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Doctoral thesis

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Abstract

Spatial quality is the perception of the quality of the physical space. The user perceives spatial quality through the relationships between physical elements. The interface between walls, ceilings, doors, windows and columns, as well as inside and outside spaces under different (day) light conditions all define spatial quality. This PhD research thesis proposes a spatial quality definition, and a measurable and objective assessment framework to evaluate and predict the impact of energy efficiency renovation of dwellings on spatial quality.

The definition and assessment are based on four spatial quality determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces, and (4) perceived density, built and human densities. These spatial quality determinants are developed during the PhD research, based on a literature study on the quality of life in the urban environment, spatiality and spatial perception, energy efficiency renovation of dwellings, and a study of seven actual dwelling renovation cases. The prime reasons why this research has focused on spatial quality are the lack of a clear spatial quality definition on the building scale in the literature, and the sometimes unintended but always unmeasured impact of energy efficiency renovation of dwellings on spatial quality.

Climate change and the urge for sustainability have led the building industry into a radical re-thinking of how they construct new buildings and renovate existing ones. Energy efficiency renovation of dwellings is an opportunity to increase people's well-being in a dwelling, rather than just improving its technical energy performance. The positive link between the renovation and benefits to people's everyday life has the potential to increase end users' acceptance and building

owners' willingness for renovation. The spatial quality definition and assessment developed in this PhD research are intended to strengthen the understanding of the quality of physical spaces in dwellings. The assessment can help to evaluate and predict the effect of energy efficiency renovation on spatial quality in dwellings. It can also help design teams to include spatial quality in energy efficiency renovation, and explore the potential of the renovation to improve the spatial quality in dwellings.

This PhD work has two contributions and two main findings. The first contribution is the spatial quality definition for dwellings. The second contribution is the assessment framework. The first main finding of the research is that energy efficiency renovation affects spatial quality in dwellings, and that the renovation can improve spatial quality, not only energy performance. The effects can be positive, for example, if there are new openings in the facade, or negative if the changes in the plan result in excessively deep rooms in relation to the size of the windows. The second main finding follows from the literature study on the renovation of dwellings, on spatial quality related issues, and from the study of the renovation cases. In order to improve spatial quality in energy efficiency renovation, increased spatial quality may be planned at an early stage of the renovation process together with the increased energy performance.

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I would like to thank my main supervisor Professor Annemie Wyckmans for her mentoring of this PhD research work. I would also like to express my gratitude to Professor Barbara Matusiak for her assistance during my PhD. I thank Associate Professor Rolee Aranya and postdoctoral researcher Carmel Lindkvist for their help. I would also like to thank the Department of Architecture and Technology at the Faculty of Architecture and Design at NTNU, for the opportunity.

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2015/04 Paper: Dwelling Renovation and Spatial Quality: The Impact of the Dwelling Renovation on Spatial Quality Determinants. International Journal of Sustainable Built Environment, IJSBE.

2014/06 Paper: Spatial Quality Determinants for Residential Building Renovation: A Methodological Approach to the Development of Spatial Quality Assessment. International Journal of Sustainable Building Technology and Urban Development, SUSB.

2014/10 Paper: Spatial Quality in Building Performance Assessment Tools, The case of Dwelling Renovation for Energy Efficiency. Conference proceedings of the WSB14 Conference, World Sustainable Building 2014, Barcelona, Spain.

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‘But if you cannot define what quality is, what makes you believe that it exists? Something exists if the world does not function normally without it.’

Robert Pirsig 1974/2009

1. Introduction

1.1 How it all started

The goal of this PhD research is to define spatial quality and create an assessment framework to evaluate and predict the impact of energy efficiency renovation on the spatial quality in dwellings. The awareness of this impact enables design teams to find optimal renovation solutions that are both technically efficient and appropriate in terms of spatial quality. The spatial quality assessment method has the potential to enhance understanding of the impact of the renovation on spatial quality. The understanding of the potential of the renovation to improve spatial quality and living conditions in dwellings can help convince end users to renovate and therefore supports the renovation. This understanding can also help to avoid decisions in dwelling renovation that can have a negative effect on spatial quality.

Energy efficiency renovation does not automatically improve spatial quality in dwellings. A model that predicts how and how much spatial quality improves before starting to build can be valuable for real estate developers because if done correctly, renovation can also give added value to dwellings beyond technical gains in energy efficiency. Increased energy efficiency and increased spatial quality can together give strong arguments to promote energy efficiency renovation.

The topic of the announced PhD position was ‘resilient architecture: morphological strategies on neighbourhood level’. During the first year of the PhD, the scale of the research changed from the neighbourhood to the building scale. This is because the initial literature studies indicated a clear gap in terms of the definition and assessment of spatial quality, prior to being able to develop corresponding morphological strategies. As the gap was most prominent on the building scale, the scope of the PhD research was decided to emphasize this scale.

The elements of the present PhD research are spatial quality definition and assessment, and energy efficiency renovation of dwellings:

- **Spatial quality definition and assessment**

Spatial quality is the perception of quality of the physical space. The user perceives space through the relationships between physical elements (walls, ceilings, doors, windows and columns) and the void created by these elements. The lack of a spatial quality definition on the building scale in the literature, the existing impact of energy efficiency renovation of dwellings on spatial quality, and my interest in the topic as an architect, drove the research towards the study of spatial quality.

The assessment framework proposed in this PhD research is a translation of the theoretical spatial quality definition developed during the same research, into a method that can be used in the practice of energy efficiency renovation. The assessment framework is designed to evaluate and predict the impact of the energy efficiency renovation on spatial quality in dwellings. The assessment framework is based on a spatial quality definition, which consists of four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces and (4) perceived density, built and human densities (Chapter 8. Spatial quality definition and assessment).

The four determinants are considered equally relevant in the study of spatial quality in dwellings in this PhD work. Each of the four determinants has five principles, and each principle has three sub-principles (Tables 1 to 4, Chapter 2. Objectives of the research work). The sub-principles represent specific characteristics in relation to the principles. The sub-principles are represented by three specific physical features that are proposed in the PhD work to assess spatial quality (Tables 18 to 21, Chapter 8. Spatial quality definition and assessment). The spatial quality determinant of '(1) View' and the principle of '(C) Distance and degree of sight protection' can exemplify the relationships between the determinant / principle / sub-principles / indicators in the spatial quality assessment framework (Table 18):

(1) Spatial quality determinant of 'View':

(C) Principle of 'Distance and degree of sight protection':

(C2) Sub-principle of 'Availability and configuration of private outdoor spaces', which is represented by the following three indicators:

'(a) Availability of private outdoor spaces (yes or no question)'

'(b) Possibility of controlled visual contact with neighbour's private outdoor spaces (yes or no question)' ‘(c) Availability of private outdoor spaces on the ground floor level (yes or no question)’

Spatial quality is a complex term with the possibility to include more topics than the ones addressed in this research. The spatial quality definition and assessment framework proposed in this PhD cover subjects related to the literature on the quality of life in the urban environment, spatiality and spatial perception. The PhD does not cover other subjects that can be related to spatial quality, for example, universal design principles, colour, and acoustic and thermal performance.

- **Energy efficiency renovation of dwellings**

The focus of the PhD research became energy efficiency renovation on the building scale from an early stage of the PhD work. The reasons for working with energy efficiency renovation of dwellings in the PhD are many. Improving energy efficiency in existing buildings is among the challenges of sustainable (re-) development of the built environment (Cotgrave & Riley 2013, Pombo et al. 2016). Renovation processes are challenging because they often involve several owners with different viewpoints and interests. Non-energy related arguments are necessary to convince users to choose for energy efficiency renovation. Dwellings are among the core functions for people and for the city. Improving the quality of dwellings is a strong motivation for people to foster initiatives that aim to consistently achieve excellence in the built environment.

Considering these key elements, the main research question in the PhD research is: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* Sub research questions are: *What are the main spatial quality determinants for dwellings? What potential effects* *are there between energy efficiency renovation and spatial quality?* And *how can energy efficiency renovation increase spatial quality in dwellings?*

1.2 Research field

This research defines a systematic and measurable description of the spatial quality changes that occur when dwellings are renovated for energy efficiency. Changes in the physical features of dwellings as a consequence of energy efficiency renovation, are analysed in relation to their impact on spatial quality. The results of the work can support design teams to explore the potential of energy efficiency renovation, in order to improve spatial quality in dwellings.

The individual who performs the spatial quality assessment needs to have knowledge on technical aspects of building renovation and spatial quality in order to use the assessment. The individual also need to be able to identify the impact of the renovation on spatial quality. Building owners and end users do not necessarily have the technical or architectural background to understand spatial quality or technical aspects of the renovation.

The research is based on the theory of the quality of life in the urban environment, spatiality and spatial perception and energy efficiency renovation of dwellings, and the study of actual cases of renovation of dwellings. The results of the literature study (Chapter 3. Research background), and the study of six cases of energy efficiency renovation (Chapter 7. Energy efficiency renovation of dwellings) were combined to develop a spatial quality definition and assessment framework (Chapter 8. Spatial quality definition and assessment). The assessment framework is tested in a case of energy efficiency renovation of dwellings in Grenoble, France (Chapter 8. Spatial quality definition and assessment).

The spatial quality definition and assessment framework resulting from this research, can be tested and further improved by including interviews with end users and practitioners. This PhD research can be a starting point for developing qualitative-based research on spatial quality, for example by means of evaluation of user satisfaction and priorities (Section 10.2 Recommendations for further research).

1.3 Methodology

This research is characterized by a quantitative research approach based on cause and effect relations (deductive process): measuring the impact (effect) of energy efficiency renovation (cause) on the spatial quality in dwellings. This PhD work includes characteristics of the correlational research strategy, such as the search for 'patterns of relationships' between two or diverse variables, and the measurement of specific variables (Groat & Wang 2013, p. 206).

A post-positivism research paradigm forms the theoretical background for this PhD research. Post-positivists believe that objectivity in research may be achieved, but in an imperfect way (Groat & Wang 2002, Creswell 2014). Quality standards for post-positivism research paradigm are internal and external validity, reliability and objectivity (Guba 1981). Internal validity concerns whether or not the main concepts of the study properly represent the object of the study (Guba 1981). In this PhD research, internal validity is whether the spatial quality definition properly represents spatial quality. The spatial quality definition and assessment are based on theory on the quality of life in the urban environment, spatiality and spatial perception, and energy efficiency renovation of dwellings (Chapter 3. Research background). External validity concerns whether the framework of the study where the results are valid, is clearly defined

(Guba 1981). The framework of the study, the spatial quality definition and assessment, is defined and it can be applied to other cases (Chapter 8. Spatial quality definition and assessment).

