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Demolition versus Transformation, “mortality of building structures” depending on their technical building properties

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Abstract. This paper describes the assessment of 60 multi-story buildings in the Netherlands, the followed approach and the main results. The 60 buildings have been assessed on their technical building properties to see which building parameters could be influential on the probability of an elongated Service Life for the building structure. The buildings, (of which 40 buildings have been given a “Second Life” through Transformation and 20 buildings have been demolished) have been assessed, initially on 64 different parameters. The number of parameters has then been reduced to 20, more or less influential parameters. A “quick scan” of building structures has been derived from these parameters. This quick scan uses an aggregated value expressing the re-use potential in a single adaptability/flexibility score. In a similar approach as often is used in medical survival analysis, the “Mortality of Buildings” have been calculated for different Flexibility Scores. Further elaboration will make it possible to assess building structures and then give an indication on their probability for (future) transformation. This is important, not only to assess our existing building stock but also to improve elongated Service Life’s for new buildings. By optimizing the Service Life of buildings structures, negative material impacts can be further reduced and the Re-use and Transformation on building level, rather than on material level, can be improved. More realistic Service Life Estimations will make comparisons of different solutions with different levels of Flexibility much more feasible.

Keywords: Service Life, Circular Building, Mortality, Reuse of building Structures.

1. Introduction

Transformation and re-use of buildings in new functions is not a new phenomenon. Vacancy of buildings, especially for a longer period are a clear indication that these buildings no longer fulfil the requirements of their previous (and new) users. Inevitably the decision comes closer on whether the building should be refurbished, upgraded, perhaps be transformed into another function (Transformation) or whether the building should be demolished and a new building should be erected.



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Assessment of the transformation potential in this stages is important. Another reason for studying transformation potential comes from the need for Circular Building.

Currently the Dutch Government has adopted a commitment to Circular Building within the EU framework. The Netherlands have committed themselves to a 50 % Circularity in 2030 and a full Circularity in 2050. This means that apart of *energy neutrality* also a large *shift in material use* is inevitable. For this, re-use of materials, elements, and indeed if possible, re-use at the highest possible level is needed. In short: Re-use of buildings structures must become mainstream and given the need for circularity, it will be unavoidable that in the future the balance will tip much more in the direction of re-use of the building structure, Transformation of the building, instead of Demolition. In [1], while evaluating the influence of different Service Life Scenarios on a building's environmental impact, one of the main conclusions was: "*The environmental impact of buildings depend directly on the length of the assumed Service Life. Improvement on techniques to take into account possible differences in the Lifespan of a structure are needed. For example a method to evaluate differences in functional quality of a structure, and therefore a possibly longer expected Functional Working Life, is needed.*" We now know that for future buildings *Design for Re-use and Transformation* as well as *Design for Disassembly* must become mainstream. Apart from other considerations such as urban city planning, preservation of historic buildings (monuments) or development of land prices, the technical aspects of a building are influential on how complex or how simple it is to transform buildings. In [2], Durmisovic has proposed a knowledge model for the assessment of Transformation Capacity and in [3] a framework for quantifying structural Flexibility has been proposed. However, to what extend Structural Flexibility or Transformation capacity influences the reuse of structures in terms of Service Life Elongation remains largely unclear. In [1] the first approach towards quantifying the relation between flexibility properties and Service Life Expectancy is described. The study described here builds further on these approaches.

