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Interdependency of LCCA and LCA in the assessment of buildings

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ABSTRACT: Sustainability aspects in the assessment of buildings using the life cycle approach have become more and more common. Due to the rise of fossil fuels prices and the increasing importance of global warming, economic and environmental assessments also gain more and more attention.
This paper gives an overview of the role of environmental and economic performance in current building certification systems. Furthermore it focuses on the interdependency of life cycle cost analysis (LCCA) and life cycle assessment (LCA) in the assessment of buildings in the case of ÖGNI/DGNB building certification system. Based on a case study in Graz, the results of LCCA and LCA are presented. The main part of the paper draws the attention to a new method to improve building performance behind a systematic approach. In summary, this paper provides an overview of new methods based on systems thinking in the assessment of buildings.

1 INTRODUCTION

The advancement of building techniques in the last decades has greatly increased the complexity in the construction sector. Sustainable buildings - according to the upcoming CEN/TC 350 standards - should include environmental, social and economic as well as functional and technical aspects simultaneously. Current building certification systems try to cover these requirements in different criteria sets separated in qualitative and quantitative assessment. The latter are often pictured in life cycle assessments (LCA) or life cycle cost assessments (LCCA). At current decisions in view of improving building performance are mainly based on initial costs. Due to the increasing focus on systems thinking, LCCA and LCA are becoming more and more important, as published in (Hunkeler D., Lichtenvort. K., Rebitzer G. 2008), (Vester F. 2008), (Cole R. J. 2011). Further more due to the increasing number of building certification systems the consideration of social aspects in course of building optimizations is from high importance.

1.1 *State of the Art*

With regard to building certification most investors strive simultaneously for high certification results and optimized initial costs simultaneously.

Up until now there is great number of various methods for the assessment of building performance and improvements respectively. From the Authors point of view these methods are mainly suitable for the assessment of individual qualities within the building performance assessment, i.e. environmental or economic performance, but the role of these single aspects of performance in the overall assessment of buildings often remain disregarded.

Complete criteria sets are indispensable for the assessment of economic effort and measurable benefits (i.e. DGNB/ÖGNI). The methods of influence and network analysis allow investigations of cause and effect and their relation within a complete criteria set e.g. systems thinking (Vester F. 2008). Several approaches based on systems thinking to improve building performance are described in (Girmscheid G., et.al 2010), (Thomas E. and Köhler A. 2011), (Schneider C. 2011). Investigations of both qualitative and quantitative assessments, based on a systems approach, could not be found in other studies.

In the planning process, when a choice must be made between different design options, it is necessary to base the decisions on assessments which include the interdependency of separate assessment criteria.

This can be managed by using systems thinking instead of reductive thinking

(see Figure 1, acc. to (Cole R. J. 2011)).

This paper describes a new approach for an improvement of building performance considering the qualitative interdependency between the assessment criteria as well as quantitative economic and environmental performances with the use of LCCA and LCA are described. The assessment of different design options is based on the identification of their technical feasibility (i.e increased thermal insulation, external sun protection, new ventilation system, improved glazing, choice of energy sources, etc.). Several de-

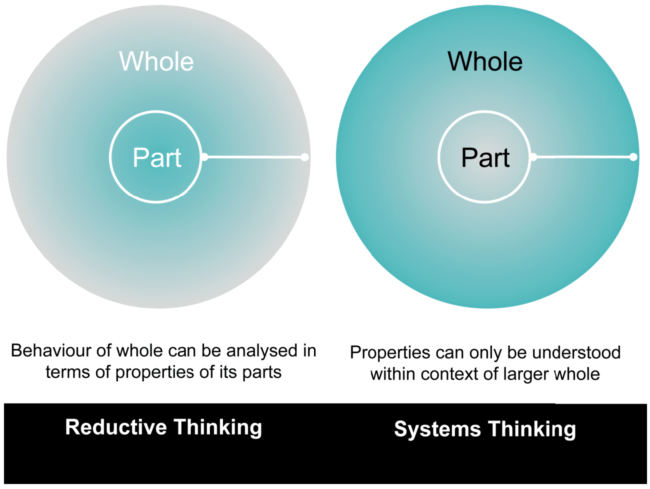

Figure 1: Reductive vs. systems thinking.

sign options have complex effects (interdependencies) within the building assessment. This paper gives an overview of the new methodology, whereas comprehensive investigations are described in (Kreiner H. 2012).

2 SUSTAINABILITY ASSESSMENT OF BUILDINGS

Various building certification systems were placed on the market during the last two decades, reflecting an increasing demand for such labels to endorse green building (Henzelmann T., et.al 2010). The best-known of these systems include LEED[1], BREEAM[2] and DGNB[3]. In Austria, three national certification systems currently exist: DGNB/ÖGNI[4], klima:aktiv[5] and TQ-B[6](ÖGNB).