Reliability in the context of this PhD research is whether other individuals would achieve similar results of the spatial quality assessment for the same case. In this PhD work, the assessment is only performed by the author, so reliability is not tested. However, the results are expected to be similar if the assessment, the weighting and the scale are the same as the ones used in this study. Objectivity consists of minimizing the interference of the researcher when performing the spatial quality assessment proposed in this research. The assessment is developed to minimize the interference of the researcher when performing it, by using indicators that are based on the evaluation of clear physical features.

This PhD research includes seven cases of energy efficiency renovation of dwellings. Six of the seven cases are analysed to collect technical information about the renovation (Chapter 7. Energy efficiency renovation of dwellings, and Acre & Wyckmans 2015a). An in-depth case of energy efficiency renovation of dwellings in France is used to test the spatial quality framework developed in this PhD research. The spatial quality assessment is applied to one of the residential buildings in the Arlequin case in Grenoble, France, to evaluate the impact of the energy efficiency renovation on spatial quality (Chapter 8. Spatial quality definition and assessment, and Acre & Wyckmans 2015b).

1.4 Structure of the thesis

The thesis has thirteen chapters plus appendices and references. Being an article-based PhD, the research is organized around the three main articles of the thesis.

The first chapter consists of an introduction to the main topics and findings of the PhD work. It gives a general overview of the research design and the reasons for the issues covered by the research work. This chapter also presents the research field and methodology with the principles that guided the work. A list of papers and other dissemination activities is included in the beginning of the thesis.

Chapter 2 ‘Objectives of the research work’ provides information about the relevance of the work and its contribution to the research field, the research gap, framework, goals and questions. Chapter 3 ‘Research background’ provides information about the state of the art that is relevant for the thesis, and presents the theoretical foundation for the thesis, more thoroughly than the information presented in the articles. The European ZenN Project (7^{th} Framework Programme, Grant Agreement number 314363), to which the PhD research contributes, is presented in Chapter 4. Chapter 5 presents the definition of the indicators considered in this research. Chapter 6 consists of the research methodology and strategy. Chapter 7 presents the knowledge on energy efficiency renovation of dwellings, and the impact of the renovation on spatial quality. The spatial quality definition and assessment proposed in this research are presented in Chapter 8. In Chapter 9, the aim is to explain how the articles complement each other, including a comparison and synthesis of the problems and conclusions put forth in the publications. Conference papers are presented in Chapter 9. Chapter 10 contains the conclusions of the PhD work and directions for further research. Chapters 11 and 12 consist of the description of the duty work and other activities developed during the PhD. Chapter 13 presents a complete list of papers and other dissemination activities.

2. Objectives of the research work

2.1 Relevance

The link between building renovation and its benefits on people's everyday lives and well-being needs to be highlighted to strengthen the marketplace for energy efficiency renovation of dwellings. Amenities (for example extra spaces, new kitchen, or extra bathrooms) can be used to influence users to choose to renovate dwellings to improve energy efficiency (Judson & Maller 2014, Wilson et al. 2013, 2015). Amenity renovation, which consists of the renovation that aims to increase comfort and amenities, is more common than energy efficiency renovation (Wilson 2008, Wilson et al. 2015). In the North America for example, there is a 'social trend' for 'new and evolving drivers' related to improved comfort and amenities as a result of energy efficiency renovation of dwellings (Waide et al. 2007, p. 13). Increasing spatial quality in dwellings as a result of energy efficiency renovation might increase end users' acceptance for the renovation. This is because enhanced spatial quality as consequence of the renovation might contribute to the attractiveness and public image of a building, as well as to end users' well-being.

This research often mentions the term non-technical driver referring to spatial quality. Non-technical drivers refer to comprehensive features such as architectural values and cultural heritage, stakeholder awareness and behaviour, economic and ownership structures, legislation, governance and policy (ZenN 2012). Building appearance for example, is a non-technical related feature that can influence end users to decide to renovate their dwellings (Novikova et al. 2011, Wilson & Dowlatabadi 2011). Non-technical drivers are often conclusive for households that neither have implemented nor are planning a retrofit, and for those that are planning a retrofit (Novikova et al. 2011, p. 3). People 'want to see the results of their investments' on building renovation (Whitmarsh et al. 2011, p. 105). End users want to see overall improvements in their dwellings as a result of the renovation, not only improvements in energy efficiency (Wallenborn & Wilhite 2014). Energy efficiency is often not clearly visible, while improvements in physical features usually are visible (Judson & Maller 2014). However, physicality has not been amply explored in domestic energy use (Wallenborn & Wilhite 2014). The spatial quality assessment proposed in the PhD research can help end users achieve overall improvements in their dwellings as a result of the renovation.

'Technology provides an enabling or modifying set of criteria in the design process, not a determining one' (Rapoport 1982, p. 336). Energy efficiency is usually the focus in building renovation processes (Burton 2012, JCHS 2009, Novikova et al. 2011, Wilson & Dowlatabadi 2011, Whitmarsh et al. 2011, Patterson 2012, Tweed 2013, Judson & Maller 2014, Wallenborn & Wilhite 2014, Wilson et al. 2013, 2015). Energy efficiency renovation is often a technical matter only, and not related to 'home improvements' (Wilson et al. 2015, p. 12). Wilson et al. (2013) found from studies on energy efficiency renovation of dwellings in the United Kingdom, that only one in ten renovations focused on energy efficiency alone. Most renovations of dwellings are amenity-based, and energy efficiency measures are complementary to the overall renovation (Wilson et al. 2013). In the United States, most of the costs related to renovation in dwellings are done to improve comfort and spatiality (JCHS 2009). In another study, Judson and Maller (2014) found that energy efficiency measures often happen in connection with expansions of the house.

The PhD work contributes to the fields of quality of life in the urban environment, spatiality and spatial perception, and energy efficiency renovation of dwellings. The literature study indicates that a clear spatial quality definition on the building scale in missing in the theory. This PhD research contributes to these fields in two ways: first, with the proposal of including non-technical drivers such as spatial quality in energy efficiency renovation of dwellings. The second main contribution of the PhD is the spatial quality definition and assessment (Chapter 8. Spatial quality definition and assessment).

Four determinants, which are the result from the literature study, are the basis for the definition and the assessment: (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces and (4) perceived density, built and human densities (Tables 1 to 4, reviewed version, the first version is in Acre & Wyckmans 2014) (Chapter 8. Spatial quality definition and assessment). The assessment can be a support for design teams to keep an overview on how the renovation affects spatial quality in dwellings. Therefore, the assessment has the potential to help preventing negative effects of the renovation on spatial quality. This is because if the assessment is performed prior to implementation, it can predict how the renovation is going to affect spatial quality. The renovation project can change before physical changes to the building with negative effects on spatial quality are implemented.

The research contributes to theory and is a potential contribution to practice in the field of building renovation. The main theoretical contribution is the spatial quality definition and assessment, while the potential contribution to practice is the implementation of the spatial quality assessment by design teams. The assessment is an interpretation of the theory in order to bring it closer to practice in energy efficiency renovation of dwellings. The spatial quality assessment has been tested by the author in an actual energy efficiency renovation case, the Arlequin demonstrator in Grenoble, France, which is part of the ZenN Project (Chapter 4 The ZenN Project and the PhD research). The results of the spatial quality assessment of the Arlequin demonstrator are published in Acre and Wyckmans (2015b), and they were presented to the ZenN Project partners in project meetings in 2014 and 2015 (Chapter 4 The ZenN Project and the PhD research).

Table 1. Principles and sub-principles for the spatial quality determinant of view (reviewed version)

Spatial quality assessment – Determinant 1: View (Building and block scales)
(A) Facade transparency[a,b]
1. Ratio between facade area and apertures (windows and doors) area
2. Ratio between apertures (windows and doors) area and glazing areas
3. Glazing properties of transmittance[c,d]

[a] Uytenhaak 2008
[b] Baker & Steemers 2002
[c] CEN 2015
[d] Matusiak 2014

(B) Depth of vision[e]	
	1. Visibility[f,g]
	2. Quality of the view (composition of the view)[c,d,e,f,h]
	3. Internal division of space and views[c,g] (configuration of the plan that affects views from inside to outside, and from outside to inside)
(C) Distance and degree of sight protection (visual privacy and protection of the private domain)	
	1. Level of privacy and view of arriving visitors and entrance[h,i]
	2. Availability and configuration of private outdoor spaces[a,f,j]
	3. Placement of balconies[a]
(D) Lighting (daylight access)	
	1. Daylight access (yes or no question)[a,c,d]
	2. Ratio between glazing and room areas[d]
	3. Daylight factor (DF)[b,c,d]
(E) Closure, enclosure and peripheral density (configuration of the block that affects views)[k]	
	1. South-west orientation of the main living areas (yes or no question)[e]
	2. Height-to-width-ratio of the enclosed space (courtyard)[e,f]
	3. Difference between the height of the building and the average height of surrounding buildings (difference in height > than ⅔ of the average height of the surroundings) (yes or no question)[f]

[e] Lynch 1960
[f] Gehl 2010, 2011
[g] Indraprastha & Shinozaki 2012
[h] Chermayeff & Alexander 1966
[i] SBTool 2012
[j] Rapoport 1970/1994, 1977
[k] Weber 1995

Table 2. Principles and sub-principles for the spatial quality determinant of internal spatiality and spatial arrangements (reviewed version)

Spatial quality assessment – Determinant 2: Internal spatiality and spatial arrangements (Building scale)
(A) Centricity and concavity
1. Geometric centre of the space[a,b]
2. Perceptual centres of the space[b,c]
3. Placement of entrances (concavity and privacy)[b]
(B) Internal division of space and spatial density[b]
1. Placement of columns and internal walls
2. Placement of the stairs
3. Ceiling heights[d]
(C) Spatial hierarchies and system complexity[b]
1. Coordinated spatial relationship (spaces with similar dominance)
2. Subordinated spatial relationship (primary and secondary spaces)
3. Spatial system complexity
(D) Privacy within the dwelling (zoning according to the needs of different family group members)[e]
1. Differentiation between social and private zones (yes or no question)
2. Children's domain is directly accessible from the circulation area (yes or no question)
3. Buffer zone between the children's private domain and the parents' private domain (yes or no question)
(E) Lighting[f]
1. Daylight access
2. Light distribution in the space[g,h]
3. Internal zoning of the diverse functions and daylight access[i,j]

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[a] Von Meiss 1997
[b] Weber 1995
[c] Indraprastha and Shinozaki 2012
[d] TEK10
[e] Chermayeff & Alexander 1966
[f] Matusiak 2014
[g] Hopkinson et al. 1966
[h] Baker & Steemers 1996, 2002
[i] BREEAM UK 2008
[j] SBTool 2012

Table 3. Principles and sub-principles for the spatial quality determinant of transition between public and private spaces (reviewed version)

