

Comparison of adaptability measures in building design - CSA Method: Functionally effective and technically efficient design founded on (future) user demands

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Comparison of adaptability measures in building design

CSA method: Functionally effective and technically efficient design founded on (future) user demands

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Abstract: Most buildings are hardly technically equipped to fulfil the ever changing user requirements. Stimulation of flexible use of buildings is a strategy that aims at extending the functional lifespan of buildings. Adaptability of building components is an important technical aid to facilitate flexible use. Due to the large number of variables and the many dependencies and uncertainties in the translation of (changing) user requirements into technical solutions, a methodical approach is indispensable. Therefore the CSA method is developed. The method is designed to impartially select and compare a number of adaptability measures. The degree of efficiency of the chosen measure is assessed by quantifying the required effort for an adaptation, costs and environmental impact. The initial (single) effects for these criteria are distinguished from the more often occurring effects that come with each adaptation. The uniqueness of the CSA method is that a best fit is sought from both the user point of view and the effects on/of the applied building technology. Operation of the CSA method proved to be valid by performing three case studies. In current building the initial phase is decisive for decision making. However, the case studies show that solutions with a high degree of adaptability are the most efficient for the long term, when adaptation occurs several times during the lifespan of a building.

1. INTRODUCTION

A large percentage of the Dutch building stock currently does not meet the quality requirements due to functional limitations, whilst it is hardly technically equipped to fulfil the ever changing user requirements on the long term.

Stimulation of flexible use of buildings is a commonly applied strategy that aims at extending the functional lifespan of buildings. The basis for flexibility approaches in building science and practice was established already in the 1960's by Habraken and the SAR (Habraken, 1961). Their approach has inspired designers, architects and engineers ever since (For an overview: Eldonk, Fassbinder, 1990; Kendall, Teicher, 2000; Schneider, Till, 2007; SEV Realisatie, 2007).

1.1 Clarity in definitions: flexibility and adaptability

The many publications on flexibility show that it has become a broad term. Therefore in this research a distinct order is introduced based on earlier publications and new insights to classify the various forms of building flexibility (Gijsbers, 2011). To reach more clarity in definitions and meanings of flexible building, firstly a clear distinction is made between flexibility and adaptability. While flexibility is about how the building is designed for multifunctional use, adaptability is exclusively about the way flexible use can be technically accomplished. In this research, adaptability is defined as: *'the ability of a building part to continuously undergo physical changes to the benefit of flexibility-in-use, with no or only minor effects on other building parts'* (Gijsbers, 2011). Ways of alteration that adaptable building components may undergo are for example movability, removability, upgradability, expandability. Essential features to realize adaptation are among other: demountability, accessibility of connections, modulation and reusability. Furthermore, the configuration of building components in relation to their function and likelihood to be adapted is of vital importance in the technical design. It is advised to implement a layering in the technical building design, where the building parts that will most frequently be adapted can be reached with minor interference to other layers (Brand, 1995, Lichtenberg, 2005, Durmisevic, 2006).

1.2 Lifespan oriented design

When flexible use is made (technically) possible, the chance increases that the building is able to fulfil changing user demands during the lifespan of it. If the principles of adaptability are implemented in the design, technical

changes can be carried out with limited costs and effort, which make refurbishments and conversions also financially worthwhile. Therefore, adaptability is a measure that has a positive effect on the functional, economic and ecologic building lifespan.

1.2.1 User oriented design

The functional quality of a building will eventually be assessed by the end user, simply by occupying and using it. User satisfaction is a first step to a long functional and economic lifespan. Therefore it is rather odd that user oriented design is uncommon in building practice (Lichtenberg, 2005). In industrial design of consumer goods it is much more common to listen to the end user. It either increases selling rates, or it optimizes the design to make the production process more efficient or flexible for future changes (Griffin, Hauser, 1993). The building sector is not yet equipped to inherit this approach because of its organization and procedures. Experiences from the consumer goods industry should however be motivating to turn the building sector into a more demand driven industry.

1.3 User demands versus building technology

To maximize the functional and economic lifespan, building design and technology should be tailored to (future) user demands. The ultimate goal is a sustained balance between supply and demand.