For the present case study the comparison between LEED, BREEAM and DGNB resp. ÖGNI published in (Wallbaum H. and Hardziewski R. 2011) has been extended with TQ-B and klima:aktiv building certification system to make a desicion which building certification should be use for the current case study. The comparison of the different certification systems has shown that the combination of a quite wide consideration of social, functional and technical performance as well as a comprehensive calculation algorithm for the consideration of life cycle cost and environmental quality is currently only available in DGNB/ÖGNI certification system.

2.1 *Life cycle analysis (LCA)*

Environmental assessment methods have been developed since the early 1990s. The International Organisation for Standardization (ISO), prepared the first standards to address specific issues and aspects of sustainability relevant to building and civil engineering ISO 21930 (ISO 2007). Already these standards were founded on the life cycle assessment methodology (LCA) - ISO 14040 (ISO 2006). On the basis of the ISO work, the European Committee for Standardization (CEN/TC 350) is currently working on a set of standards to harmonize the methodology for a sustainability assessment of buildings using the life cycle approach. According to these upcoming European Standards ÖNORM EN 15643-1 (CEN 2011a) the assessment of the environmental performance of buildings is based on LCA expressed with quantitative categories i.e. environmental indicators according to ÖNORM EN 15643-2 (CEN 2011b)).

The building certification system DGNB/ÖGNI was the first to implement the assessment of the environmental performance of buildings based on the forthcoming European framework.

2.2 *Life cycle cost analysis (LCCA)*

Current assessments of the economic performance of buildings are mainly based on performance expressed in cost terms over the life cycle or in terms of financial value over the life cycle. The economic performance primarily includes reduction in life cycle costs and the sustainable conservation of value/increase in value of a building. The general frameworks for the assessment of economic performance are regulated in ISO 15686-5 (ISO 2008), prEN 15643-4 (CEN 2011c) Whereas ISO 15686-5 (ISO 2008) differentiates between whole life cost and life cycle cost. In contrast to that currently only the initial cost (e.g. manufacturing cost) are mainly decisive for building investments. However, regarding to ISO 15686-5 and prEN 15643-4 the consideration of technical and functional performance in LCCA investigations will gain more and more attention in the near future. Due to that future assessments of buildings and, consequently, real estate valuations will have to enlarge their system boundaries.

2.3 *Systematic approach*

In building certification systems the assessment consists of separate assessment criteria. Each single criterion has an individual weight, which is then combined with the assessment result to translate into a target achievement. In complex systems these assessment criteria interact with each other, and also in building systems. Additionally the interdependency between these criteria is mostly non-linear.

In the last decades there have been developed several methods to describe complex systems. To identify the interdependency between DGNB/ÖGNI assessment criteria this case study is based on systems thinking i.e. the sensitivity model of Prof. Vester

[1]Leadership in Energy and Environmental Design
[2]BRE Environmental Assessment Method
[3]German Sustainable Building Council
[4]Austrian Green Building Council
[5]klima:aktiv building and refurbishment certification system
[6]Austrian Sustainable Building Council

(Vester F. 2008) shown in figure 2 - in acc. to (Schalcher H.R. 2008).

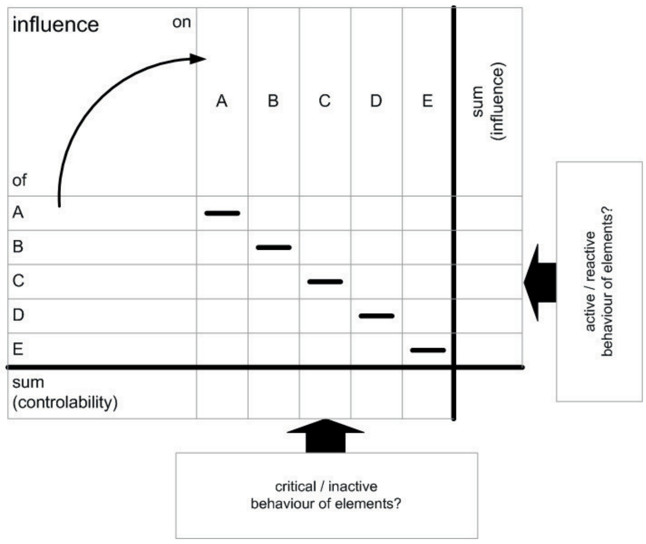

Figure 2: Influence matrix.

The inherent effects are describe as follows:

- Less variation of criterion A generates high variation of criterion B
- High variation of criterion A generates high variation of criterion B
- High variation of criterion A generates less variation of criterion B
- no/or relatively less variation of criterion B due to variation of criterion A

System effects caused by different design options are generally not considered yet. Decision of design options are mainly reduced on the instantaneous assessed criterion in the assessment of buildings. The interdependency of other criteria and the their influence in overall building performance is thereby neglected in, and especially in early planning stages. This is caused by the current linear assessment in building certification systems of singular technical feasibilities.