Spatial quality assessment – Determinant 3: Transition between public and private spaces (Building and block scales)
(A) Private entrance to dwelling is a protected and sheltered standing space (yes or no question)[a]
(B) Clear boundaries between private, semi-public and public domains[a,b,c]
(C) Outdoor private spaces[a,c]
1. Presence of outdoor private spaces (yes or no question)
2. Outdoor private spaces are actually used (yes or no question)
3. Outdoor private spaces on street level (yes or no question)
(D) Uniformity and coherence of boundaries (single building)[d]
1. Similarity in facade composition
2. Rhythm of facade composition
3. Facade roughness[e]
(E) The impact of changes in the plan on facade composition[f]
1. Changes in the plan impact similarity in the facade composition (yes or no question)
2. Changes in the plan impact the rhythm in the facade composition (yes or no question)
3. Changes in the plan impact the roughness in the facade composition (yes or no question)

[a] Chermayeff & Alexander 1966
[b] Rapoport 1970/1994, 1977
[c] Gehl 2010, 2011
[d] Weber 1995
[e] Serra 1997
[f] Acre & Wyckmans 2015b

Table 4. Principles and sub-principles for the spatial quality determinant of perceived density, built and human densities (reviewed version)

Spatial quality assessment – Determinant 4: Perceived density, built and human densities (Block scale)
(A) Spatial complexity
1. Surface contrasts[a]
2. Form simplicity[a,b]
3. Dominance[c]
(B) Closure, enclosure and peripheral density[c]
1. Presence of physical or perceived continuity of space boundaries (stability of the block perimeter) (yes or no question)[c]
2. Height-to-width ratio of the enclosed space in relation to the 1:1 proportion (relation between the dimensions of the courtyard and the heights of the peripheral buildings)[c,d,e]
3. Articulation of space boundaries (contrast between the heights of the peripheral buildings and the proportion between the block heights and surrounding blocks in relation to the 1:1 proportion)[c]
(C) Built density (per square metre)[d,e,f]
1. Floor space index (FSI) and average number of floors (L=FSI/GSI)
2. Ground space index (GSI)
3. Open space ratio (OSR)
(D) Human density (people per square metre of block area)[d,f]
1. Percentage of residents of the total users population
2. Percentage of non-residents of the total users population
3. Relation between square metres per person and the built area according to the functions' demands
(E) Functions (use of the space)[d,e]
1. Percentage of square metres per function
2. Compatibility of functions within the block (yes or no question)
3. Functions with low human presence located on the ground and first floors (such as parking and storage areas) (yes or no question)

[a] Lynch 1960
[b] Serra 1997
[c] Weber 1995
[d] Rapoport 1970/1994, 1977
[e] Gehl 2010, 2011
[f] Uytenhaak 2008

2.2 Research goals and questions

The literature study of mainly European authors led to the hypothesis that energy efficiency renovation does affect spatial quality in dwellings. The goal of this work is to pursue measurable and objective assessment of the effect of the renovation on spatial quality, and to explore the potential of the renovation to improve spatial quality in dwellings in Western contexts.

Improvements in spatial quality of dwellings have the potential to increase occupants' well-being (Patterson 2012, Tweed 2013). The aim in this PhD research is to illustrate that the benefits brought by energy efficiency renovation in dwellings improve not only energy performance, but also non-technical drivers such as spatial quality. Views, spatial arrangements, and relations between public and private domains are examples of spatial quality related issues, which are clearer to users in comparison to technical performance, and may therefore help users to agree to pursue energy efficiency renovation. This work is intended to benefit design professionals, and end users, because it points out underlying relations between energy efficiency renovation and spatial quality that are often not clearly considered in the renovation of dwellings (Acre & Wyckmans 2015a).

The main goal in the PhD research is:

- *To create an assessment framework to evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings.*

Subsequently the sub-goals are:

  - *To define spatial quality for dwellings, with measurable determinants;*
  - *To evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings.*

- *To explore the potential of dwelling renovation to improve spatial quality.*

The main research question in the PhD research is:

- *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?*

Sub-questions are:

- *What are the main spatial quality determinants for dwellings?*
- *What potential effects are there between energy efficiency renovation and spatial quality in dwellings?*
- *How can energy efficiency renovation increase spatial quality in dwellings?*

3. Research background

3.1 State of the art on spatial quality

The PhD research defines spatial quality considering three scales: the residential unit, the building, and the block. The study of scientific literature on spatial quality, performed as part of this PhD research, indicates the most important determinants for residential use in these three scales. A determinant is 'a thing that decides whether or how something happens' (Oxford Dictionary 2013). The word determinant is used in the PhD research to indicate what influences spatial quality[a].

The research background section is the foundation for this PhD work. The study of scientific literature on spatial quality, and on energy efficiency renovation of dwellings was necessary to answer the sub research questions: *What are the*

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[a] The term "parameter" was initially used in this research instead of determinant. The term "determinant" started to be used in the PhD research from 2014. The term "parameter" was used in two conference papers in 2013, the CESB13 and SB13 conferences. A parameter is a 'measurable factor forming one of a set that defines a system or sets the conditions of its operation' (Oxford Dictionary 2013). The word parameter is often related to mathematics and statistics, and therefore it became confusing for readers to understand the spatial quality parameters, when they were not explained in mathematical models.

main spatial quality determinants for dwellings? And what potential effects are there between energy efficiency renovation and spatial quality? The work of authors that emphasize the potential of non-technical concerns to promote end user acceptance of building renovation, gave valuable indications about *how energy efficiency renovation can increase spatial quality in dwellings*, which is the third sub research question in this PhD research.

The main authors, whose work is used as reference literature in this PhD work are organized in five groups. The authors included in the literature study either mention the term spatial quality in their work, or focus on similar issues related to spatial quality even if they do not use the term spatial quality explicitly.

The first exploration in the literature aimed to find authors that use the term spatial quality. The references found were filtered to select the authors who approach spatial quality on the neighbourhood, block or building scales, and not only on the city scale. The authors in this group are for example Lynch (1960, 1990), Rapoport (1970/1994, 1971/1994), Uytenhaak (2008) and Gehl (2010, 2011). The knowledge acquired in the first exploration in the literature was the starting point for further investigation on theory. The next step was to find authors that focus on similar issues related to spatial quality but without using the term spatial quality. These references are clustered in the first group of authors (Section 3.1.1 Spatial quality relevance and research gap).

In addition to spatial quality related references, references on perception of space compose an important part of the literature study of the PhD research. The references on the perception of space are clustered in the second and third groups of authors (Sections 3.1.2 Universal principles on the perception of space and spatial quality, and 3.1.3 Physical characteristics of space relevant to spatial perception).

The difference between the sencond and third groups is that the authors in the third group focus on specific physical characteristics of space that are relevant to space perception. The references on energy efficiency renovation of dwellings are clustered in the fourth group of authors (Section 3.1.4 Energy efficiency renovation, and relevance of non-technical drivers in renovation of dwellings). The references about specific topics related to spatial quality are clustered in the fifth group of authors (Section 3.1.5 Development of the spatial quality definition and assessment).

The five groups of authors are presented in more detail below:

- The first group consists of authors who call attention for the relevance of spatial quality related issues (Section 3.1.1 Spatial quality relevance and research gap). The literature study reveals the lack of a clear definition of spatial quality. Many spatial quality related issues are mentioned in the work of these authors but in a general way and on the city scale. For example, Gehl (2010) describes issues such as views and transitions between public and private spaces as determinants for the quality of spaces, under the titles 'senses and scale', and 'the lively, safe, sustainable, and healthy city' (Gehl 2010, p. 31 and p. 61 respectively). The spatial quality definition and assessment proposed in this PhD gather several of these spatial quality related issues that are applicable in the building scale under the term spatial quality. The authors in this group are Rapoport (1970/1994, 1971/1994), Uytenhaak (2008) and Gehl (2010, 2011), and to a certain extent Lynch (1960). These authors are important to both identify the research gap, namely the lack of a spatial quality definition in the literature, and to indicate the relevance of this PhD work.

- The second group consists of the authors who have studied how people perceive space, and have defined universal principles about the human perception of the physical environment (Section 3.1.2 Universal principles on the perception of space and spatial quality). Coherence, complexity and mystery for example, are essential in the perception of space (Kaplan 1992). These authors are Lynch (1960), Kaplan (1989, 1992), Nasar (1992/2000) and Berman et al. (2008).
- The third group consists of authors who study physical characteristics of space that are significant to spatial perception (Section 3.1.3 Physical characteristics of space relevant to spatial perception). Authors such as Rapoport (1970/1994, 1977, 1982/1994, 2005), Weber (1995), Von Meiss (1997) and Gehl (2010, 2011) define for example, visual aspects and formal characteristics such as proportion and hierarchy in spatial relationships that are central to spatial quality (Weber 1995). These relationships are included in the spatial quality definition and assessment proposed in the PhD research.
- The fourth group consists of authors that technically describe renovation of dwellings for energy efficiency, and those that emphasize the potential of non-technical drivers to promote user acceptance of building renovation (Section 3.1.4 Energy efficiency renovation, and relevance of non-technical drivers in renovation of dwellings). These authors are Baker (2009) and Burton (2012), JCHS (2009), Novikova et al. (2011), Wilson and Dowlatabadi (2011), Whitmarsh et al (2011), Patterson (2012), Casey (2013), Tweed (2013), Judson and Maller (2014), Wallenborn and Wilhite (2014), and Wilson et al. (2013, 2015).

- The fifth group consists of authors whose work was relevant to the development of the spatial quality definition and assessment in specific topics, such as daylight and privacy in dwellings (Section 3.1.5 Development of the spatial quality definition and assessment). The majority of the authors are in this group: Chermayeff and Alexander (1966), Hopkinson et al. (1966), Altman and Wohlwill (1976), Alexander, Ishikawa, and Silverstein (1978), Ashihara (1981), Goulding et al. (1992), Baker and Steemers (1996, 2002), Denizou et al. (2011), Indraprastha and Shinozaki (2012), Patterson (2012), Tweed (2013), Matusiak (2006, 2008, 2014, 2015), European Committee for Standardisation, CEN (2015). The works of Lynch (1960, 1990), Rapoport (1970/1994, 1971/1994, 1977), Uytenhaak (2008) and Gehl (2010, 2011) are also included in specific topics of the spatial quality definition and assessment.

3.1.1 Spatial quality relevance and research gap

The authors in group 1 call attention for the relevance of spatial quality related issues, without proposing a clear definition for the term. Their work emphasizes the lack of a clear definition of spatial quality on the building scale in the literature, which also indicates the relevance of working on spatial quality: Lynch (1960), Gehl (2010, 2011), Rapoport (1970/1994, 1971/1994) and Uytenhaak (2008).

