The interaction between sustainability and quality in building – systemic approach and case study buildings

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Summary

Today sustainability gains a growing acceptance in the building sector and is seen as a trendsetting part for buildings. On the other hand building processes up to date are still only evaluated through price competition and marked by the handling of failures and insufficiencies in the construction and erection of buildings. Positive effects of better building quality are not identified widely.
Therefore this paper examines the interaction and impacts between aspects of sustainability and the criteria of quality in buildings. The analysis is carried out through a sensitivity model and evaluation of results through case studies. Cybernetic modelling is introduced to highlight interactions and their influences on each other.

Firstly the elastic terms of quality in the building context and sustainability are discussed. A sensitivity analysis is made to show the interactions of the different aspects on each other and to work out the important aspects.
Therefore twenty variables are deduced from the firm establishment of the terms, which matter most for this topic. They constitute the set of variables for a sensitivity analysis from Vester. With the sensitivity analysis an impact matrix and an effect system are elaborated to emphasise the critical variables for the processes and variables which matter most.
On these results and for closer inspection of the correlations, sustainable buildings, which are recognised as exemplary representatives, are examined to identify the underlying principals. Processes behind planning and erection of each building were observed critically. The results of the building analysis are then contrasted with the results of the (previous) sensitivity analysis.

An effect system for the creation of sustainable buildings is developed as a cybernetic model. In this model it is outlined which prerequisites are required to develop sustainable buildings. Certain aspects, which generate high impact for the whole system, were emphasised and starting points for improvements elaborated.
True sustainable buildings can only evolve from stronger interactions between the separate disciplines. The first step is to understand the interdependencies and interactions between the variables and then to develop the main factors so that the system changes with the lowest input. In reaching sustainable buildings, design with its complex dependencies has to regain a central position. Client behaviour as well as quality of construction work on site are also fundamental. Motivation of planners and builders and communication between them is highly important.
More training for all parts of the building sector in these issues is necessary. A honest culture of teamwork for the best result rather than only the economic success is fundamental.

Keywords: sustainability; quality in buildings; sensitivity analysis; interaction

1. Introduction

In recent years sustainability has gained growing acceptance in the building sector and is seen as a trendsetting part of buildings. The certification of sustainability with systems like DGNB / BNB, bream etc. have introduced further requirements to building processes. Various guidelines have been developed for this gain. Newly developed calculation tools (e.g. for LCA / LCC calculation) are being used more and more.
On the other hand building processes up until now have still only been evaluated through differences in price and marked by the handling of failures and insufficiencies in the construction and erection of buildings.
Communication and exchange of data is often insufficient. Clients often only look at construction costs without concern for later operational costs.
Positive effects of better quality of buildings are not widely identified or at least not realised consistently with early quality assurance systems. Extra money is spent on sustainability criteria but not invested in obvious quality assurance.
This paper examines the interaction and impact between aspects of sustainability and the quality in buildings. Through this the main influencing factors of the building process on sustainability goals is examined through a sensitivity model and their influence is visualized by analysis of different realised buildings.

2. Main issues and their definition

Firstly the elastic terms of quality in the building context and sustainability, as well as complex interactions are discussed. Then a sensitivity analysis is produced to work out the most important aspects and to show their interaction with each other.

2.1 Quality in buildings

The term quality has a broad meaning. In the ISO standard ISO 9001 quality is defined as a “degree to which a set of inherent characteristics fulfils requirements.”[1] To bring it into practice quality for the building sector can be defined as adherence to agreed properties. According to Trost [2] quality in buildings can be divided into concrete, abstract and indirect characteristics. Technical issues and their realisation belong to the first category, aesthetics and image of the building to the abstract category and indirect issues are communication and cooperation in building sector.
Main objective for quality in buildings is the adherence of the agreed qualities. If the quality is not complied with, we speak of faults, defects / insufficiencies and damages. To the left, figure 1 shows the percentage of faults and defects in building context and how many of these end in damages [3]. To the right, figure 1 shows the reasons for such faults [4].