With regard to systems thinking therefore a new approach leading to the integration of system theory in the field of building assessments is shown. Based on the sensitivity model of Prof. Vester and ÖGNI building certification system for new office buildings (ÖGNI) the new approach should provide the identification of the most important assessment criteria in the system.

Due to the holistic approach in LCCA and LCA method system thinking will gain more and more importance also in building assessments. Further more, from the Authors point of view, it is indispensable to implement a systematic approach to improve building performance prerequisiting the comparison of functional and technical quality e.g. as mentioned in (Passer A.; Kreiner, H. and Kainz F. 2009), (Passer A.; Kreiner, H. and Maydl P. 2009) with the economic and environmental outputs. Also in early planning phases it is of great interest to identify appropriate design options to optimize the building performance.

The system model is defined by the criteria matrix of the building certification system of ÖGNI. Table 1 gives an overview of the considered criteria (inn acc. with (German Sustainable Building Council 2012) and of the individual weighting. Thereby criteria Nr. 1-5 and Nr. 10,11 which describe the quantifiable environmental outputs are combined to criterion LCA. Criterion 16 (life cycle cost) is pictured in LCCA.

Table 1: Description of the criteria.

LCA	Life Cycle Assessment	13,5%
C6	Risks to the local environment	3,4%
C8	Sustainable use of resources / wood	1,1%
C14	Drinking water demand and volume of waste water	2,3%
C15	Space demand	2,3%
LCCA	Building related life-cycle costs	13,5%
C17	Suitability for third-party use	9,0%
C18	Thermal comfort in the winter	1,6%
C19	Thermal comfort in the summer	2,4%
C20	Interior air hygiene	2,4%
C21	Acoustic comfort	0,8%
C22	Visual comfort	2,4%
C23	User control possibilities	1,6%
C24	Quality of outdoor spaces	0,8%
C25	Safety and risk of hazardous incidents	0,8%
C26	Handicapped accessibility	1,6%
C27	Space efficiency	0,8%
C28	Suitability for conversion	1,6%
C29	Public access	1,6%
C30	Bicycling convenience	0,8%
C31	Assurance of design and urban development quality in a competition	2,4%
C32	Percent for art	0,8%
C33	Fire prevention	4,5%
C34	Sound insulation	4,5%
C35	Quality of building envelope with regard to heat and humidity	4,5%
C40	Ease of cleaning and maintenance	4,5%
C42	Ease of dismantling and recycling	4,5%
C43	Quality of project preparation	1,3%
C44	Integral planning	1,3%
C45	Optimization and complexity of planning method	1,3%
C46	Evidence of sustainable aspects in call for and awarding of tenders	0,9%
C47	Creation of conditions for optimal use and management	0,9%
C48	Construction site / construction process	0,9%
C49	Quality of contractors / prequalification	0,9%
C50	Quality assurance for construction	1,3%
C51	Commissioning	1,3%

The interdependency between the criteria was modelled in an influence matrix (as shown in figure 2) based on a previous description of several design options for each criteria.

To identify the role of each criterion an appropriate method is shown in figure 3. In general there are five main areas (active, reactive, critical, buffering and neutral).

The interpretation of the criteria is based on these areas, described as follows:(Vester F. 2008)

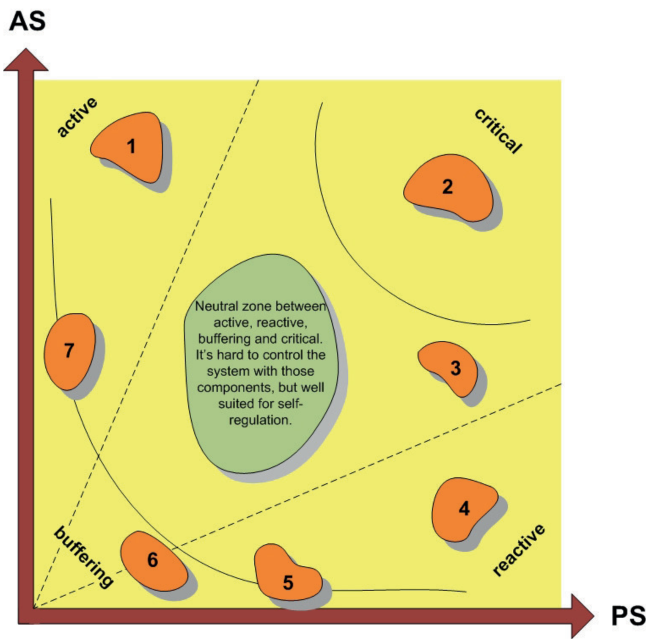

Figure 3: Interpretation of criteria roles.