Spatial quality is often considered on the macroscale of the city and neighbourhoods (Rapoport 1971/1994). It is often referred in strategic and institutional spatial planning and urban design (Moulaert 2011). The term is often addressed in planning in relation to the quality of the built environment, for example regarding proximity, accessibility, transportation, safety, green infrastructures and public spaces network, spatial, social and cultural diversity (Rapoport 1971/ 1994, Southworth 2003, Friedmann 2004, Gehl 2010, 2011, Salat 2011).

Many spatial quality related issues were found in the work of diverse authors during the literature study in this PhD research. However, a specific term that groups the issues considered in this PhD was not found in the literature. Spatial quality related issues can be grouped under a single term, which might ease the inclusion of spatial quality in building renovation processes. The definition is also fundamental for the development of methods to assess spatial quality.

Lynch (1960) and Gehl (1995) have similarities in the way they approach spatial quality. Lynch (1960) considers physical characteristics from the residential unit to the neighbourhood scales to describe spatial quality. For example, in the analysis of urban elements, Lynch (1960) describes the spatial quality of an urban area by considering building heights and facade composition as attributes that emphasize the 'feeling' of human scale (p. 160). Gehl (2010) describes spatial quality by mentioning features from the residential unit to the block scales. Gehl (2010) highlights the importance of proportions and dimensions of buildings and facade elements to emphasize the human scale in urban environments. In the PhD research facade, composition is considered in the spatial quality determinant of (3) transition between public and private spaces, principles (D) and (E) (Table 3). Building heights and proportion are included in the spatial quality determinant of (4) perceived density, built and human densities, principle (A) (Table 4).

Gehl (2010, 2011) discusses quality related issues in the urban environment under the term spatial quality. In his analysis of urban environments, Gehl (2010) discusses the importance of the 'good view', the 'unhindered lines of vision', and the 'visual contact between outside and inside' spaces as indicators of spatial quality on the building scale (p. 148−149). Quality of the view is included in the determinant of (1) view, in principle (B), and visual contact and privacy are considered in principles (B) and (C) (Table 1).

Uytenhaak (2008) highlights the relevance and potential of spatial quality in urban environments. Uytenhaak (2008) considers spatial quality an instrument for improving urban environments on building and neighbourhood scales. The main spatial quality related issues are privacy, transition between public and private domains, articulation between the micro scale of architectonic details (such as facade composition) and the macro scale of the neighbourhood, building heights and density, views and daylight (Uytenhaak 2008). Daylight is included in the spatial quality determinant of (1) view, in principle (D), and in the determinant of (2) internal spatiality and spatial arrangements, principle (E) (Tables 1 and 2). Density is included in the determinant of (4) perceived density, built and human densities, principles (C) and (D) (Table 4).

3.1.2 Universal principles on the perception of space and spatial quality

The authors in group 2 are the ones that have defined universal principles about the perception of space, which have been considered in the study of spatial quality in the PhD research. Lynch (1960), Kaplan (1989), Russel and Snodgrass (1989), Nasar (1992/2000) and Berman et al. (2008) are the main authors in this group. The cognitive preference model proposed by Kaplan (1992) (Figure 1), and the theory on the evaluation of human experiences of a place (Figure 2) developed by Russel and Snodgrass (1989) are the starting points in this PhD research for the study of the perception of space, and for the development of the spatial quality definition and assessment.

Kaplan (1992) developed a cognitive preference model to explain the origin of universal aesthetical preferences and their evolution. Aesthetical preferences are related to survival strategies and adaptation during the evolution of humankind. Survival depends on quick understanding of and adapting to changes. Adaptation is the result of exploration (Kaplan 1992). Kaplan (1992) indicates that the human reactions of understanding, exploring and adapting depend on the immediate and inferred understandings of the environment. The immediate understanding of the environment is determined by coherence, while inference (deduction) depends on legibility (clarity, how understandable the environment is and how easy it is to predict future conditions) (Zajonc 1984, Kaplan 1989). The complexity of the environment causes people to strategically explore survival alternatives in the struggle for life (Zajonc 1984). More exploration leads to more information (Kaplan 1992). Kaplan (1992) considers that discoveries, which result from the exploration of the environment throughout human trajectory, form the core of developing aesthetical preferences. Universal aesthetical preferences are a result of the balance between complexity and coherence of the environment where human interaction takes place (Kaplan 1992).

	Understanding	**Exploring**
Immediate	Coherence	Complexity
Inferred	Legibility	Mystery

Figure 1. Cognitive preference model (Kaplan 1992).

The emotional appraisal (assessment) of a place is personal and can vary considerably across observers. However, Kaplan (1992), Hull and Revell (1989), Ulrich (1993) and Nasar (1992/2000) highlight universal principles among different cultures that influence emotional appraisal. These common principles are consequence of human evolution (Hull & Revell 1989, Kaplan 1992, Ulrich 1993, Nasar 1992/2000). Humans had to survive various threats through adaptation, and the ones that survived passed on a genetic predisposition for a certain evaluative image (Nasar 1992/2000). An evaluative image is a visual interpretation of a physical context. Individuals have similar direct initial responses to formal characteristics of space such as shape, proportion, rhythm, scale, colour, illumination, shadowing, geometry, hierarchy in spatial relations, complexity, incongruity, ambiguity, surprise, novelty and order (Altman & Wohlwill 1976, Lang 1987, Groat 1990, Weber 1995, Nasar 1992/2000). These responses are survival mechanisms that are independent of previous experiences, thus prior to cognition (Zajonc 1984).

People usually evaluate visual aspects when asked to evaluate their surroundings (Nasar 1992/2000). Visual quality is one of the aspects that influence the perception of spatial quality (Rapoport 1982/1994). Nasar (1992/2000) defines visual quality and assesses it considering monotony, dryness, ugliness and the sense of order or the lack of it. Nasar and Di Nivia (1987) observed the changes the inhabitants of new industrialized houses made to their houses. The houses did not have insulation nor heating, among other technical deficiencies. Despite of the cold weather, the inhabitants preferred to paint the facades of the houses first, to make them look better instead of adding insulation or heating (Nasar & Di Nivia 1987).

Nasar (1992/2000), and Russel and Snodgrass (1989) propose an evaluation of human emotional experiences of the physical environment (affective appraisals of a place), based on individual emotional considerations. Russell and Snodgrass (1989) define four emotional states to evaluate human emotional experiences of space: pleasant, arousing, unpleasant and sleepy (Figure 2). Preference and interest are the main feelings that drive human choices and perception of quality (Kaplan 1989). Preference is dependent on excitement and complexity (Russell & Snodgrass 1989). The higher the complexity of a space, the higher is people's preference for it, but until a certain limit (Russell & Snodgrass 1989). Kaplan (1989) observed that preference decreases when the environment becomes too complex and loses coherence. Therefore, he concludes that humans prefer a moderate level of complexity (Kaplan 1989).

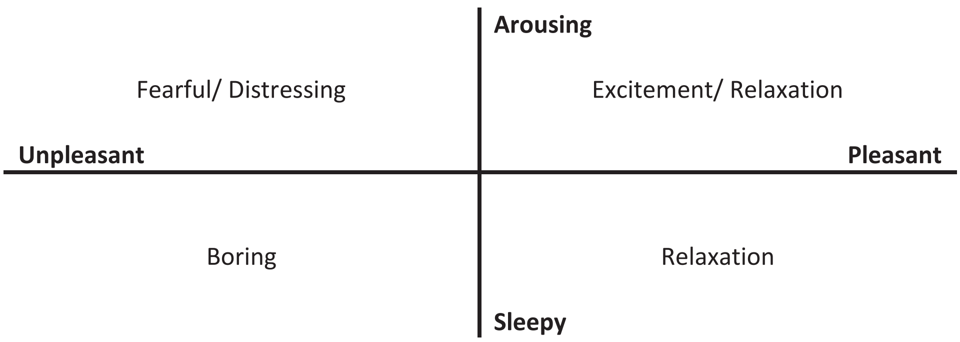


Figure 2. Affective appraisals are based on the dualities pleasant/ unpleasant and arousing/ sleepy (Russel & Snodgrass 1989, Nasar 2000).

Nasar (1992/2000) and Kaplan (1982) identify six attributes of preference that define the coherency of space: order, moderate complexity, openness, naturalness, upkeep, and historical significance. Order, complexity and openness represent formal variables, whereas naturalness, upkeep and historical significance represent content or symbolic variables (Nasar 1992/2000). Order is the main attribute among the formal variables of preference (Kaplan 1982). Other variables related to order are organization, coherence, fittingness, congruity, legibility and clarity (Nasar 1992/2000).

Complexity or visual diversity (Kaplan 1989) refers to the relation between different elements in a space. The presence of several elements that appear to be unconnected, leads to a higher sense of complexity, which increases interest (Kaplan 1982). Research on facade compositions confirms the increase of interest by measuring the viewing time that participants stared at a certain facade (Oostendorp 1978; Nasar 1988). Complexity depends on novelty and familiarity (Nasar 1992/2000). The observer who is familiarised with a certain space would experience it as a space with low complexity (Kaplan 1982, Nasar 1992/2000). People prefer familiarity in complex spaces and novelty in simpler spaces (Nasar 1992/2000).

Openness consists of open spaces and wider views (Lynch 1960, Nasar 1992/2000). Open spaces provide clarity and better understanding of the scene, and provide a sense of free movement (Kaplan 1989). The ideal openness is the moderate and defined openness (bounded space) instead of unclear openness (Lynch 1960; Kaplan 1989; Nasar 1992/2000).

Naturalness refers to the presence of natural elements in the view such as water, vegetation and topographic characteristics (Nasar 1992/2000). Nature transmits order and coherence, even there is a large variety of elements that characterizes chaos (Wohlwill 1983, Berman et al. 2008). People consider natural scenes more orderly and coherent than man-made ones (Nasar 1992/2000).

3.1.3 Physical characteristics of space relevant to spatial perception

The authors in group 3 identify physical characteristics that are relevant to spatial perception. The main authors in this group are Rapoport (1970/1994, 1977, 1982/1994, 2005), Weber (1995), Von Meiss (1997) and Gehl (2010, 2011). The main contributions of Rapoport's (1970/1994, 1977, 1982/1994, 2005) and Gehl's (2011, 2011) work to the PhD research are the general principles for the analysis of spatial quality in urban environments. The main contributions of Weber's (1995) work to the PhD research are the five three-dimensional principles of figural segregation, and the three two-dimensional principles of stability in facade composition. The work of these authors are included in the spatial quality definition and assessment.