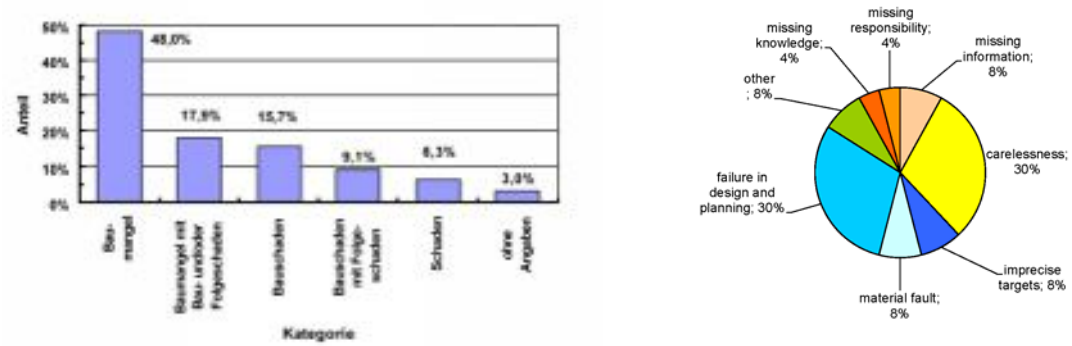

Fig. 1: categories of defects [3] and faults / defects in building sector according to [4]

By looking at these figures the conclusion can be drawn that a high percentage of faults could be avoided by accurate planning and in improvements in communication and knowledge. Knowledge here applies mainly on having sufficient information and explicit dedicated responsibilities.

2.2 Sustainability

The term of sustainability is used according to the sustainability triangular and the definitions underlying the actual certification systems of BNB and DGNB [5]. Individual criteria are included in the considerations on assessable factors for sustainability issues in the building sector. As shown in figure 2 sustainability issues are divided in columns and then subdivided in single issues.

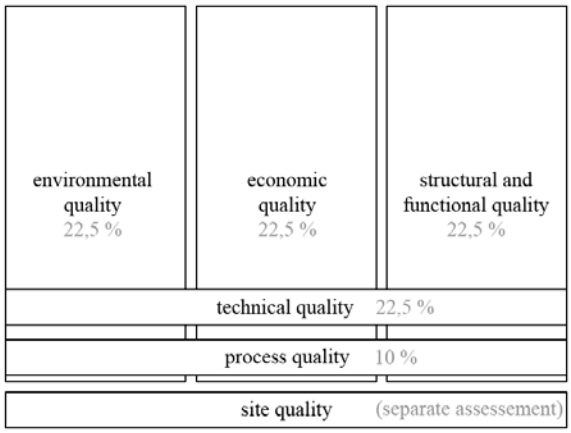

Fig. 2: subdivision of sustainability issues in compliance with sustainability certification schemes

2.3 Complex interactions – cybernetic

Interactions and dependencies have become more complex due to strong division of work, due to specialisation and also advanced communication systems. Therefore problems can often not be solved immediately and without further adjustments further down the line. The solving of one problem often generates problems with other issues. Frequently cause and effects are not easily connected. Complex systems and interactions are dynamic systems. The characteristics for these systems are that even small faults can have a major influence on the whole system.
The building sector is marked by the involvement of many participants, very diverse objectives and a new approach for every project.
In that context cybernetics is introduced to allow visualisation and handling of complex issues and interactions. Cybernetics is an interdisciplinary science to regulate and control open loop projects. It aims at identification of nature and control of complex systems. The systemic approach is introduced with this.

3. Interaction between sustainability and quality in building

To study the interactions between sustainability and quality in buildings twenty variables are deduced from the firm establishment of the terms explained above. Systematic approach is introduced to emphasise on changes of interactions. They constitute the set of variables for a sensitivity analysis from Vester. The most effective variables are filtered trough the impact matrix and effect system. Simulation of individual parts of the system help to visualize the overall effect of changes to the system. Based on these results, sustainable buildings, which are recognised as exemplary, are examined in order to identify the underlying principals and their correlation. The results of the building analysis are then matched with the results of the sensitivity analysis. An effect system for the creation of sustainable buildings is then developed as a cybernetic model.