Active area: Criteria with great steering potential are located in this area. Here criteria are located, which effective steering potential stabilizing the system again after a change (plastic stability).

Critical area: Here you find accelerators and catalysts, suitable as a trigger for things to get going at all. Uncontrolled rocking and tipping is possible, therefore (with kid gloves) extreme caution

Reactive area: If you try manage here, it just brings you cosmetic corrections (symptomatic treatment). But these components are very good as indicators.

Buffering area: Area of little influence. Exceeding certain thresholds and limits can still have a crucial effect on the system.

It is thus important to identify criteria that are linked to both active and critical or active and buffering areas. Variations on criteria which belong to the first case can destabilize the system, criteria in second case can stabilize it.(Vester F. 2008)

The evaluation of the influence matrix is shown in figure 8 for the active and passive sum. The interpretation of the assessment criteria is pictured in figure 9.

3 CASE STUDY

The investigated office building for the case study is located in the center of Graz - Austria. The view of the building complex is shown in figure 4. The building is owned and operated by the Landesimmobilien-Gesellschaft mbH and serves for various public authorities and services.

The building is a new office building and has been built within a refurbishment of the whole building complex.

An overview of the key characteristics of the building (Landesimmobilien-Gesellschaft mbH 2010) is shown in table 2.

Figure 4: View of the building.

Table 2: Key parameters of the case study.

Size	2.300 m^2 (gross floor area)
Floors	5+1
Walls	concrete, bricks
Energy certificate	B (39 $kWh/m^2 \cdot a$)
S/V ratio	0.21 [m$^-1$]
Heating system	district heating
LEK	33 [-]
Mean U-value	0.565 $[W/(m^2 \cdot K)]$

The LCA is based on the *simplified analysis* in the ÖGNI assessment system including the time related system boundary, with the *whole life cycle* separated into before use, use and end of life stage.

The *simplified analysis* consists following building components (see table 3):

Table 3: System boundaries.

Foundation
Outer and cellar walls including windows and coatings
Roof
Ceilings incl. flooring and coatings
Inner wall incl. coatings and bearing
Doors
Heat production / generation plant

The spatial system boundary covers cradle-to-gate processes for construction products (material and components) and services for building operation over a service life of 50 years. The end energy demand has been taken from the energy performance certificate(ÖNORM H 5055 2011) including the HVAC report of the investigated building. Thereby the end energy demand of heating, cooling, lightening hot water and auxiliary energy is included. Cleaning and use of tap water as well as waste water are excludes for LCA only.

LCCA covers before-use and use stages for all construction products (materials and components) based on the bill of quantities of the investigated office building. In accordance with Austrian Standard ÖNORM B1801-1 (ÖNORM B 1801-1 2009) the spatial system boundary is defined by the construction work section fabric, finishing and technical equipment. End of life stage is not included. The use stage (building operation) takes into account the end energy demand for heating, cooling, hot-water, lightening, auxiliary energy, tap- and waste water as well as cleaning services. To identify and quantify the most important steering criteria for LCCA and LCA influences of all parameters have been calculated separately, and this makes possible a holistic comparison between the absolute assessment performance of different disciplines in LCCA and LCA.

To quantify the role of each parameter a detailed identification of the ratio of several disciplines on the assessment performance in the ÖGNI certification system is necessary.

4 RESULTS

The results are first presented for LCCA and LCA in general and then evaluated for the target achievement of LCCA and LCA within the ÖGNI assessment for different life cycle stages and depth of the assessment (from overall to construction work sections). Last but not least, the evaluation of the influence matrix and the interpretation of the assessment criteria are discussed.

4.1 *Results LCCA and LCA*

The overall results of LCCA and LCA assessment[7] (ratio of the environmental and economic indicators) over the building life cycle for construction products and operation are shown in table 4.

Table 4: Ratio of LCCA and LCA results over life cycle.

	LCC	GWP	ODP	POCP	AP	EP	PEne	PEges
Fabric	15%	14%	42%	22%	15%	18%	24%	16%
Technical eq.	29%	0%	0%	0%	0%	0%	0%	0%
finishing	32%	9%	40%	39%	33%	34%	35%	39%
Operation	24%	77%	18%	38%	51%	48%	41%	45%

It can be observed that finishing and technical equipment have the highest influence on LCCA, whereas the highest contribution to LCA results derives from finishing and building operation. For further decisions in view of building performance optimization the next step is to find feasible design options to increase the assessment performance of operations and finishing. Due to the weighting of LCCA and LCA as well as especially different weighting of LCA indicators within the ÖGNI assessment method absolute assessment results of LCA (e.g. $kgCO_2/m^2$) are not suitable for further decisions.