2. MPG calculations

In the Netherlands a so-called MPG calculation (in Dutch: Milieu-Prestatie Gebouwen; in English: Environmental Performance Buildings) is required for all new building permit applications. The aim of the MPG is to calculate the level of environmental impact, however the MPG considers only the material use of a building (The energy use is covered in a so called EPC calculation). For new housing as well as for new office buildings this calculation is now mandatory per 1-1-2018 (a calculation for other buildings or for the civil engineering sector, (roads, bridges etc.), is not yet mandatory). The MPG calculates the so-called environmental (shadow) costs. It is assumed (but not proven) that the lower the environmental shadow costs are, the more sustainable the buildings material use is. The current maximum environmental cost for new buildings is set at 1,0 euro per m² brute floor area / per year. This maximum value is expected to be lowered in the coming years thus aiming at a significantly reduction of the environmental cost for new buildings. The environmental costs represent the current level of cost needed to avoid the calculated impacts of the material used. The MPG calculation is based on a Dutch national database of approved Life Cycle Assessments (LCA calculations) of materials and products. These LCA's, use 11 damage indicators, that are aggregated into one indicator figure, thus the so-called environmental "shadow cost" is the result. The total sum of all the material shadow costs for the building is divided by the years of use (using forfeit values, taken into account life cycles, expected repairs and replacements during this life cycle) and the brute floor area [4]. The MPG calculation uses various forfeit values of which the most influential: 50 years as the maximum Service Life of Housing and 75 years as the Service Life of Offices. This way Design for Re-use, Flexibility etc. are not rewarded. On the contrary, wider spans, larger floor to ceiling dimensions, associated with increased flexibility in future use, now mean more initial material-use for the building, resulting in higher "penalty" material shadow costs in the MPG calculation. It is clear that more research is needed on to what extend Service Life Elongation of buildings structures can be achieved by applying different measures in the design phase of the building.

3. The study and assessment method

Goal of the study was to see whether and to what extend **technical building properties** have an influence on the **length of the functional service life** and/or possible **reuse of a building structure**. A large part of the study described here: “The relationship between the technical Building Properties with the Technical Probability of Elongating the Functional Service Life” was carried out in 2016 by graduating MSc. student M. Landman. In [1] a test run on 18 buildings already showed that such a relationship could be expected, however the amount of buildings at that time was insufficient to analyse statistically. Based on a literature study of other approaches towards evaluating flexibility (for example the assessment method of the Brink Group, it was decided to start this study with a very wide selection of 64 possibly influential technical parameters. ‘Figure 1’ shows a matrix with indicated the total number of considered parameters for each configuration.

3.1. Building Layers

The columns of ‘table 1’ show the so-called *building layers*. These building layers are based on [5] and [6]. The layers are **Site, Structure, Skin, Services, Access** and **Space plan**. (The building layer *Stuff*” by S. Brand [5] representing for example furniture is not considered. The layer *Access* of B. Leupen [6] was added in the study.

Table 1. Matrix of Building Layers (columns) with Indicators (rows) and number of parameters.

Layers	Site	Structure	Skin	Services	Access	Space Plan	Total indicator score
Indicators							
Segregation			2	2	2		6
Demountability		2	3	1	2	1	9
Reachability			2	2	6		10
Dimension		5	3	1	4		13
Capacity		5	2				7
Adjustability	2	3	2	3	3	1	14
Fire safety		1	2		1	1	5
Total Building Layer Score	2	16	16	9	18	3	64

3.2. Indicators

The initially used indicators as represented by the rows of the matrix in ‘figure 1’. They are **Segregation, Demountability, Reachability, Dimension, Capacity, Adjustability** and **Fire safety**. The indicators have been defined and named in such a way that a higher extend of an indicator results also in a higher value. This means that for example *Segregation* replaces the previously used term of (the opposite) *Integration*. This indicator represents to which extend functions of the layers are mixed. **Demountability** measures the ease of disassembling/demounting the connection between layers. The accessibility of a component in another building layer was named **Reachability** in order not to confuse it with the layer *Access*. **Dimension** measures the amount of space the structure offers for the purpose of the other layers. **Capacity** defines the structural load bearing capacity provided by the structure for the purpose of the other building layers. **Adjustability** was defined as to which extend for example settings of a building layer can be adapted to new functions. **Fire safety**, evaluating fire resistance and length of escape route or other measures to prevent the spread of fire was also added to the evaluation. A configuration is a crossing of an Indicators with a Building layers (see table 1).