3.1 Sensitivity model for interactions (according to Vester)

Frederic Vester developed a methodical tool for network thinking [6]. With this tool it is possible to recognise, control and self-regulate networked processes with minimal input. The individual parts of the system depend in many ways on each other and have many direct or indirect interactions. Sensitivity modelling, according to Vester’s model, shows a systematic approach to the analysis of

complex interactions. It also allows to show correlations and reactions in a transparent way. This systemic analysis is basis for the sensitivity analysis according to Vester and results in a cybernetic modelling system which is applicable to all areas of interest.
For an exact representation, three preconditions have to be complied with: right choice of the variables, definition of interactions between variables, linking variables. [6]

3.1.1 Variables and sensitivity analysis

Starting point for the sensitivity model are the variables. Variables are adjustable measurements - points in the system – from which the cybernetic of the system is identified. These variables were defined by carving out core competences for the individual issues and condensing the set to gain a manageable set of variables.
The variables consist of the components of *sustainability*, *quality in buildings* and other factors, which are important for the model. The variables are shown in figure 3. A criteria matrix in the Vester system checks the completeness of the variables. This ensures that no crucial issue is missing.

Impact categories

sustainability	**quality in buildings**	**others**
1 hight of impacts on environment	11 implementation of integral planning	20 legal ajustments
2 hight of material consumtion	12 decisivness of client	
3 hight of construction cost	13 quality control during building process	
4 hight of operational cost	14 intensity of motivation	
5 hight of end-of-life cost	15 intensity of competition	
6 durability	16 communication	
7 improvement of maintenance	17 performance of technical aspects	
8 health of occupants	18 holistic approach to design	
9 comfort of occupants	19 holistic approach to functionality	
10 consumer satisfaction		

Fig.3: variables for sensitivity analysis

3.1.2 Influence matrix

Dependencies of the variables were defined and interferences estimated with the use of the influence matrix. Each variable was examined on its conversion in regard to all the other variables. Dependencies were defined by literature studies, previous knowledge and experience in sustainability certification and quality management certification.

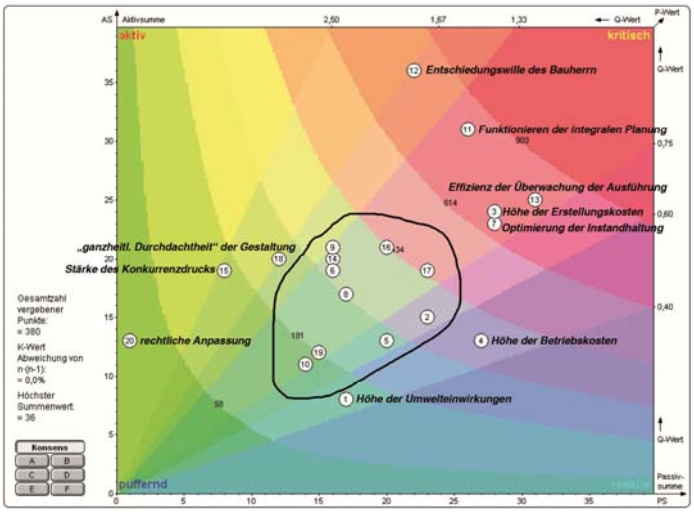

Fig. 4: influence matrix

Figure 4 shows the influence matrix with the parameters and the results. The picture shows the variables very clearly which have most effect on the system. Variables in the red area mark a high influence on others with minimal change. These are: *decisiveness of client, implementation of integral planning, quality control during building process, amount of construction cost and improvement of maintenance*. They are the most critical variables.
Variables which influence the system sparsely but steadily are *holistic approach to design and intensity of competition*. They have a slow but steady influence. Variables in the circle in the centre of figure 3 reach an equilibrium. This means that whenever changes in one variable occur all the actions and reactions of the involved system help to stabilise the system. Changes in these variables cannot influence the system in a big way. But these variables are necessary to keep the system in an equilibrium.
The influence matrix clearly shows that the above mentioned variables within the red area are of major importance to the system. They need to be a focal point in the planning and building process in order to influence sustainability and quality of buildings positively. Therefore main focus in the work was dedicated to these issues.