To compare LCCA and LCA results the weighing of ÖGNI is used to aggregate the LCA results for a single score indicator (in the ÖGNI building certification system) of the investigated work sectors on LCCA and LCA.

[7]The present case study is still in assessment status, final results (conformity check by ÖGNI) needs to be confirmed.

4.2 *Target achievement of LCCA and LCA*

A general overview of the the influence of several construction work sections and building operation on LCCA and LCA performance is pictured in figure 5. In the ÖGNI building certification system LCCA and LCA can reach up to 13,5 % each of the overall scoring. The assessment shows that LCCA reaches maximum scoring and LCA a quite high performance level.

In the case study other assessment criteria don't reach the maximum scoring design options to improve the overall assessment performance are to be analysed. Due to interdependency of assessment criteria different design options can influence various criteria simultaneously.

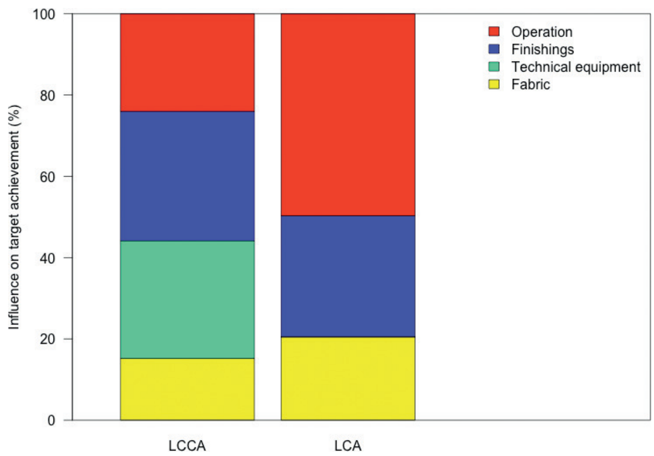

Figure 5: LCCA and LCA life cycle overview.

Improving the environmental performance, it can be observed that building operation has the highest contribution on LCA scoring, whereas building finishes have the highest percentage on LCCA followed by technical equipment. The low percentage of technical equipment (0,01%) in LCA is caused by the simplified assessment of LCA in the before use stage due to the used energy source district heat and therefore the assessment only considers the heat transmission station.[8] The results indicate that building fabric is not appropriate to improve the ÖGNI assessment performance.

Next step is to identify those design options which have value in the improvement of the overall building performance. Therefore a more detailed investigation was carried out. Hence target achievement ratio of both, building operation and building finishing is evaluated in detail. Looking at building operation in this case study heating and lighting show the highest optimization potential.

[8]At present there is a lack of consideration of environmental performance of technical equipment. Due to that in this case study the simplified assessment was chosen, as rather this study in generally focus on the systemic approach. However, the main findings of a study concerning the influence of technical equipment in LCA(Passer, A.; Kreiner, H. and Maydl P. 2012) recommend a detailed consideration of technical building equipment in future life cycle assessments.

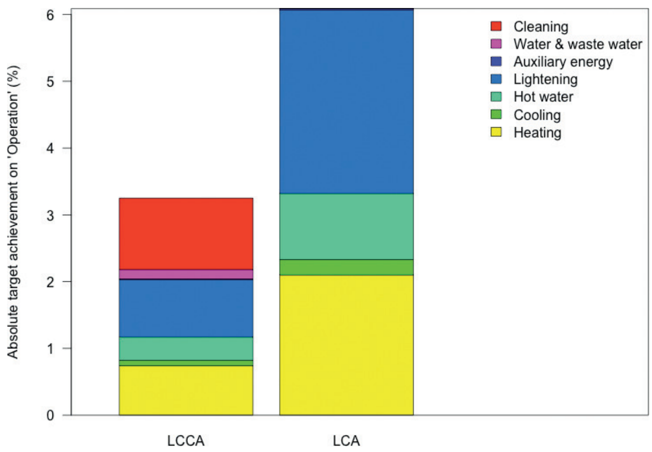

Figure 6: Target achievement building operation.

In figure 6 and 7 possible optimization potentials to improve LCA performance on the construction works level are shown.

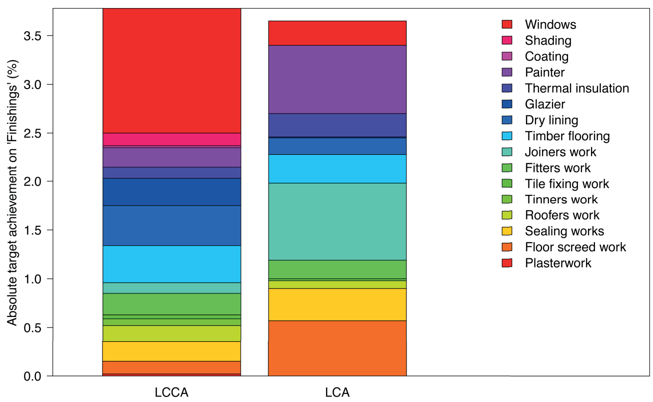

Figure 7: Target achievement finishing.