3.3. Parameters

This evaluation of a building on the different configurations is done by making up an average score of the parameters using parameter questions. The matrix in ‘figure 1’ shows the number of parameters (parameter questions) per configuration. ‘Figure 2’ and ‘figure 3’ show examples of these parameter questions. They are explained in the next section.

3.4. Data quality and objectivity of parameters.

Existing building information did sometimes not provide sufficient information. In this case estimated values were used by comparing the building to other similar buildings with the same kind of building properties and construction methods regarding the specific parameter. Based on an estimated high and low value the estimated average was taken. Objectivity as high as possible was pursued. The model has different types of answers: Answers based on objective observations, based on a property that has a numbered value, or answers based on a choice of descriptions. This last type of answers is probably less objective and sometimes co-depending on the evaluator’s opinion. However 89,1 % of the parameter questions fall within the first two categories. As mentioned, ‘figure 1’ and ‘figure 2’ show examples of parameter questions. In this case, ‘figure 2’, the skin (both roof and façade) are evaluated on the extent of (functional and physical) **Segregation**. (To what extent can the facade be changed without the necessity to also make changes to the layer structure itself) For example a non-loadbearing façade scores a maximum of 1,0 , where a fully loadbearing façade wall scores 0,0. The parameter question on the indicator **Demountability** in ‘figure 2’ investigates the level and ease of disassembly of the connection between the layer **Skin** and the **Structure**.

Segregation - Skin		1,0
To which extent is the façade integrated into the structure?		
0.0	Fully integrated (loadbearing façade walls)	
0.2	Largely integrated (loadbearing façade walls and columns)	
0.4	Integrated (loadbearing façade columns placed within a small grid)	
0.6	Partly integrated (loadbearing façade columns placed within a large grid)	
0.8	Partly independent (façade with stability elements on cantilevered floor)	
1.0	Fully independent (façade without stability elements on cantilevered floor)	

Figure 1: Example of Parameter questions related to the Demountability of the Layer Skin

Demountability - Skin		0,8
To which extent could the façade be demounted from the structure?		
0.0	Merged connection (in-situ poured concrete)	
0.2	Fully grouted rod connection	
0.4	Mortar or sealant connection	
0.6	Screwed or nailed connection	
0.8	Bolted connection	
1.0	Clamp connection or no connection due to fully independent façade	

Figure 2. Example of Parameter questions related to the Segregation of the Layer Skin

4. Assessed buildings

To see to what extent these parameters could be influential on the decision for Transformation (Elongation of service life) versus Demolition (End of service Life) a total of **60 buildings** have been evaluated. The buildings were divided in a test group and a control group, each of 30 buildings. In both the test group and the control group there were 10 demolished and 20 transformed buildings. The Buildings that have been selected had a minimum of three building stories, and a minimum gross floor

area of 2000 m². (For this reason the building function of sports was not represented in the buildings). This approach has been taken to exclude buildings that can easily be demolished and to guarantee that the existing building structure would still represent a certain economic value. Also monuments or historic buildings were excluded because the technical properties are in this case guaranteed not to play a role in the demolition or transformation decision. 'Figure 3' shows ten of the demolished buildings to give an impression of what kind of buildings were considered in the study.