Existing studies typically focus on only one part of the problem. On one side there is the focus on the gathering and classification of user requirements to support strategies for freedom of choice and user participation during the design process. These studies however do not concentrate or elaborate on specific technological solutions or building methods (Min. v. VROM, 2001; Hacquebord, 2003, Hofman, Halman, Ion, 2006; Luft, 2008). On the other side studies focus on technological measures or design choices to improve the possibilities for flexible use (Van der Werf, 1993; Geraedts, 1996; Bijdendijk, 2006) or transformation capacity (Durmisevic, 2006). These studies however do not specifically take into account user preferences or the drivers that cause requirement changes in time.

The studies and methods shown above surely have *raison d'être* to assist in selecting or assessing specific aspects. However, still a methodology is lacking to bridge the gap between user demands and tailored (technical) solutions for flexible building design.

1.4 Demand driven solutions

The technological implementation of adaptable building components in a design is only useful if it proves to effectively contribute to flexibility-in-use. In addition, a positive effect on ecological and economic aspects is aimed at, taking into account all phases in the lifespan of a building (from design to construction, use, maintenance, renovation and demolition). Due to the large number of variables and the many dependencies and uncertainties in the translation of (changing) user requirements into technical solutions, a methodical approach is indispensable, so that a balanced choice can be made for fitting adaptability measures.

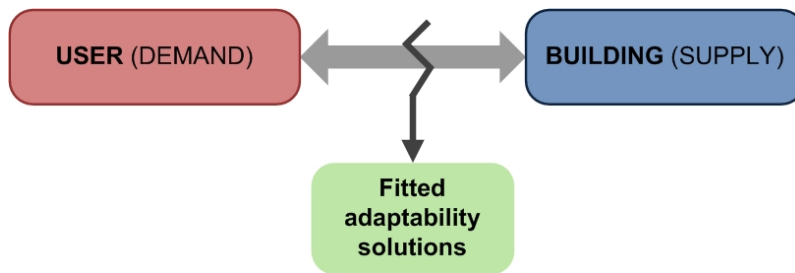


Figure 1. Flexible use and adaptability solutions are the connecting factor between supply (technical quality of buildings) and demand (future user requirements) in the determination of functional quality of buildings in the long term

Since the methodology should be demand driven, it will focus firstly on user requirements. It is seen that the needs expressed in research on user requirements often are rather vague and cannot directly be translated into technical performance indicators (Magrab, 1997; Otto, Wood, 2001). With the purchase of a product, users strive for fulfilment of certain values (Eekels, Poelman, 1995), which are the underlying motivations of human behaviour. Users may not be aware of this. For functional analysis however, it is of indispensable importance. It is the engineers' job to translate user values into concrete functional demands that can serve as boundary conditions for a technical solution. In figure 2 is shown how the relation between user and product is put in a hierarchical flowchart, where the expressed user values, (e.g. comfort, health, image) are on top of the hierarchy. The product in this research is in fact a building, which can be seen as an assembly of numerous products. Therefore, the principle remains the same. The meeting point of supply and demand is where functional demands become concrete enough to be translated into parameters for building design.

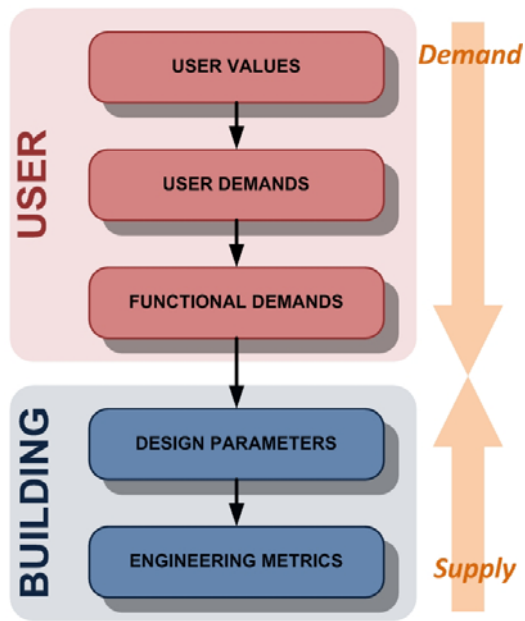


Figure 2. The hierarchical relation between user values and building performance. The meeting point of supply and demand is where functional demands are concrete enough to be translated into design parameters.

It has proved to be difficult for engineers to point out exactly which requirements are the most important ones for users. Developers have the tendency to approach the problem through the identification of technical shortcomings and apply solutions accordingly (Griffin, Hauser, 1993). For an effective translation of functional demands into design parameters for building components, the design tool Quality Function Deployment (QFD) can be applied (Hauser, Clausing, 1988; Griffin, Hauser, 1993; Otto, Wood, 2001).