There are different ways to improve LCA performance. Taking into account the results in the use stage for building operation - heating on the one hand increasing the thermal insulation system as well as lowering the U-value of the windows seems suitable lowering the end energy demand and optimize LCA performance respectively. However the influence of these design options on LCCA must be taken into account simultaneously, otherwise the overall performance is hardly predictable. On the other hand design options with high LCA performance in finishing (i.e floor screed work, joiners work, etc.) with relatively low influence on LCCA performance show good optimization potential - at first sight. Still the interdependency of design options on the various assessment criteria is unknown. A optimization in one assessment criteria e.g. LCA (resp. the indicators behind LCA) does not mean that the overall performance can be increased automatically.

Furthermore it can be seen, that it's quite difficult to say which design option is best suitable to improve building performance. Therefore next step is to find system criteria that have a high level of influence on performance.

4.3 *Results systematic approach*

A first overview an overview of the level of influence (active and passive) sum of all criteria in the ÖGNI system is pictured in 8 (in acc. with (Vester F. 2008)).

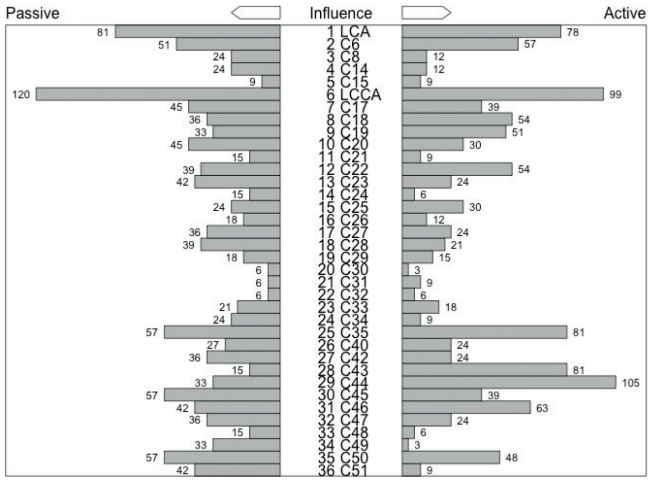

Figure 8: Active and passive sum.

The bars with highest level as well on left as on right side indicate those to be investigated in more detail. Criteria with a high level on left side are more influenced by other (passive), criteria with high level on right side have more influence on other criteria (active). In this case it clearly shows the critical role of e.g. LCCA and LCA in the building certification system.

To be in line with the sensitivity model (Vester F. 2008) a comprehensive calculation algorithm (Vester F. 1991) needs to be applied to the evaluated influence matrix to receive a more detailed interpretation of the role of the several criteria.

The results of the analysis are pictured in figure 9 for all criteria, while the only criteria worth mentioning for the description of the systemic approach are explained in more detail further on (white circles with numbers of criteria).

At first sight it can bee seen that both criterion LCCA and LCA are critical within the system. Secondly it can be seen that both have a strong influence on other criteria and are also strongly influenced by others (indicated by high active and passive sum). Due to the high active and passive sum in total are dedicated to critical area (see figure 3), additionally neutral because of the similarly characteristic of active and passive sum. In terms of the overall scoring in the ÖGNI assessment method one might note that the scoring ratio of LCCA and LCA is 27 % of the absolute target achievement.

Criterion 44 (Integral planning) and criterion 35 (Quality of building envelope with regard to heat and humidity) are active, so well steering criteria (criteria to improve the system quality). Both criteria are critical, which means they plays an important role in the system.

In contrast to that criterion 47 (creation of conditions for optimal use and management) is reactive and