3.1.3 Effect system

The effect system shows the chain and their reactions. This makes the interactions visible and allows further simulation on scenarios. The effect system only shows real effects and distinguishes between rising or descending effects on the variable included. In that context a dashed line means that a rising of a starting variable results in a lowering of resulting variable. The normal line means that a change in the starting variable also results change of resulting variable in same direction. In general this system shows less interconnections than the influence matrix. Close interactions with reaction coupling can be seen e.g. for variable "*decisiveness of client*" and "*implementation of integral planning*".

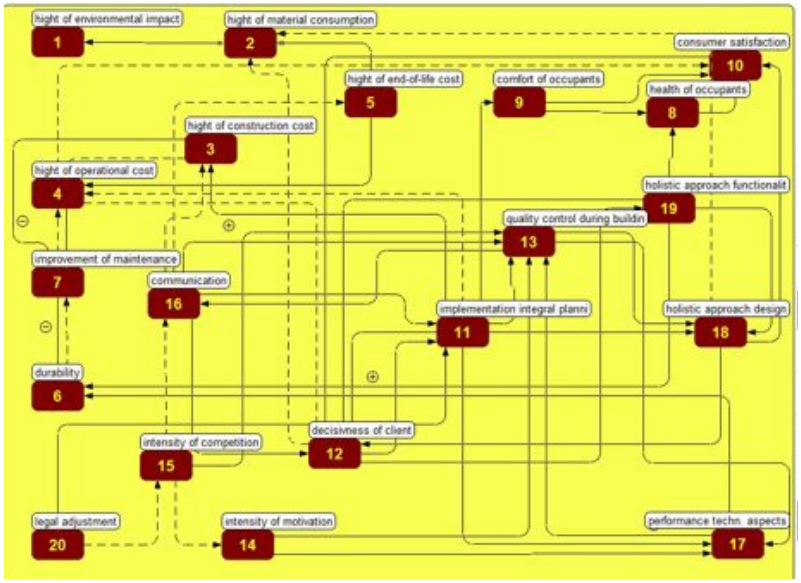

Fig. 5: effect system of interactions between sustainability and quality in buildings

3.2 Comparison of case study buildings

The results of the sensitivity analysis were contrasted with the results of building analysis. Four buildings, publicly approved as sustainable and awarded various awards for sustainable building, were analysed. Buildings serve different uses and are built from diverse materials. For all of them the underlying processes and their interactions where analysed. Analysis was done for the areas of:

- design and connection to site and localities
- planning and building processes
- influence on energy concept
- materiality and processes behind the choices
- cost, maintenance, use of building

3.2.1 Case study buildings

Each building was analysed through plans and interviews with planners. Main focus were: surrounding, design quality and the underlying process to come to these results; planning and building phase including obstacles to reach the goals; trace decision-making process; timeframe for introduction of energetic issues in planning process, material choice, cost / maintenance; user comfort.
For each project a flow-chart was developed to show dependencies of different issues. In figure 6 the chosen case study projects are shown.Analysis of buildings are shown in [7].

Case studies are:

- Hotel in an apple garden, Hohenbercha / Germany (Deppisch Architekten)
- Patchworkhouse (house for two families, Müllheim / Germany (Pfeifer Roser Kuhn

Architekten)
- Multi story dwelling, Zurich / Switzerland (Maier Hess Architekten)
- Community centre, Ludesch / Austria (Hermann Kaufmann ZT GmbH)

Fig. 6: chosen case study buildings (from left to right): Hotel Hohenbercha, Patchworkhouse, Multi-story dwelling Zurich, community centre Ludesch

3.2.2 Results of comparison

The analysis of the processes behind building development shows, that the client played a major role in defining reachable goals at the beginning of the project and helped to achieve them by supporting quality assurance in the construction process. In each project integral planning was implemented at the beginning of the projects. The energetic and technical concepts were developed right at the start with minimal extra impact, adjusted during the process and reflected on construction, cost and maintenance issues. Material choice and health issues for the users were a major task. All decisions had to be justified in regard to cost, gains and maintenance.
An effect system of all interactions was generated to highlight most important variables for case studies.