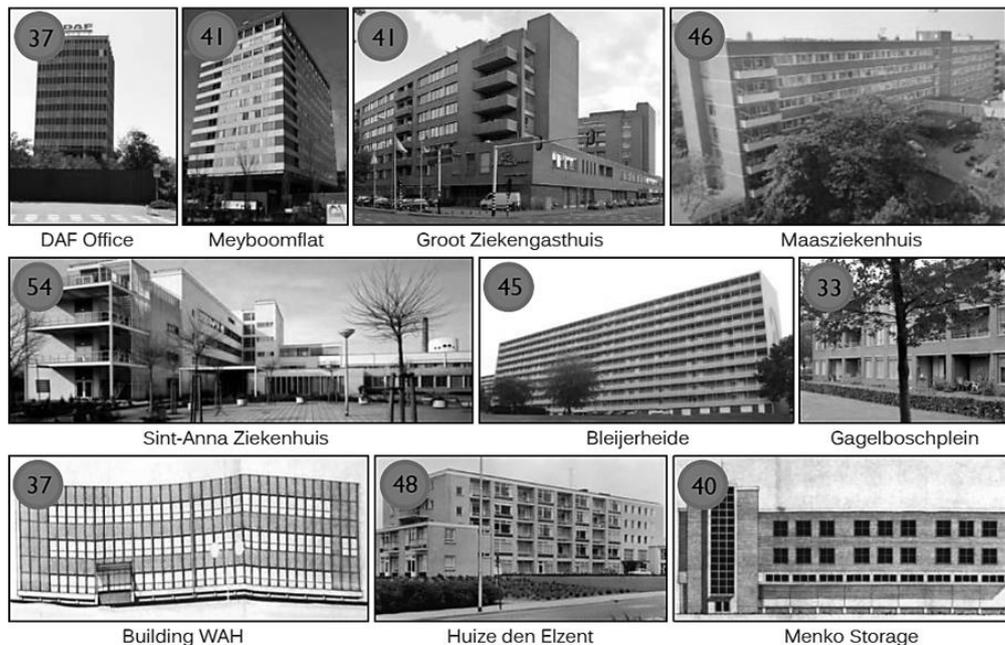


Figure 3: Impression of the 10 demolished buildings in the Test group. The age of the building at demolition is indicated in left corners. In total 60 buildings were assessed.

5. Correlation study

For each of the 62 parameters the influence on the final *State* of the building (*Demolished* versus *Transformed*) and on the total aggregated *Score* has been evaluated by calculating the linear correlation coefficient *R*. This was also done for the (vertically) aggregated values of the Building Layers as well as the (horizontally) aggregated values of the Indicators.

Table 2. Correlation of Building layer scores with State and Score

Building Layer	State	Score
Structure	0,099	0,467
Skin	0,445	0,740
Services	0,381	0,595
Access	0,253	0,523
Space Plan	0,324	0,686

With a significance level of $\alpha = 0,10$ (90%) critical values of $R = + 0,306$ and $- 3,06$ were used. Possible fluctuations of the correlation are accepted because of the limited number of buildings ($n = 60$) in the study. 'Table 2' gives the correlations of the Building layer, they show a high correlation with score, but only building layer skin and service show medium correlations with the final score. *Score* and

State should ideally be more in line. The building layer **Structure** shows the lowest correlation, probably because it shows the *adaptability/demountability* of the structure itself, so it can be concluded that the **adaptability** of the structure itself is not influential on the probability of transformation of a building.

6. Quick Scan Flex Score

Based on this study 20 out of 64 parameters with the highest correlations were selected. No final threshold for the correlations was set, but part of the selected parameters had high correlations with a significance level of 95% with both state (demolished versus transformed) and score, others were selected based on a correlation with a significance level of 90% with either state or score. With these a Quick Scan Flex Score was derived. 'Figure 4' shows the graph of the Service Life versus this Flex Score of the **Demolished Buildings**. The average Service Life of the Demolished buildings was 41 Years, the average Flex Score was 0,5.