QFD aids to clarify which product features are most appealing to the user and to what extent a product satisfies user requirements. QFD provides insight into the interrelations of user requirements, product features and product functions. It is necessary to unravel and structure user requirements to fully exploit the opportunities of QFD. Therefore, the following three steps are required (Griffin, Hauser, 1993) regarding user demands: [1] Identify [2] Structure; [3] Prioritize. For building designers, detailed information on user demands and priorities is of great value to develop future-proof building design.

2. COMPARATIVE SELECTION METHOD FOR ADAPTABILITY MEASURES (CSA METHOD)

Currently, it is impossible to give a well-substantiated prediction on the effectiveness of design choices for flexible use and adaptability measures. To fill this niche, the *Comparative Selection method for Adaptability measures (CSA method)* is developed. The method is designed to impartially select and compare a number of adaptability measures based on expected scenarios of future changing user demands.

2.1 Goal of the method

The CSA method is developed to be used by the building design team during the preliminary design stage, just before design decisions become permanent. This makes it possible to still apply changes in the building design. However the CSA method is used by designers, the stakeholders for whom an optimized design is sought can vary (e.g. building users, owner, developer and investor). Each stakeholder may have another goal for using the method, for example long term effects such as an increase of functional, economical or ecological lifespan, or short term effects like cost reduction or shortening of construction time.

In the CSA method firstly a number of effective adaptability measures are selected and developed based on a scenario of (future) user requirements. Subsequently, the degree of efficiency of the chosen measures is assessed by quantifying:

- the required effort for an adaptation [*man-hour x nuisance*];
- costs [€];
- environmental impact / environmental costs [€].

Each adaptability measure will score differently on these three sub scores, which will all be evaluated individually, and not in a total score. Firstly, since the units are not compatible, secondly because different stakeholders have different priorities. However, a differentiation will be made in this quantification by distinguishing the (initial) single effects from the more often occurring effects that come with an adaptation. When the full lifespan of a building is considered, this distinction is essential to ensure a well-founded decision for the most appropriate adaptability measure.

The uniqueness of the CSA method is that a best fit is sought from both the user point of view and the effects on/of the applied building technology. The CSA method makes it possible to derive an optimized solution from the wide array of solutions in a structured way. This may lead to less obvious and only minor measures of adaptability in the design, however, with significant positive results for users.

2.2 Lay out and operation

The CSA method will strictly process functional demands arising from (expected) changes in the user situation and user demands. This restriction results in the assessment of flexible building performance exclusively.

A transparent and segmented approach is indispensable to maintain overview of the choices made, because of the multiplicity of relevant aspects and interrelations. This approach is founded on the relations between user and building, as seen in figure 2. Connections between interrelated design aspects will be established step by step. A sharp distinction is made between the domain of user demands and the domain of building technology. The switch from one domain to another, where functional demands are translated into design parameters, is confined to a single step halfway the process.

The process model of the CSA method is shown in figure 3, wherein the user-building relation of figure 2 is implemented. The sequence of the steps to take is numbered. The upper part of the model (steps 1-3, in red) can be described as the user domain. This is where a scenario of changes in a certain user situation will be translated into user demands and functional demands. The middle section (steps 4-7, in blue) represents the domain of the building technology. This is where fitting adaptability measures are developed and tested for compatibility with the (current) technical system design. The lower part (steps 8-10, in green) is where the developed measures will be quantified and compared and where the final solution is selected.

A short description of the different steps in the CSA method

USER REQUIREMENTS

1. Scenario description: change in user situation;
2. Identification and prioritization of functional demands;
3. Definition of required flexibility-in-use;

BUILDING TECHNOLOGY

4. Identification of building components in the preliminary design and analysis of the technical and functional interrelations;
5. Identification of building parts that are of great influence on the relevant functional demands using Quality Function Deployment;
6. Selection of an appropriate adaptability measure for the identified building parts of step 5, followed by technical concepts for suitable solutions;
7. Determination of the building technical cohesion and interrelations between the solution variants (of step 6) and the building parts in the

preliminary design (step 4) using the Coupling Index; Definition of construction plan for each adaptability solution;