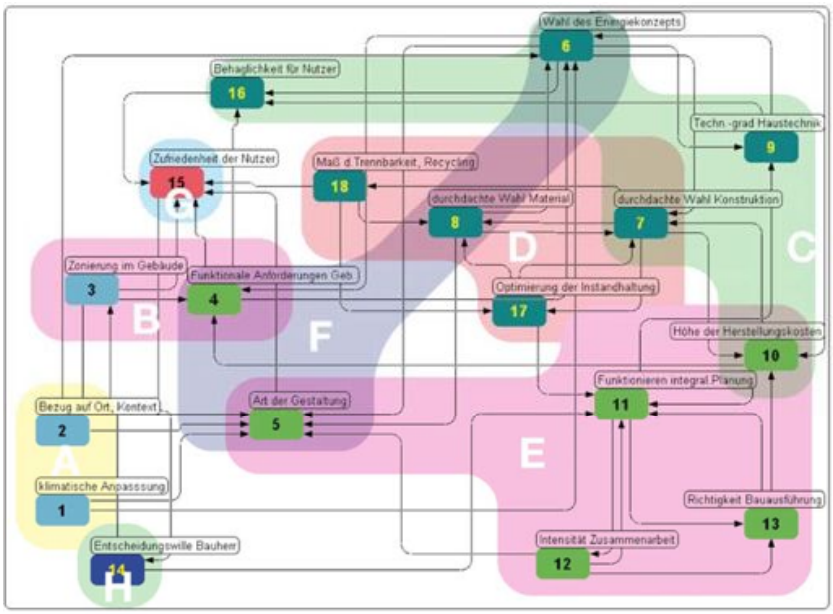

Fig. 7: effect system of interactions between sustainability and quality in buildings on case studies

In addition to important indicators in figure 5 results showed that the site and site specific issues model a different framework for each project. Complex interactions between the issues of energy concept, materiality and quality assurance, but also between design, client, integral planning are visualized.

4. Results

Theoretical effect system and effect system according to case studies were combined to an effect system for the creation of sustainable buildings was developed as a cybernetic model. The cybernetic model indicated which prerequisites are required to develop sustainable buildings.
Certain aspects, which generate high impact for the whole system, can be highlighted and starting points for improvements elaborated.
In figure 8 the interactions of the individual variables are shown. The main issues, which have a major effect on the system of interactions of sustainability and quality in buildings can be outlined. Keeping these in mind helps to strengthen results for sustainable building.
Main issues are:

Client:
The client has an important role to play at the beginning of the project with the definition of the goals for the different aspects and keeps to them throughout the whole project. Clients need to realise about the consequences of changes in goals during the planning process. Also it is important to evaluate quality on site continually in the construction phase, with consistent reparation of mistakes.

integral planning:
An integral planning team at the early stages of the project means an inclusion of all necessary specialist input right from the beginning. Questions which might arise on specialist issues (e.g. fire safety, energetic standard, use of renewable energies) can be properly integrated considering its interactions on other parts. The project coordinator needs to be able to integrate all aspects and has to be mindful of the independence of each other.

construction quality:
Improving the quality of construction can be influenced by precise communication and good motivation of employees on all levels. Constructive cooperation on site has a positive influence on the building. Extensive quality assurance on site produces extra costs but helps to integrate a level

of quality for the building. Therefore the extra cost for an external quality control is invested wisely, as it reduces damage to the building in the life cycle. Not only the actual construction costs should be given attention to in tendering. Also later maintenance and replacement should be included.