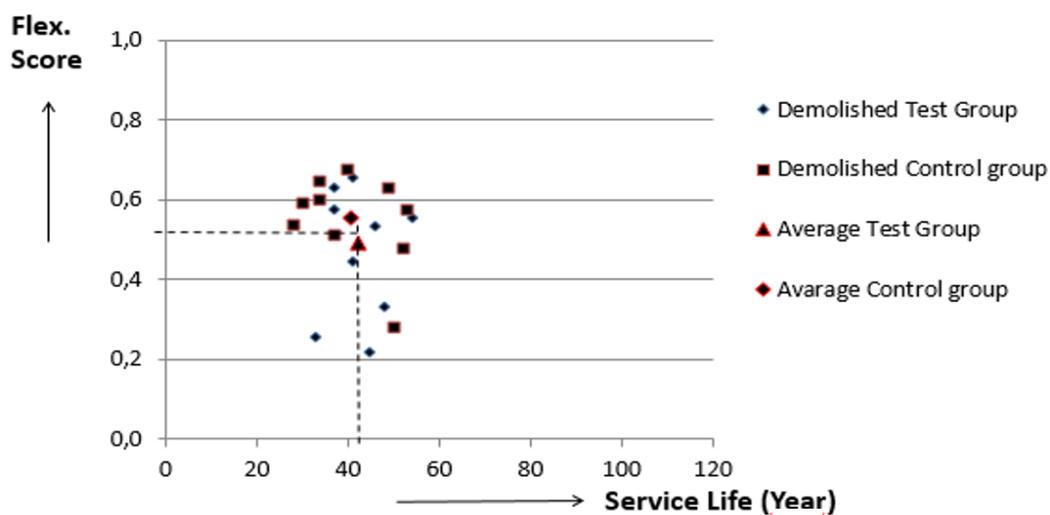


Figure 4: Demolished Buildings, Flex score versus Service Life

'Figure 5' shows the results of the **Transformed buildings**. Because these buildings are still in use a Service Life was estimated based on a elongated Service Life of 20 years after their transformation. The average Service Life of the **Transformed buildings** then becomes about 64 years with an average flexibility score of 0,66.

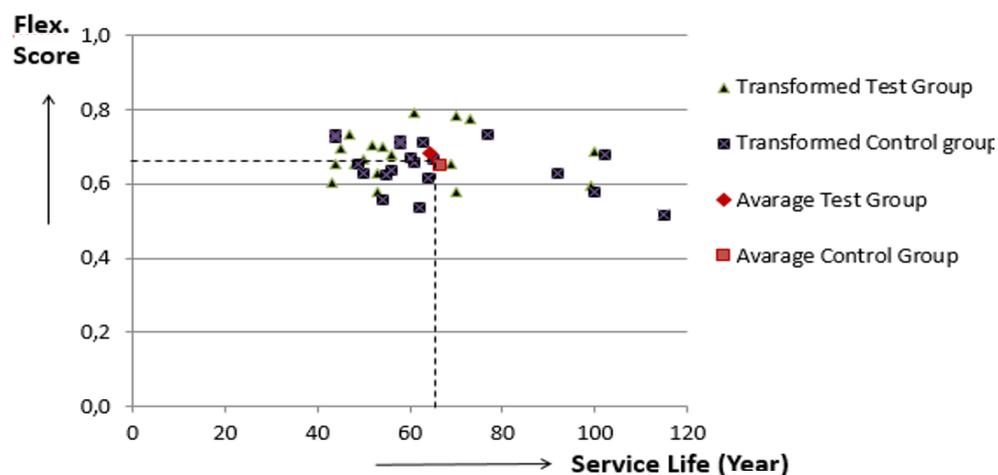


Figure 5: Transformed Buildings, Flex Score versus Service Life

7. Mortality of Buildings

Similar to mortality in Human Health Research the “Mortality” of the 60 buildings is represented in the graph shown in figure 6. It shows the Mortality of buildings with a Flex Score below 0,55 versus the mortality of buildings with a Flex Score above 0,65. Though the differences seem not very strong it can be seen that a higher flexibility score gives a higher probability of the building being transformed and thus effectively a higher probability of a longer Service Life of these building structure, or in Health terms a lower mortality.