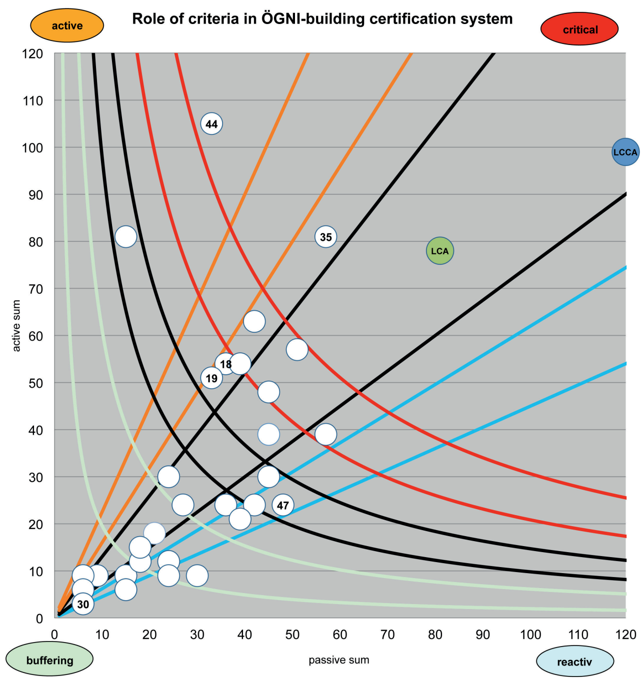

Figure 9: Interpretation assessment criteria.

therefore a not good steering criterion but a good indicator for the system. Criterion 30 (bicycling convenience), among others, is high buffering and plays therefore a limited role.

In addition to the system role of different criteria, the absolute weighting of the criteria in the ÖGNI assessment method needs to be taken into account. For example,buffering criteria that are highly weighted should be handled with care e.g. assessment category technical performance, criterion 34, sound insulation).

To conclude for investment decisions to improve building performance always the absolute ÖGNI weighting of each criterion has to be taken into account. This is also stated by (Thomas E. and Köhler A. 2011).

4.4 *Discussion*

A ranking of possible optimization potentials can not be derived in general by using a systematic approach to improve building performance. Depending on the status quo of a project, whether high or low energy efficiency and high or low finishing standard respectively, the interdependency of all criteria has to be investigated for the individual projects. This is made necessary by the different social and functional targets of different buildings. Regarding to that feasible design options to optimize the target achievement of criterion 35 can be only found by taking into account the chain of causes (labelled as 1 in figure 10) and effects (labelled as 2). Thereby the functional and technical feasibility is a prerequisite for further investigations. It is indispensable to model the related chain of causes and effects in the context of all system criteria to identify the most relevant design options for the observed criteria (here e.g. criteria 35).

Taking into account that the influence matrix consists out of 36*36 possible inherent effects, the high degree of complexity of a detailed identification of all interactions between individual criteria becomes obvious. Further the interdependency of the chosen design option (e.g. triple glazing instead of double glazing - as pictured as green box labeled M2 in figure 10) on the system (e.g. on criterion 18 and 19) has to be identified by the chain of causes and effects. Further detailed results are presented in (Kreiner H. 2012).

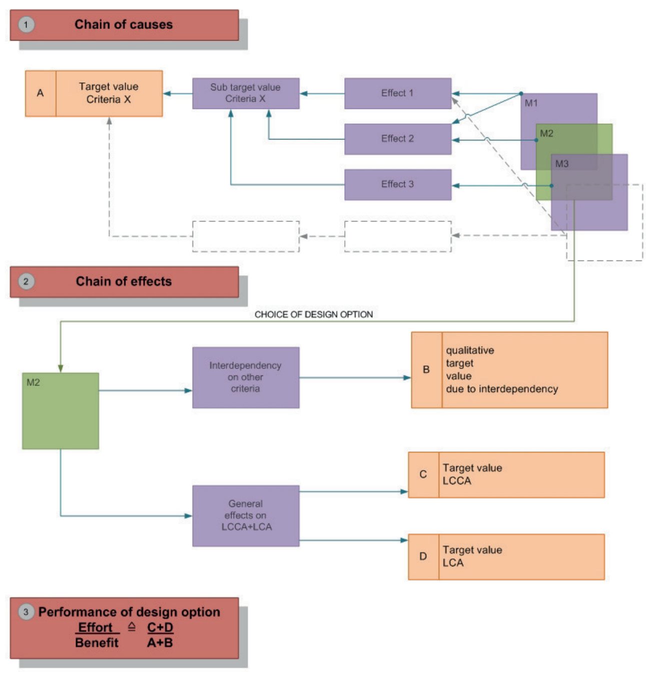

Figure 10: Life cycle performance of design options.

Regarding to cost efficiency both LCCA and LCA target achievement (labelled as C and D in figure 10) it can be seen as sustainable effort of the chosen design option. The aggregation of qualitative target achievement of the investigated criteria (labelled as A) and qualitative target achievement due to interdependency on other criteria (labelled as B respectively) maintain the sustainable benefit. At least the quotient of effort and benefit (labelled 3) gives an overview about the life cycle performance of the chosen design option. Thereby these technical options with a quotient higher than 1 are the most suitable to improve the life cycle performance of buildings. The higher the life cycle performance quotient the higher the sustainability of the design option.

The assessment of design options to improve buildings performance of the present case study is presented in (Kreiner H. 2012) in detail.