A) Rapoport (1970/1994, 1977, 1982/1994, 2005) and Gehl (2010, 2011)

Rapoport (1970/1994, 1977, 1982/1994, 2005) suggests general principles in the analysis of spatial quality in dwellings, which correspond to the principles proposed by Gehl (2010) in the analysis of spatial quality in the urban environment. The principles that are relevant for the PhD research are:

A1) Daylight. Daylight is relevant to the proper fulfilment of functions in a space (Rapoport 1970/1994, 1982/1994, Gehl 2010). Daylight incidence is included in the spatial quality determinants of (1) view, principle (D), and (2) internal spatiality and spatial arrangements, principle (E) (Tables 1 and 2, Chapter 2. Objectives of the research work);

A2) Privacy level. Rapoport (1970/1994, 1977) and Gehl (2010) define privacy levels as the desired level of visual interaction with neighbours and strangers. Privacy levels change according to culture but there is always some level of privacy desired in urban environments to protect activities and individuals from unwanted interaction (Rapoport 1970/1994, 1977). Privacy in the sense of visual interaction between inside and outside spaces is included in (1) view, principle (B) (Table 1, Chapter 2. Objectives of the research work);

A3) Density. Density affects the quality of life in the urban environment (Rapoport 1977, 1982/1994, Gehl 2010, 2011). Built and human densities are considered in the spatial quality determinant of (4) perceived density, built and human densities, principles (C) and (D) (Table 4, Chapter 2);

A4) Clear definition of public and private domains (Rapoport 1970/1994, 1977, Gehl 2010). Clear boundaries affect users' behaviour, for example regarding the responsibility for maintaining private outdoor spaces (Rapoport 1970/1994). People tend to be more engaged when they own spaces in comparison to common and public spaces, in which responsibilities can become blurry (Rapoport 1977). Clear definition of public and private domains, and the nature of the boundaries between these domains are included in (1) view, in principle (C), and in (3) transition between public and private spaces, principles (A), (B) and (C) (Tables 1 and 3, Chapter 2);

A5) Transitions between public and private spaces (Rapoport 1970/1994, Gehl 2010, 2011). Strict boundaries may be difficult to overcome (Gehl

2010, 2011). Abrupt transitions between public and private domains generate insecurity, because the defences that protect the private domain disappeared (Gehl 2010) (Table 3, Chapter 2);

A6) Meeting places in outside areas, and proportion and configuration of the empty (negative) urban space (Rapoport 1970/1994, 1977, Gehl 2010, 2011). Dimensioning of these outside areas considering building heights in the surroundings are relevant to whether these areas attract people and function as meeting places (Gehl 2010, 2011). The human scale is an important factor to consider when designing meeting places, whether it is a public square or an intimate courtyard (Rapoport 1970/1994, 1977); Proportion and configuration of the empty space are included in the spatial quality determinant of (1) view, principle (E), and in the determinant of (4) perceived density, built and human densities, in principles (A) and (B) (Tables 1 and 4, Chapter 2. Objectives of the research work).

A7) Areas with diversity of uses (mixed-use), such as residential, commercial, cultural and institutional uses on the scales of the building and neighbourhood (Rapoport 1970/1994, 1977, Gehl 2010). Diversity of uses is considered in (4) perceived density, built and human densities, in principle (E) (Table 4, Chapter 2);

A8) The connection between the building's ground floor and the street. The relationship between the ground floor and the street might be more relevant than the functions in the building, because the street level is the connection between the building and its urban environment (Gehl 2010, 2011). The relationship between the building's ground floor and the street is included in (3) transition between public and private spaces, principle (B) (Table 3, Chapter 2);

A9) The importance of natural elements in the view such as water and trees (Rapoport 1982/1994). The quality of the view is considered in (1) view, principle (B) (Table 1, Chapter 2).

B) Weber (1995), three-dimensional principles of figural segregation

Spatial quality is the perception of quality of the physical space. People perceive space through the relationships between physical elements such as walls, ceilings, doors, windows, and columns, and the void created by these elements (Von Meiss 1997). The quality of the space is direct related to the quality of the relationships between these elements, such as windows size and dimensions of the room, and ceiling heights (Weber 1995, Von Meiss 1997). Weber’s (1995) and Von Meiss’s (1997) investigations of architectural form and composition explore these relationships. For example, they suggest criteria that can be relevant in the renovation of facades in terms of composition, such as stability, balance, and dynamic properties of shapes.

Space consists of physical boundaries that are perceived two- and three-dimensionally (Weber, 1995). Weber (1995) defines space with five three-dimensional principles of figural segregation: centricity, concavity, internal division of space and spatial density, uniformity and coherence of boundaries, and closure, enclosure and peripheral density. Weber’s (1995) principles can be relevant in the renovation regarding to facade composition and the configuration of the plan. Room dimensions and placements of windows and doors for example, influence spatial quality in rooms and therefore, changes need to be considered in relation to the whole apartment unit and functionality (Weber 1995). Weber (1995) proposes the three-dimensional principles to complement the two-dimensional principles of figure–ground segregation described by the Gestalt[b] psychologists.

B1) Centricity

Weber (1995) defines the perceived centre (or centres) that results from the play of forces in the composition of space, for example the placement of windows and doors in a room. The perceived centre does not necessarily coincide with the geometrical centre of the space (Weber 1995). Convergence of forces resulting from the entire organization of the space and the articulation with its boundaries defines space (Weber 1995, Von Meiss 1997, Indraprastha & Shinozaki 2012). A shape may have many secondary perceived centres, but the fewer perceived centres the clearer is the space (Figure 3) (Weber 1995). Weber (1995) states that spaces with secondary perceived and geometrical centres can preserve figural character and balance by arranging these centres symmetrically in the space. Indraprastha and Shinozaki (2012) propose a method to find the perceived centres considering the influence of windows and doors, with the geometrical centre of the space as the starting point (Section 3.1.5 Development of the spatial quality definition and assessment).

B2) Concavity

The placement of the entrance of the room, and of elements such as columns may emphasize concavity (Weber 1995). The perceptual concavity becomes stronger as the entrance gets closer to the geometrical centre of the space (Weber 1995) (Figures 4a, 4b and 4c). Columns, niches and angular walls can enhance concavity in spaces. Entrances placed close to the axes of the space, and

[b] The Gestalt laws of grouping (proximity, similarity, closure, symmetry, continuity, common fate, good Gestalt, and experience) consist of a tool to analyze the perception of visual form (Metzger 2006).

on the longitudinal axis also increase concavity (Weber 1995). Centricity and concavity are relevant for the study of spatial quality in this research, because they influence the perception of order, complexity and openness of space (Kaplan 1982, Nasar 1992/2000, Weber 1995).

Centricity and concavity are included in the spatial quality determinant of (2) internal spatiality and spatial arrangements, in principle (A) (Table 2, Chapter 2. Objectives of the research work) (Acre & Wyckmans 2015a).

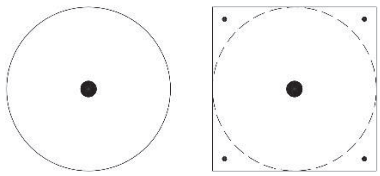


Figure 3. Geometrical centre and perceived centres in simple shapes (3a) (Weber 1995, p. 139).

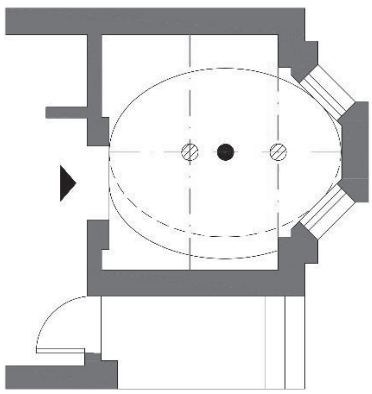
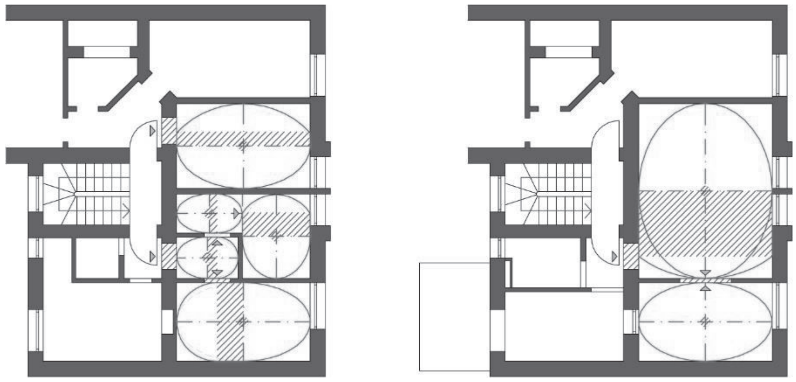


Figure 4(a). Perceived centre of a room in the Willitts House. The central placement of the entrance on the longitudinal axis, and the bay window emphasize concavity in the room. Willitts Ward W. House, Illinois, United States, architect Frank Lloyd Wright, 1902 (Frank Lloyd Wright Foundation 1976). Figure: Fernanda Acre.



Figures 4(b) and 4(c). Plans of the first floor before (4b) and after (4c) the building renovation. Concavity of the living rooms in a residential building. The closer the entrance is placed to the cardinal axis of the room from the geometrical point, the higher the concavity in the room. The concavity in the rooms is represented by an ellipse drawn in relation to the placement of the entrance(s) in the rooms. The more accurate the ellipse, the higher the concavity of the room. Residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL. Figures: Fernanda Acre.

B3) Internal division of space and spatial density

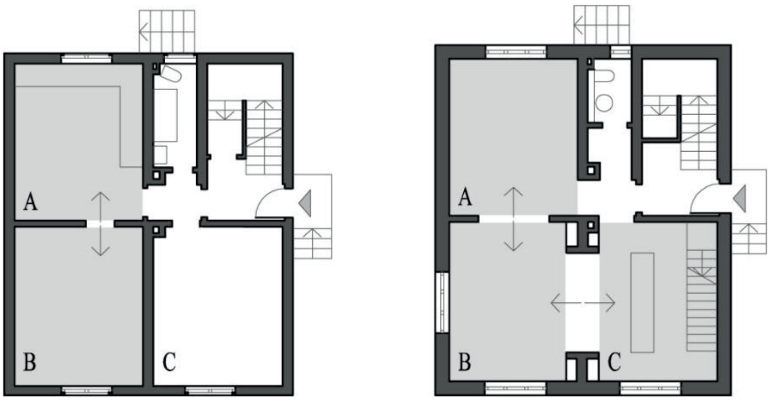
In this principle, Weber (1995) considers spatial density, and spatial arrangements among spaces within the whole. Spatial density refers to the volume occupied by internal walls and columns in relation to the total volume of the space (Weber 1995, Von Meiss 1997). Plans where walls occupy a high percentage of the total volume of the dwelling unit for example, tend to present large circulation areas, and may therefore have a less efficient area use, in comparison to dwellings with little circulation areas (Weber 1995). Plans with few walls on the other hand, may not properly fulfil the function of dwelling needs. The placement of physical elements in the space can subdivide or articulate spaces: ceilings heights and columns for example, can subdivide interior spaces into smaller ones without the use of walls (Weber 1995) (Figures 5a and 5b). The sense of division depends on the density of the spacing between these physical elements.