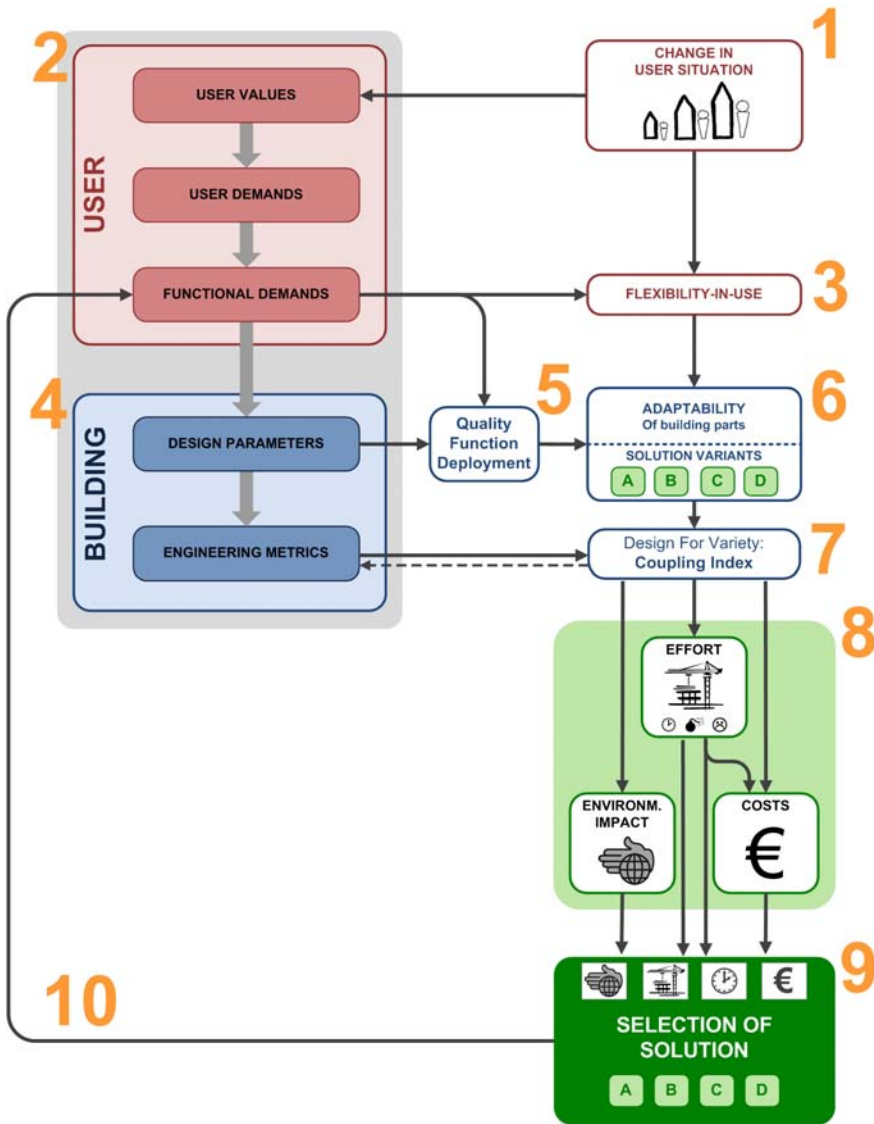


Figure 3. Model of the CSA method

QUANTIFICATION, COMPARISON AND SELECTION

8. Quantification of construction effort, costs and environmental costs for each adaptability solution;

9. Comparison of the efficiency of the adaptability solutions based on the scores in step 8; Selection of most appropriate solution based on stakeholders preferences;
10. Verification of the suitability of the selected adaptability measure to the user demands from step 2.

3. ELABORATION AND RESULTS: A CASE STUDY

In paragraph 2 the steps in the CSA method are only roughly defined. In the research, three case studies are executed to verify if the CSA method functions properly. One of these cases is presented here to give insight into the way the CSA method functions and a view into the results it will deliver the building designer when using it.

3.1 Case Study: changes in the spatial plan

This case study deals with the design of a residential multi-storey building. The owner is a housing corporation that wishes to ease changes in the spatial plan to be able to quickly and economically transform the apartment to fulfil spatial demands of future tenants. In the left of figure 4 the basic floor plan is shown.