5 CONCLUSION

In summary the results show, that the improvement of building performance by a linear approach is only suitable for criteria that do not interact with each other. If there is an interaction between criteria a systematic approach seems more appropriate to improve buildings performance. Therefore, those design options which have the lowest economic and environmental impact as well as the highest qualitative target achievement are recommended for realization in practice.

The interdependency on other criteria generates automatically economic and environmental impact next to the investigated criteria. So a consideration of both (direct and indirectly impacts) is indispensable for holistic improvements and further assessments.

In the present case study the identification of chain of cause and effects was stressed out for several design options. Due to the high complexity of interdependency in several criteria the individual study results do not allow any final statements in general.

Only the linking of environmental and economic performance makes cost and benefit of different design options visible. This is prerequisite to implement environmental protection behind economic and social acceptance(Rottke, N 2010). Only by ensuring that already design options are based on a holistic life cycle performance assessment, the demanding challenge of a holistic improvement of building performance can be reached in future.

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REFERENCES

CEN (2011a). European Committee for Standardization, Sustainability of construction works - Assessment of buildings, Part 1: General Framework, ÖNORM EN 15643-1:2011.

CEN (2011b). European Committee for Standardization, Sustainability of construction works - Assessment of buildings, Part 2: Framework for the assessment of the environmental performance, ÖNORM EN 15643-2:2012.

CEN (2011c). European Committee for Standardization, Sustainability of construction works - Sustainability assessment of buildings - Part 4: Framework for the assessment of economic performance, FprEN 15643-4:2011.

Cole R. J. (2011). Environmental Issues Past, Present & Future: Changing Priorities & Responsibilities for Building Design. In *World Sustainable Building Conference, Keynote, Helsinki*.

German Sustainable Building Council (2012). Criterias' Overview. Technical report.

Girmscheid G., et.al (2010). *Nachhaltig optimierte Gebäude*.

ÖGNI. Kriteriensteckbriefe NBV09 AUT 01 - Stand 2010-03.

Henzelmann T., et.al (2010). Nachhaltigkeit im Immobilienmanagement. Technical report.

Hunkeler D., Lichtenvort. K., Rebitzer G. (2008). *Environmental Life Cycle Costing*. SETAC.

ISO (2006). International Organization for Standardization, Environmental management - Life cycle assessment - Principles and framework, ISO 14040:2006.

ISO (2007). International Organization for Standardization, Sustainability in building construction - Environmental declaration of building products, ISO 21930:2007.

ISO (2008). International Organization for Standardization, Building and constructed assets - Service Life Planning - Part 5: Life-cycle costing, ISO 15686-5:2008.

Kreiner H. (2012). *Interdependency between LCCA and LCA in the assessment of buildings, not yet appropriated*. Ph. D. thesis, Graz University of Technology.

Landesimmobilien-Gesellschaft mbH (2010). Bau- und Austattungsbeschreibung Karmeliterhof. Technical report.

ÖNORM B 1801-1 (2009). Bauprojekt-und Objektmanagement - Teil1: Objekterrichtung.

ÖNORM H 5055 (2011). Gesamtenergieeffizienz von Gebäuden.

Passer A.; Kreiner, H. and Kainz F. (2009). Gebäudebewertung im Kontext zu funktionalen und technischen Qualitäten-Teil 1. *OIB aktuell 10. Jahrgang, Heft 3*, 8–11.

Passer A.; Kreiner, H. and Maydl P. (2009). Gebäudebewertung im Kontext zu funktionalen und technischen Qualitäten-Teil 2. *OIB aktuell 10. Jahrgang, Heft 4*, 26–32.

Passer, A.; Kreiner, H. and Maydl P. (2012). Assessment of the Environmental Performance of Buildings – A critical evaluation of the influence of technical building equipment on residential buildings. *submitted to Int. JLCA*, 12.

Rottke, N (2010). *Ökonomie vs. Ökologie - Nachhaltigkeit in der Immobilienwirtschaft*.

Schalcher H.R. (2008). *Systems Engineering*. IBB-Institut für Bauplanung und Baubetrieb.

Schneider C. (2011). *Steuerung der Nachhaltigkeit im Planungs- und Realisierungsprozess von Büro- und Verwaltungsgebäuden*. Ph. D. thesis, TU Darmstadt.

Thomas E. and Köhler A. (2011). Strategien zur Prävalenz von Kriteriensteckbriefen. *greenbuilding 10*.

Vester F. (1991). *Ausfahrt Zukunft Supplement*.

Vester F. (2008). *Die Kunst vernetzt zu denken-Ideen und Werkzeuge für einen Umgang mit Komplexität*. Deutscher Taschenbuch Verlag.

Wallbaum H. and Hardziewski R. (2011). Minergie und die Anderen – Vergleich von vier Labels. *TEC21 47*, 32–39.