Figures 5(a) and 5(b). Examples of the use of ceiling heights to define spaces and functions, such as a kitchen (5a) and a living room (5b). Figure 5(a): Private house, Herentals, Belgium, © [Toon Grobet]. Reproduced by permission of Toon Grobet. Figure 5(b): Private house, Alvite, Portugal, © [Fernando Guerra]. Reproduced by permission of Fernando Guerra.

Most of the spaces are usually not isolated but part of complex spatial systems (Weber 1995). Symmetry, order and balance in spatial relationships affect the complexity of the spatial system as a whole (Von Meiss 1997). Weber (1995) defines complex spatial arrangements based on hierarchy within spatial systems: the coordinate and subordinate spatial relationships[c]. In the coordinate

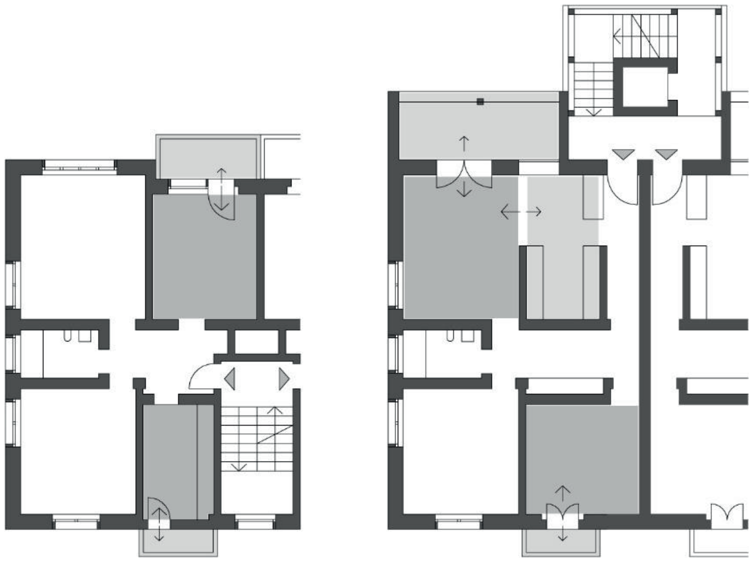
[c] Weber (1995) does not include complex spatial arrangements in his principle of internal division of space and spatial density. This inclusion is proposed in this PhD work to summarize Weber's (1995) definitions.

organization, the adjacent spaces have similar dominance since they are similar in size, shape and articulation (Weber 1995) (Figures 6a and 6b). Direct connection between two or more coordinated spaces may lead to large circulation areas. This can be particularly relevant if one or more spaces in a coordinated organization of adjacent spaces do not have direct access to circulation areas.



Figures 6(a) and 6(b). Plans of the ground floor before (6a) and after (6b) the building renovation. Coordinated relationship of spaces. Private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL. Figures: F. Acre.

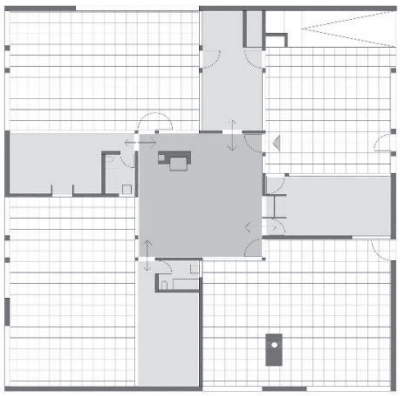
The subordinate spatial organization is characterized by hierarchical spatial arrangements between rooms, which are diverse in size, format and articulation (Weber 1995) (Figures 7a and 7b). Subordinate spatial arrangements present a higher complexity than coordinate spatial arrangements (Weber 1995). This is because of the different perceptual dominance of the individual parts, which allows the observer to 'distinguish between primary and ancillary spaces' (Weber 1995, p. 171). The primary space is the dominant space and the secondary is the space subordinated to the main (primary) space. Subordinated spatial relationships are the most usual in dwellings. For example, the relation between a balcony and a living room, the living room is the primary space and the balcony is the subordinate space. Nonetheless, the living room retains its figural character, but the boundary to which the balcony was added becomes more dominant, because it now contains perceived centres created by the balcony, which is the subordinate space (Weber 1995). Subordinate spaces can reinforce the main centre when placed symmetrically in the space (Weber 1995).



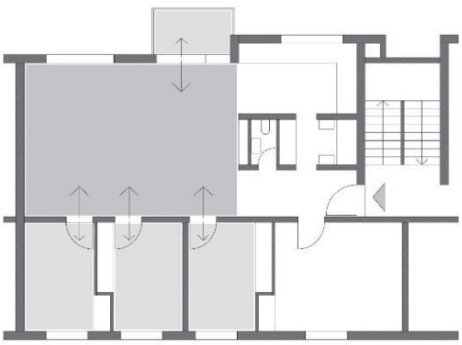
Figures 7(a) and 7(b). Plans of the first floor before (7a) and after (7b) the building renovation. Subordinated relationship of spaces. Residential building, Chur, Switzerland, © [DETAIL]. Reproduced by permission of DETAIL. Figures: F. Acre.

Spatial arrangements can be rhythmical or coordinated in subordinated spatial relationships (Weber 1995). That is, secondary spaces can be arranged rhythmically or in a coordinate way (Figures 8a, 8b and 8c). Rhythmical arrangements of secondary spaces increase the spatial complexity of the whole system (Weber 1995).

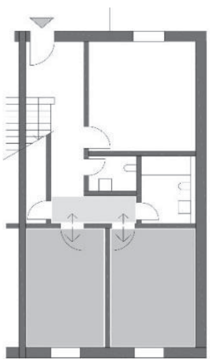
Internal division of space and spatial density are included in the spatial quality determinant of (2) internal spatiality and spatial arrangements, in principles (B) and (C) of the spatial quality definition and assessment (Table 2, Chapter 2. Objectives of the research work).



a



b



c

Figures 8(a), 8(b) and 8(c). Subordinated spatial relationships: Rhythmical arrangement of secondary (subordinated) spaces. House in California, United States, architect Donald Olsen (8a) (Chermayeff & Alexander 1966). Coordinate arrangements of secondary spaces. Residential building, Örebro-Baronbackara, Sweden, 1955, architects Per-Axel Ekholm and Sidney White (8b) (Schneider 2004). Residential building, Im Büel, Switzerland, 1986, architects Schnebli, Ammann, Egli and Rohr (8c) (Schneider 2004). Figures: Fernanda Acre.

B4) Uniformity and coherence of boundaries (facades)

Weber (1995) considers uniformity and the coherence of boundaries in relation to physical features of the block and the facade composition. For the spatial quality definition proposed in this research, the principle of uniformity and coherence of boundaries is considered in relation to the facade composition only. This is because physical features of the block are already included in (4) perceived density, built and human densities, in the principle of (A) spatial complexity (Lynch 1960) (Table 4, Chapter 2). Lynch's (1960) principle of spatial complexity is more comprehensive than Weber's (1995) principle of uniformity and coherence of boundaries for the analysis of the physical features of the block.

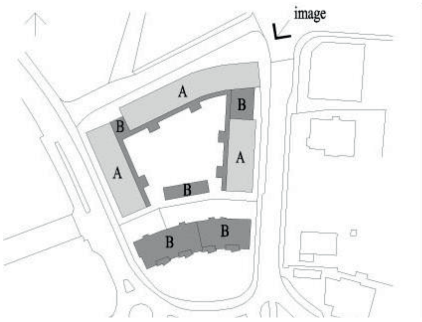
The principle of uniformity and coherence of boundaries considers homogeneity and heterogeneity in facade composition, namely facade roughness (Serra 1997) and similarities in materials and formats of architectural elements (Weber 1995) (Figures 9a, 9b and 9c). Facade roughness is the relation between the projected bounces on the facade (such as balconies and bay windows) and the facade as a whole (Serra 1997). The consequence when some parts are more dominant than others is the weakening of the overall figural strength (Weber 1995).

Nevertheless, Weber (1995) states that homogeneity of spatial boundaries does not mean that all the facades should be identical. However, it should be possible to identity formal similarities and patterns, which provide an overall unified effect to the facade (Weber 1995). Uniformity and coherence of boundaries are considered in the spatial quality determinants of (3) transition between public and private spaces, in principle (D) (Table 3, Chapter 2).

Figures 9(a), 9(b) and 9(c). Similarities in scale, proportion, materialization, rhythm and facade roughness. Student housing, Copenhagen, Denmark. Figures: Fernanda Acre.

B5) Closure, enclosure and peripheral density

The block is the element of analysis of this principle, which is included in (4) perceived density, built and human densities (Table 4, Chapter 2). Closure refers to whether the block is physically bounded, or whether a space between the buildings may be perceived as a mass in itself (Weber 1995). Weber (1995) describes the perceived mass of a block as 'cognitive contours' (p. 149) (Figures 10a and 10b). Enclosure refers to the height-to-width ratio (proportion) of the courtyard (Weber 1995). Peripheral density expresses the internal articulation of the spatial boundaries (namely building heights and continuity of block borders) (Weber 1995) (Figures 10a to 10d).



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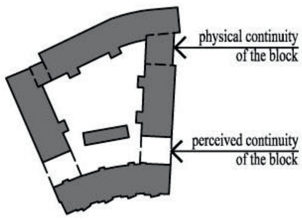


b

c

d

Figures 10(a), 10(b), 10(c) and 10(d). Residential block, Chur, Switzerland. Plan and picture of the residential block after the renovation with the addition of a new building (10a to 10c). Buildings 'A' are existing; buildings 'B' are additions that close the perimeter of the block. © [DETAIL]. Reproduced by permission of DETAIL. Figures: Fernanda Acre. Residential block before and after the renovation (10c and 10d) © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.