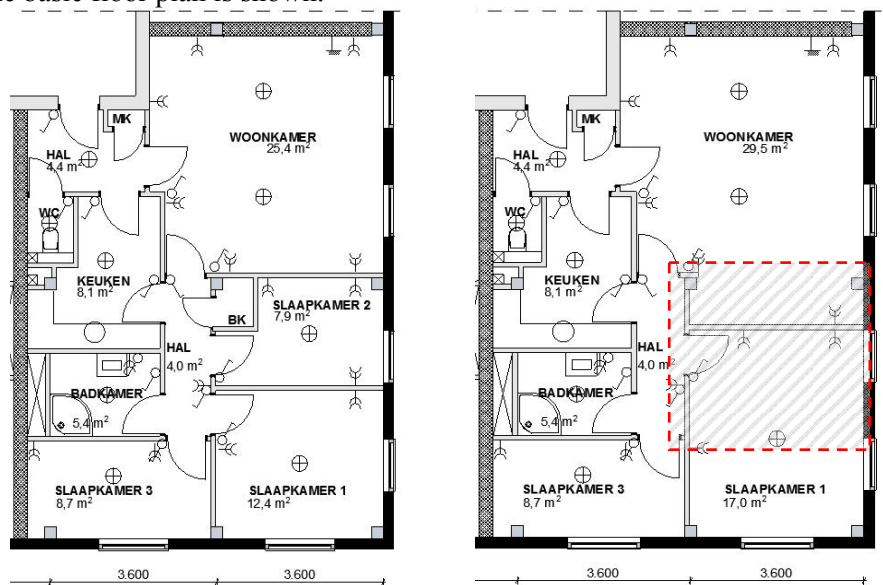


Figure 4. Case study floor plan; on the left the basic floor plan, on the right the floor plan as suggested in the scenario of change. The shaded part is where the adaptation is required.

3.1.1 Step 1: Scenario of change

The apartment has three bedrooms and a small living room and is inhabited by a family with two children. In the new situation an elderly couple wants a larger living room and has only need for one bedroom and a guest room.

The principal function of the spaces does not change, but the spatial layout will. It is expected that such changes will appear each five years (Gijsbers, 2011). In figure 4 is shown how the new layout is implemented. One bedroom is split to enlarge both the main bedroom and the living room. Further, a cupboard will be removed. The result is that a number of building parts such as doors, walls and electrical wiring need to be adapted. A total of 22 m² inner wall needs to be removed and 12 m² will be placed back

3.1.2 Step 2 to 5: Functional demands related to building parts

Regarding the scenario of change, a number of relevant functional demands is selected from a standardized list (Gijsbers, 2011). Because these functional demands are all interrelated, and referring eventually all back to a limited set of user values, it is necessary to prioritize them for this scenario. For this purpose a rank order matrix will be composed in which the demands will be evaluated in pairs. The aspect of interrelation and influence on each others performance quality is also taken into account, using a scoring procedure slightly adjusted from Benes and Brokelman (1986):

- *Demand A scores 3 points when it only can be fulfilled if demand B is fulfilled. B is rewarded 2 points;*
- *Demand A scores 4 points when demand B enhances the possibilities of fulfilling demand A. B is rewarded 1 point;*
- *Demand A scores 5 points if it is not influenced by B. B is rewarded no points.*

In table 1 is shown how the relevant functional demands are prioritized.

The results show that the functional demands related to spatial aspects have the highest priority in fulfilling the user demands in this scenario. This result also indicates that the type of flexibility-in-use that is needed in this scenario can be defined in step 3 as 'partition flexibility' (Gijsbers, 2011).

In step 4 the technical assembly of building parts in the preliminary design is analysed. The current building design is rather conventional, and is supported by concrete columns and a hollow-core beam floor. The partition walls are made of 100 mm sand-lime blocks. Pipes for water distribution and air ducts are embedded in the floor. Electrical wiring is distributed from the main lighting point, also embedding in the flooring elements.

Table 1. Prioritization of relevant functional demands in step 2

Functional demands	Position of space determining elements	number of rooms	room dimensions	shape of room	distribution of lighting points	Electricity points per m2	Total score	Constant (=n/2)	Totalscore + Constant
Position of space determining elements	2	4	3	5	5	19	3	22	
Number of rooms	3	2	4	5	5	19	3	22	
Room dimensions	1	3	4	5	5	18	3	21	
Shape of room	2	1	1	3	3	10	3	13	
Distribution of lighting points	0	0	0	2	4	6	3	9	
Electricity points per m2	0	0	0	2	1	3	3	6	
(n=6)						75		93	

