strong></td>
<td>8 385</td>
<td>8 645</td>
</tr>
<tr>
<td><strong>Building</strong></td>
<td>18 000</td>
<td>19 000</td>
</tr>
<tr>
<td><strong>Agricultural Waste</strong></td>
<td>1 815</td>
<td>1 820</td>
</tr>
<tr>
<td><strong>Industrial Waste</strong></td>
<td>20 320</td>
<td>20 225</td>
</tr>
<tr>
<td><strong>other</strong></td>
<td>8 820</td>
<td>9 060</td>
</tr>
</tbody>
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Fig. Building waste in Holland against total and other categories (RIVM)

The best ways to “deal with waste” is prevention, or re-cycling with highest possible value. Less wanted is incineration or dumping. The prevention of building waste is directly influenced by the possibilities of disassembling, re-using, or recycling of structures, components and materials together with minimizing the use of materials and energy.

“EFFICIENCY OF USING SEMI-RIGID JOINTS IN COMPOSITE FRAMES” is a topic discussed by ALEKSANDER KOZLOWSKI with possible savings in the use of material as a result.

Decisions made during the design of the building structure and its elements play perhaps the most important role in trying to minimise waste production and extending the life of building structures.

From the important notion to strive for sustainable building rose the concept of IFD, Industrial, Flexible and Demountable Building.

3 IFD BUILDING

Industrialised and flexible building in itself is not new. However, the combination with de-mountable building is. The three elements of IFD building may be defined as follows:

By **industrial building** in this context we mean industrially making of building products.

In building the word ‘prefabricated’ is often used as a synonym for ‘industrial’. In this context prefabrication means to perform in the factory what was originally done on the building site, manufacture here is project specific. An example of this is prefabricated concrete for columns, facade elements and the like.

Besides there are industries that have of old only been able to realise their production in the factory, because the material, the process and the necessary machines require such. Examples are steel construction workshops, but also industries that produce prestressed floor slabs.

**Flexibility** is the quality of a building or building component which allows adjustments according to the demands and wishes of the users. [1]

Flexibility may relate to two stages:
- the design stage: variability in the composition and the use of material;
- the user stage: flexibility to adjust the composition and the applied building components to the changing demands and/or wishes of the same or varying users while in use.

On the structural level, flexibility in the user stage may be translated into possible adaptability of the floors to higher working loads (the so called extreme live load) and the realisation of recesses for stairwells, lift shafts or pipes and ducts. The placing of extra floors or mezzanines and the construction of extensions on ground level must also be counted among these.

**Demountable building** is the construction of a building in such a way that a building component may be removed and possibly re-used or recycled, soiled as little as possible by other materials, and without damaging the surrounding building components.[1]. In recycling we do
not use the complete product, but only its raw or pure material. Demountable building is also a means for the realisation of flexibility, because building components may be easily detached and replaced by other (industrial) building components.

4 CONCLUSIONS

Many different aspects influence the service life and the life cycle of building structures. Both the requirements and the performance of building structures are likely to change during its functional working life. Therefore structural designers of building structures should consider besides the design working life also the technical service life and the functional working life as design parameters. The technical service life does not need to be much longer than the functional working life. Designers need to strive for the best possible match between design working life, technical service life and functional working life. The design should concern not only the service life but also the whole life cycle of structures and their components in order to minimise negative environmental impacts. An example of an approach in which the functional working life of structures can be increased is Industrial, Flexible and Demountable (IFD) building.

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