C) Two-dimensional principles of stability in facade composition

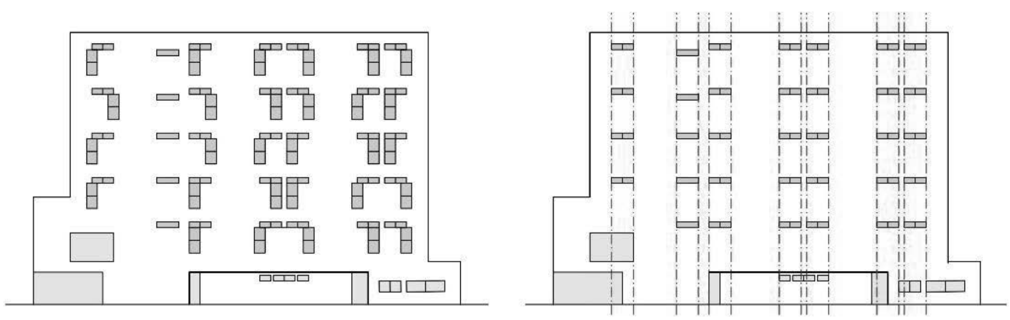
Weber (1995) illustrates perceived stability in facade composition with the analysis of physical properties of shapes in relation to dynamic properties, location of the centre and perceptual mass. A shape is not a 'face bounded by a contour' only; 'it is an entity whose parts have different visual impact' (Weber 1995, p. 186). The centre of a shape is the 'centre of balance between perceptual forces', and 'the centre of fixation for the eyes during the process of visual scanning', and it does not necessarily coincide with the physical centre of the space (Weber 1995, p. 186). The understanding of a facade composition depends on the distribution in patterns of its main masses, and of visual weights in relation to its centre. Visual weights are size, articulation, regularity, dominance, location and direction, which influence the perceived stability in facade compositions (Weber 1995). Weber (1995) defines some general two−dimensional principles for stability in facade composition, where three of them are relevant to this research in the study of facade composition: hierarchical relationships between elements in the facade composition, figure (windows and doors) and ground (walls) articulation, and perceived stability and dynamic of a shape.

C1) Hierarchical relationships between elements in the facade composition

Weber (1995) classifies the hierarchical organization of architectural elements such as windows in the facade, into subordinate and coordinate arrangements of component groups and subgroups. Component groups and subgroups are elements in the facade composition that are clustered in segregated perceptual units according to difference in size, rhythm, symmetry, contrast in tone, colour or texture (Weber 1995) (Figure 11b). Ideally, the facade composition should have the 'arrangement of a subordinate type' at the highest levels, while ‘coordinate arrangement may govern at lower levels’ to achieve high perceived stability and balance of visual forces in the composition (Weber 1995, p. 212).

In Figures 11 the facade composition presents subordinate and coordinate arrangements at lower levels of component groups and subgroups (Figure 11b), and subordinate arrangement type at the highest level considering the entire facade composition (Figure 11a). All windows are shaped after the same basic components; the difference between the secondary and primary groups at the highest level in the facade composition is the reduction of the number of windows on the left side of the facade (Figure 11a).

In Figures 12 the facade composition presents coordinate arrangements at lower levels of component groups and subgroups (Figure 12b), and subordinate arrangement type at the highest levels considering the entire facade composition (A+, A, A-, Figure 12a). The windows are also shaped after the same basic component as in the example in Figures 11. The subordinate arrangement at the highest level in this example of facade composition is defined by the variations A and A+, which consist of the primary group, and the variation A- that is the secondary group (Figure 12a).



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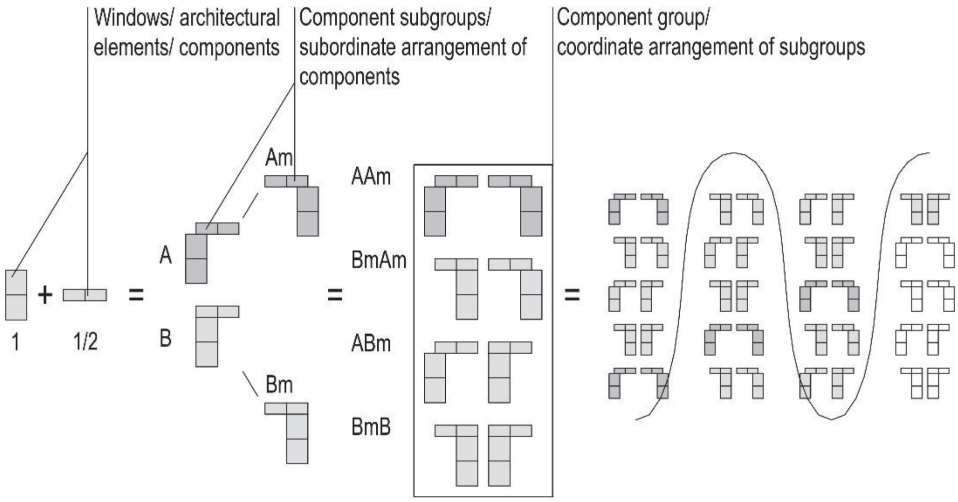

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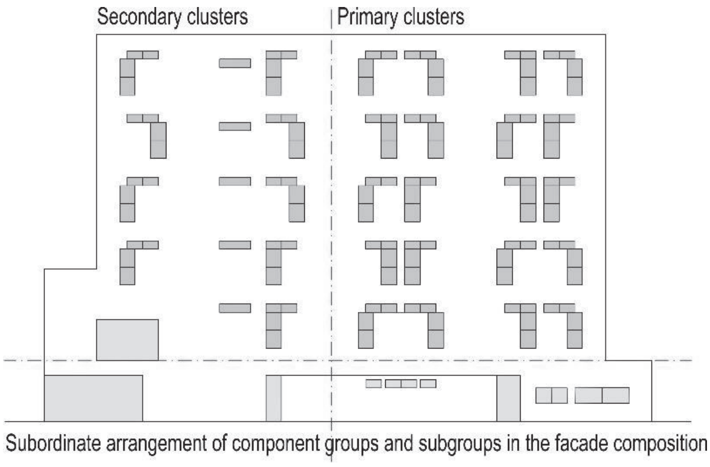
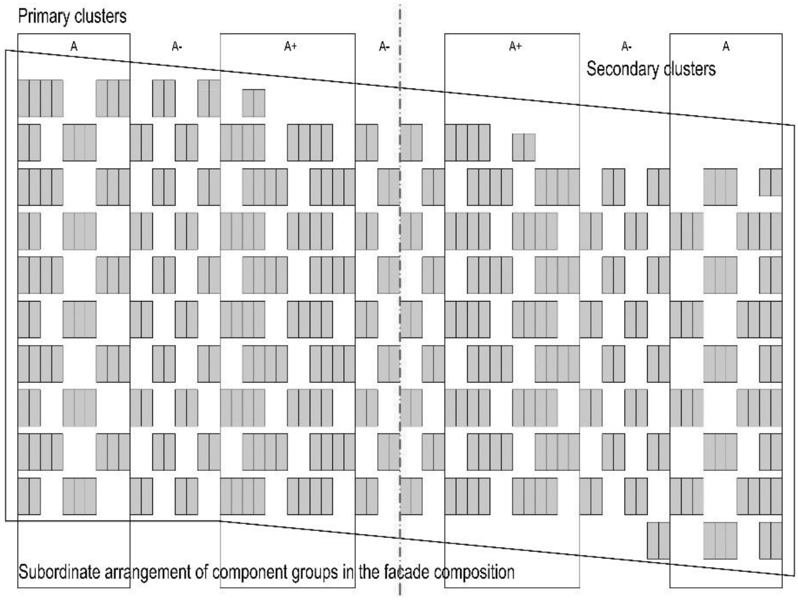
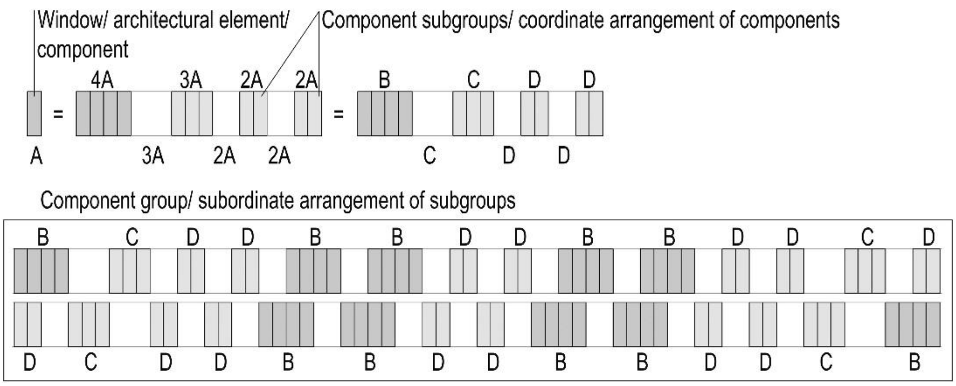


c

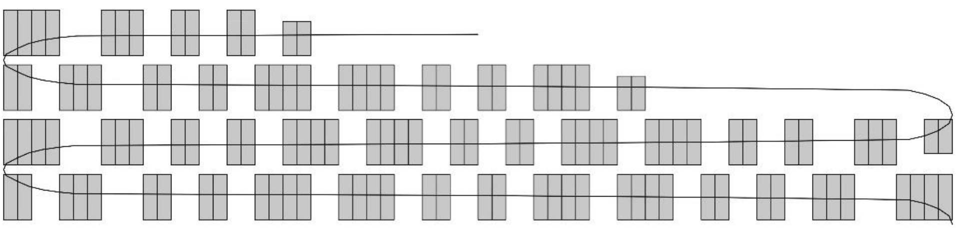
Figures 11(a), 11(b) and 11(c). Hierarchical relationships between elements in the facade composition. Facade and main axes of facade composition (11a). Subordinate and coordinate arrangements of component groups and subgroups originating from a basic shape (11a and 11b). Rhythm of facade composition with vertical orientation (11c). Residential building, Los Angeles, United States, architect Michael Maltzan (Fernandez et al. 2007). Figures: Fernanda Acre.


Primary clusters
A
A-
A+
A-
A+
A-
A
Secondary clusters
Subordinate arrangement of component groups in the facade composition

a


Window/ architectural element/ component
Component subgroups/ coordinate arrangement of components
4A 3A 2A 2A
A = 3A 2A 2A
B C D D
C D D
Component group/ subordinate arrangement of subgroups
B C D D B B D D B B D D C D
D C D D B B D D B B D D C B

b



c

Figures 12(a), 12(b) and 12(c). Hierarchical relationships between elements in the facade composition. Facade and main axes of facade composition (12a). Subordinate and coordinate arrangements of component groups and subgroups originating from a basic shape (12a and 12b). Rhythm of facade composition with vertical and horizontal orientation (12a and 12c). The Whale building, Amsterdam, the Netherlands. Figures: Fernanda Acre.

Figures 12d and 12e. Articulation between figure (patterns, arrangements of windows) and ground (walls), and the facade as a whole. Residential and office building, Amsterdam, the Netherlands. Figures: Fernanda Acre.

The facade needs a clear compositional (perceived) centre for the whole and a 'distinct (compositional) centres for each of their component groups' (Weber 1995, p. 212). The compositional centre attracts the eye during the scanning process (Weber 1995). Weber's (1995) assumptions trace back to studies such as Brandt's (1945), republished in 2013, and Brengelmann's (1967). Both authors studied the perception of stability in images. Brandt (2013) for example, performed a series of experiments on eye movements with college students as observers. Brandt (2013) concludes that there is a strong preference for the left side, and that upper parts receive more attention than lower parts in image scaning.