Table 2. QFD matrix, showing the relative importance of relevant building parts (step 5)

Functional demands	Building parts (N1 Sfb)		Structure		Envelope		Services		Infill	
	weighting (step 2)	relative weight (step 2)	Structural floors	Primary bearing structure	Non-bearing outer walls	Outer wall openings	Electrical wiring	Lighting	Non-bearing inner walls	Inner wall openings
Position of space determining elements	22	0.24	O	▲	O				⊖	O
Number of rooms	22	0.24							⊖	O
Room dimensions	21	0.23	▲	▲		▲	▲		⊖	▲
Shape of room	13	0.14	▲	▲	O		▲		⊖	
Distribution of lighting points	9	0.10	⊖			O	⊖		O	
Electricity points per m2	6	0.06	⊖				⊖	O	⊖	
Relative importance			1.5	1.1	0.6	1.4	0.8	1.4	8.4	1.6

- ⊖ = 9; Strong relation between functional demand and building part
- O = 3; Medium strong relation between functional demand and building part
- ▲ = 1; Weak relation between functional demand and building part

In Step 5 the information of step 2 and 4 will be combined to bridge the gap between the user domain and the building technology, using the method of Quality Function Deployment (QFD, see 1.4). QFD make it possible to unravel which building parts are most appropriate to be adaptable and most effectively fulfil the new set of user demands.

Table 2 shows the QFD matrix, in which the results from step 2 are used as a weighting factor. Only the relevant building parts, classified according to the CI/Sfb coding (BNA, 2005), are shown in this overview. Table 2 indicates that the non-bearing inner walls are most likely to undergo an adaptation (relative importance of 8.4). In addition special attention will be given to the structural components, inner and outer wall openings and lighting facilities.

3.1.3 Step 6 & 7: Adaptability solutions and building technical cohesion

The removal and replacement of partitioning walls, with inclusion of wall openings and electricity points, seems to be an appropriate solution. Three concept solutions are developed, of which the first two are already on the market and the third is a potentially to be developed product.

Solution 1: Sand-lime blocks of 100mm thickness, finished with plastering. This is not an actual adaptable solution but functions as a reference for conventional construction.

Solution 2: A demountable partitioning system known as Spanell (see figure 5). These walls consist of hollow, storey high lightweight panels manufactured with a core of folded cardboard and MDF finishing.



Figure 5. Spanell partitioning wall system (www.spanell.nl)

Solution 3: A potentially to be developed wall block system consisting of rectangular blocks (400x300 mm) made out of a recycled

wood/paper mixture, bonded by a inflammable biological resin. The blocks are fixated using removable adhesive strips and are fully reusable and recyclable. Chases and holes can be easily cut out and filled again with a mixture of the base material.

In step 7 of the CSA method, the concept solutions will be implemented in the current technological system and screened on the degree of cohesiveness with the other building parts. For this purpose a tool called the Coupling Index (Martin, Ishii, 2002) will be used, which makes it possible to quantify the level of technical coupling of product parts. The level of coupling depends highly on the choice of building products and their connections. In general, less coupling means less effort to perform adaptations in practice. Using the Coupling Index (CI) method shows the designer whether the choice for a certain building system or product does interfere with the degree of flexible use that an adaptability measure enables. The principles and output of the CI of this case study (Gijsbers, 2011) are too extensive to include, therefore only a summary is included here.

The results show that the CI is the lowest for solution 2 and 3 (both 31), while the solution 1 scores 41. Adapting the sand-lime wall to the new situation will prove to require to largest effort as expected. The advantage of the wall elements of solution 2 is the construction speed, The blocks of solution 3 stand out for their freedom in design. The CI also indicates a disadvantage because of the chosen floor type. Wiring needs to be replaced but is currently partly embedded in the concrete flooring. The CI shows that the choice for a hollow floor including freely dividable installation space is preferable to ease adaptations of wiring and ducts. The CI for the flooring related to the wiring will then be lowered from 15 to 3.

In step 7 also the construction actions needed to apply each solution are specified in a construction plan

3.1.4 Step 8: Quantification of efficiency

In the last part of the CSA method the three solutions will be quantified on construction effort, costs and environmental costs. This quantification will be based on the actions in the construction plans from step 7. Each action (such as the removal of walls, levelling of finishing, etc.) results in the use of a certain amount of materials, a number of needed man-hours and the use of equipment. These quantifiable aspects are the basis of the comparison in effort, costs and environmental costs.