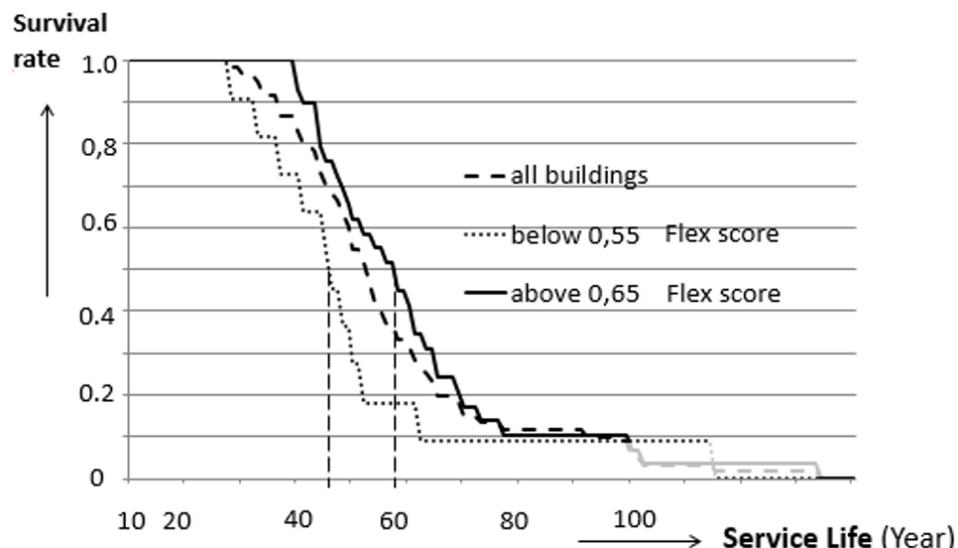


Figure 6: “Mortality” of Buildings for buildings with different Quick Scan Flex Score

8. Multiple regression model

From the 20 selected parameter a multiple regression model for a quick scan was created -using the IBM SPSS Statistics program- to calculate the probability of a successful transformation. During this stepwise process a number of parameters were eliminated from the approach in order to gain the same results with the least possible parameters. Very strong correlations were found for: the loadbearing capacity of the floors, the reachability of facade connections and the possibility to extend/ change the service elements (ducts) horizontally. Five of the remaining parameters were addressing the relation façade and structure, four parameters were addressing the Space plan. The total number of buildings that were included in the study (60) is still not big enough to arrive at reliable stable final correlations. A final relationship between technical building parameters and the probability of transformation still needs more research. However the expectation that a number of technical properties of the building significantly influence their probability of transformation and longer service life is certainly not rejected. Even with a non-weighted and a not yet perfect Flex Score, it can be shown that buildings with a higher Flex Score have indeed a higher probability for a longer Service Life. The study has initially selected 20 of the most influential parameters out of an initial of 64 considered different technical parameters, but with the multiple logistic regression and correlation study 9 of these 20 parameters have been found to have a strong to very strong correlation with the probability of transformation. The following picture with the most influential aspects/parameters emerges from this:

Building structures with a lower mortality rate (longer Service Life) have:

- Sufficient Space for change and passing of horizontal Service elements
- Sufficient loadbearing capacity and larger free usable space
- Column structures rather than load bearing Wall systems.

- A non-loadbearing and easy adaptable or removable Façade
- Good Access to stairs and floors

The influence of *Services*, vertical passing of shafts and ducts was found to be not significant, as opposed to horizontal passing of ducts. Also Fire Safety of the building structure was not influential. The relationship of *Structure* with the layer *Site* also showed no correlation.

9. Conclusions and discussion

The study gives strong indications that the found technical properties of a building do influence the “Mortality” or Service Life Expectancy of building structures. The most influential parameters for the buildings mortality have been derived as described in section 8. An extended study of up to 250 Buildings or more is recommended to ensure stable correlations. However, already from the study on these 60 buildings it can be concluded that LCA calculations or other assessments methods that use fixed or forfeited Service Lives (such as the Dutch MPG calculations) can easily give deviations or errors of up to 50% and more (for example the difference between the average Service life of Demolished Buildings and Transformed buildings in this study was more than 20 years). A better approach of the relationship between Estimated Service Life and the buildings properties regarding Structural Flexibility (or Design for Disassembly) is expected to come from an extended study with more buildings. From the EU’s ambitions on circularity it is clear that for reliable assessment results, these Flexibility Properties and their influences on the Life Expectancy of buildings need to be implemented in building (circularity) assessments. Also it could be argued that to make better use of our fossil materials the design and construction of new building structures that focus on achieving lower mortality rates should be promoted.

10. References

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