life cycle cost:
Introducing life cycle analysis on ecological and economic issues in an early planning stage helps to reach the most sustainable and economically useful solution. The earlier this happens the more interdependencies can be tackled and the fewer extra costs have to be invested in later.

design:
Design is highly dependent on the integration and performance of the interactions between the different variables. In all examined case studies, sustainable architecture is interwoven with a specific site and realised through the integration of an energy concept from design phase to detailing and material choices.

communication:
Knowledge about interactions and close relationships are the basis for explicit communication. Besides this, all parties need to be eagerly motivated in order to achieve the best results to implement sustainable buildings. Sustainability certification can help to integrate the different aspects although design is not clearly quantifiable and sustainable design is not dependent on certification.

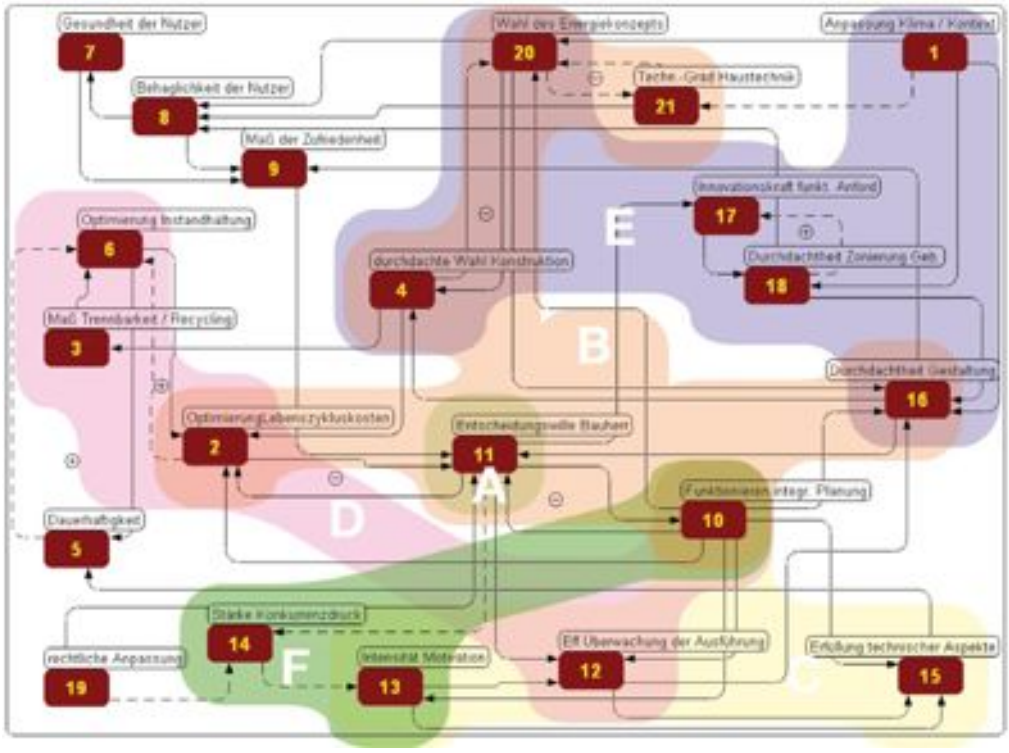

Fig. 8: cybernetic model of interactions – main focus areas

5. Conclusion

Through the cybernetic model many interactions between sustainability and quality in buildings were shown. True sustainable buildings can only evolve from stronger interactions between the separate disciplines. The first step is to understand the interdependencies and interactions between the variables and then to develop the main factors so that the system changes with the lowest input. In order to achieve sustainable buildings, design with its complex dependencies has to regain a central position in planning. The importance of client behaviour as well as quality of

construction work on site needs to come back into focus. Motivation of planners and builders and their communication is highly important.
More training for all parts of the building sector in these issues is necessary. A honest culture of teamwork for the best result rather than only the economic success is fundamental. All the shown issues help to achieve sustainable buildings through manageable processes.

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