Construction effort can be expressed in the number of man-hours needed for the adaptation. For users and also other stakeholders it is however also very important in what time span the adaptation can be finished and what the

construction actions imply in terms of nuisance. Therefore a study has been executed to be able to quantify the degree of nuisance of each action, based on user research (Gijsbers, 2011). To come to a quantification of construction effort, the duration of each action is multiplied by a nuisance score.

Based on the detailed construction actions, for each solution both the initial costs and the costs of an adaptation are quantified, using data from online cost databases (www.bouwkosten.nl / www.bouwkosten-online.nl, price level May 2010).

Similar to the cost quantification, also the environmental costs are quantified, both for initial costs and costs of a single adaptation. Environmental costs can be defined as the costs to compensate for the environmental damage of the actions. Data of the environmental impact of materials and products is used from NIBE (Haas, et al. 2007-2009). In these calculations also the expected lifespan of materials is taken into account. A total overview of all the detailed scores can be found in Gijsbers (2011).

3.2 Results: comparison, selection and verification (step 9 & 10)

The results from step 8 are shown in figure 6. The selection for the most efficient adaptability solution will be made here, to increase the possibilities for flexible use of the building.

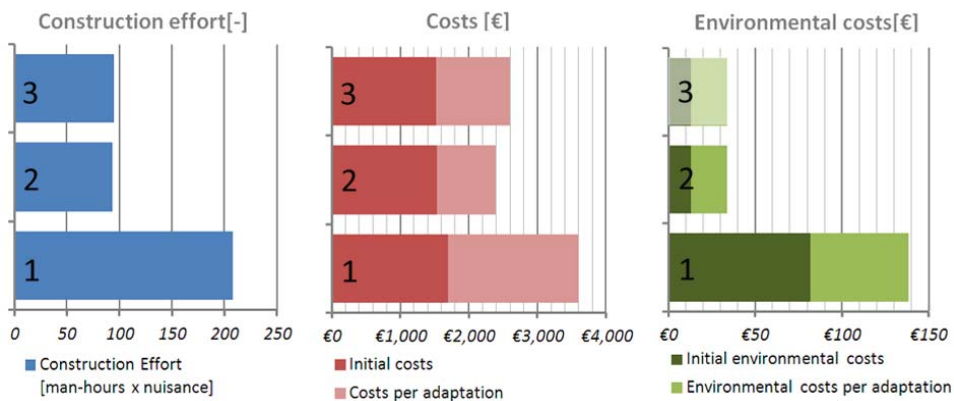


Figure 6. Results of the quantification of the efficiency of the adaptability solutions in the CSA method (1 = sand-lime block, 2 = panel system, 3 = block system)

Figure 6 shows that reference solution 1, using sand-lime blocks, proves to be the least efficient as expected, even based on initial costs. Despite relatively low cost materials, it seems that the number of man-hours needed

results in higher costs. Further, adaptation costs are high because no materials can be reused.

Solution 2, the light weight wall panels, proves to be the most cost effective, both initially and in the case of an adaptation, due to the high degree of reusability and the assembly speed. Environmentally, solution 3 scores best, however this product is not yet developed and therefore the scores might be too positive. Based on this assessment, solution 2 is the most efficient overall.

A verification in step 10 regarding the functional demands of step 2 shows that solution 2 will prove to be worthwhile according to the given requirements, and will be definitively chosen in combination with a hollow floor system (see step 7). To ensure the choice of the most efficient adaptable floor system, a new CSA session can be initiated.

4. CONCLUSIONS & DISCUSSION

From the case studies it became clear that the sequence of steps in the CSA method is logic, while the segmented approach provides a well-organized and verifiable selection process. Future research might focus on a less intense application process of the CSA method, for example by automation of certain modules. Further, the CSA method might be tested alongside an real life transformation project to confirm the reliability of the output.

In current building the initial phase is mostly decisive for decision making. However, case studies show that solutions with a high degree of adaptability are the most efficient for the long term, because adaptations might occur several times during the lifespan of a building.

The CSA method is a tool developed for the designer that can bridge the gap between (future) user needs and the functional performance of the building over time. A lasting balance between demanded and supplied building performance increases the chance of effectively extending the functional lifespan of the building. The trend in the contemporary building industry is that a long term vision, concerning the whole lifespan of a building, is becoming increasingly important. This awareness creates space and legitimacy for methods such as the CSA method.

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