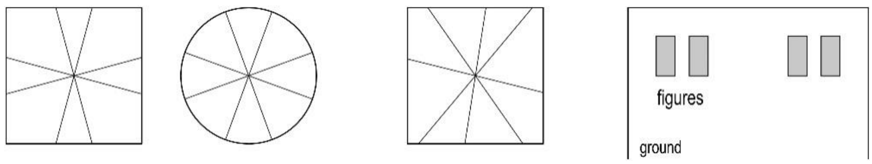
C2) Figure (windows and doors) and ground (walls) articulation

This is the articulation between patterns and the facade as a whole. Weber (1995) describes two elements for articulation in facade composition: figure (patterns, arrangements of windows) and ground (walls). In Figures 12d and 12e for example, the facade is composed by the wall, which is the ground, and the windows, which are the figures. Weber (1995) proposes the laws of figure and ground articulation based on the work of Gibson (1979/2015) on visual perception. Gibson (1979/2015) performed several experiments to study natural (real) vision by reproducing real conditions in laboratories. Gibson (1979/2015) believed that laboratories should simulate reality as accurately as possible, instead of making experiments in conditions that are only possible in laboratories, and therefore detached from the real world.

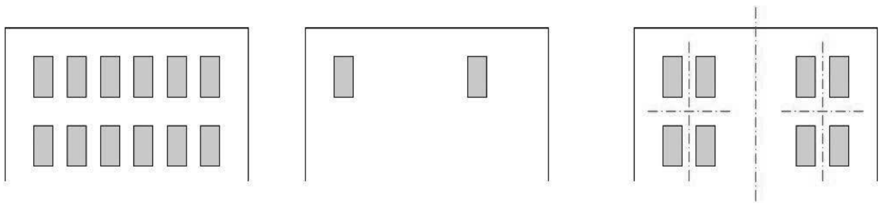
The laws of figure and ground articulation are (Weber 1995, pp. 230–231):

- Orientation. Shapes whose 'dominant orientation extends along the cardinal axes will form figures more easily than shapes with divergent orientations' (Figure 13a);
- Proximity. 'Small areas will dominate larger ones, with the larger areas tending to assume the role of ground' (Figure 13b);
- Articulation. 'By definition, the ground is always simpler than the figure, and areas with greater internal articulation will form figures −patterns− more easily than areas with little articulation' (Figure 13c);

- Symmetry. Symmetry of elements in the facade creates patterns (Figure 13d).



a b



c d

Figures 13(a), 13(b), 13(c) and 13(d). The laws of figure and ground articulation. Orientation (13a), proximity (13b), articulation (13c) and symmetry (13d). Figure 13(a): Weber (1995), p. 231. Figures 13(b) to 13(d): Fernanda Acre.

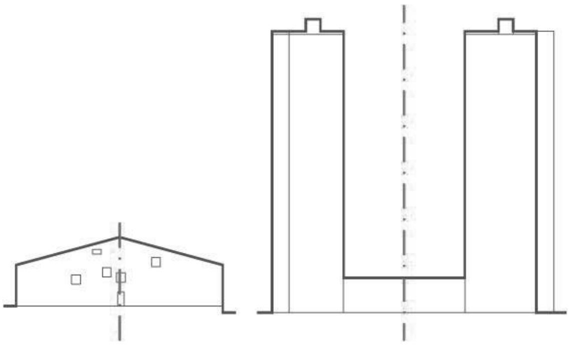
The laws of figure and ground articulation (Weber 1995) can be applied to the facade composition of The Whale building in Amsterdam (Figures 12a to 12e):

- Orientation: the facade has a dominant orientation along the horizontal cardinal axis (Figure 12c);
- Proximity: the walls assume the role of ground. However, the difference between figure and ground is rather blurry in The Whale's facades, because the dimensions of the windows are equal or proportional to the spaces between the windows;

- Articulation: the ground (the walls) in The Whale’s facades are not simpler than the figures (windows). This results in a facade composition with high articulation, however the symmetry and rhythm balance the articulation;
- Symmetry: the symmetry of elements in the facade creates patterns (arrangements of windows) and rhythm.

C3) Perceived stability and dynamic of a shape

The vertical and horizontal directions in the Cartesian system are the base for perceived stability and dynamic of a shape (Weber (1995). Based on studies of the psychologist Takala (1951), Weber (1995) illustrates that ‘of the two cardinal dimensions, the vertical has much greater significance for figural segregation than the horizontal’ (p. 206). Weber (1995) discusses the tendency in human spatial perception to overestimate vertical dimensions of objects such as towers and masts by an average of 30%. An element with strong vertical accent such as a tower, placed on the axis of vertical symmetry (the position of the main focus on the facade composition), increases the perceived stability of horizontal oriented shapes (Weber 1995). In terms of symmetry, Takala (1951) illustrates that a facade composition, for example, appears more stable when it stretches horizontally rather than vertically, and is vertically symmetrical. Vertical symmetry appears to have ‘a higher perceptual stability than those with a horizontal axis of symmetry or without any distinct symmetry’ (Weber 1955, p. 206) (Figures 14a and 14b).



Figures 14(a) and 14(b). Presence of strong vertical accents and vertical axes of symmetry (indicated by the dashed line). Representation of dwellings, Delft, the Netherlands (14a) and Hoge Heren Residential Towers, Rotterdam, the Netherlands (14b). Figures: Fernanda Acre.

The three two-dimensional principles of stability of Weber (1995) are included in the spatial quality determinants of (3) transition between public and private spaces, in principle (D), for the analysis of facade composition, and in (4) perceived density, human and built densities, principle (A) (Tables 3 and 4, Chapter 2. Objectives of the research work), for the analysis of block shape.

In this research, the formal characteristics of space of shape, proportion, scale, rhythm, geometry, and complexity are considered in the spatial quality determinants of (3) transition between public and private spaces, in principle (D), and of (4) perceived density, built and human densities, in principles (A) and (B) (Tables 3 and 4, Chapter 2). Hierarchy in spatial relations and formal characteristics of space, are considered in the determinant of (2) internal spatiality and spatial arrangements, principles (A), (B) and (C) (Table 2, Chapter 2).

3.1.4 Energy efficiency renovation, and relevance of non-technical drivers in renovation of dwellings

The group 4 consists of two types of authors. The first type of authors are the ones that technically describe renovation of buildings and of dwellings for energy efficiency. These authors are Baker (2009) and Burton (2012) and they are important for the PhD research because they are the base for the understanding of energy efficiency renovation of buildings. The technical measures for renovation of dwellings for increased energy efficiency according to Baker (2009) and Burton (2012), are described in Chapter 7. 'Energy efficiency renovation of dwellings'.

The second type of authors in this group consists of those who emphasize the relevance of non-technical drivers to increase user acceptance towards renovation, which promotes building renovation. These authors consider non-technical drivers such as organizational, social and behavioural issues as being relevant for building processes. They also emphasize the need for a cross-disciplinary approach in renovation of dwellings. These authors are: Burton (2012), JCHS (2009), Novikova et al. (2011), Wilson and Dowlatabadi (2011), Whitmarsh et al. (2011), Patterson (2012), Tweed (2013), Judson and Maller (2014), Wallenborn and Wilhite (2014) and Wilson et al. (2013, 2015). They give arguments to support that the exclusion of non-technical issues affects the acceptance of energy efficiency renovation by occupants. This is because technical issues in energy efficiency renovation remain abstract for many laypersons, contrary to non-technical aspects (Novikova et al. 2011, Whitmarsh et al. 2011, Wilson & Dowlatabadi 2011, Tweed 2013, Wilson et al. 2015).

Technology should provide an 'enabling or modifying set of criteria in the design process, not a determining one' (Rapoport 1982, p. 336). The authors from this group except for Baker (2009), point out the predominantly technical approach in dwelling renovation. Many non-technical issues are currently not considered in energy efficiency renovation of dwelling because they are not directly relevant to energy efficiency (Burton 2012, JCHS 2009, Novikova et al. 2011, Wilson & Dowlatabadi 2011, Whitmarsh et al. 2011, Patterson 2012, Tweed 2013, Judson & Maller 2014, Wallenborn & Wilhite 2014, Wilson et al. 2013, 2015). In cases in which non-technical issues are considered, the emphasis is often on occupant behaviour, satisfaction related to technological improvements, thermal comfort, and the users' potential to influence energy consumption and CO_2 emissions (Tweed 2013). This approach does not include many issues considered in this PhD research such as spatial arrangements, transition between public and private domains, and visual privacy, which may be potential determinants for successful renovation of dwellings.

Novikova et al. (2011), and Wilson and Dowlatabadi (2011) highlight the influence of building appearance on the willingness of users to decide for energy efficiency renovation. Novikova et al. (2011) explore key motivators for renovation for improving thermal performance in 2000 dwellings in Germany. The dwellings were divided in three categories: (1) 'households that have neither implemented nor are planning a retrofit'; (2) 'households that are planning a retrofit within the next two years'; and (3) 'households that have implemented a retrofit within the last five years' (Novikova et al. 2011, p. 3). This study indicates that building appearance is more likely to be an important motivation for householders in categories 1 and 2 that is, for those that have neither implemented nor are planning a retrofit (category 1), and for those that are planning a retrofit within the next two years (category 2) (Novikova et al. 2011). Building appearance is less relevant for the households that had already implemented thermal retrofit (category 3) (Novikova et al. 2011).

The results of Novikova's study indicate the potential of non-technical drivers such as building appearance, to convince users to undergo energy renovation. As Novikova et al. (2011), Wilson and Dowlatabadi (2011) also conclude, non-technical drivers are often relevant prior to renovation. Householders are more likely to pursue energy renovation if the renovation also results in improvements in the building appearance (Novikova et al. 2011). People make the effort to refurbish their homes and 'want to see the results of their investments' (Whitmarsh et al. 2011, p. 105). Energy efficiency improvements are often not clearly visible for users, while for example improvements in building appearance and spatiality are noticeable (Novikova et al. 2011, Whitmarsh et al. 2011, Wilson & Dowlatabadi 2011). Whitmarsh et al. (2011, p. 105) refers to the 'invisibility of energy' to explain the reason why people give low priority to energy issues.

People see the impact of technology when it affects their physical space (Casey 1998). Tweed (2013) and Patterson (2012) illustrate the relevance of improvements in the spatiality of dwellings in a renovation realized in 2010 in Newport, South Wales. The renovation affected form and space, facade, appliances and mechanical systems of the dwellings. Interviews with the occupants revealed that the addition of a sunspace with roof light was the most relevant improvement of the renovation. The occupants considered the sunspace, which functioned as a buffer space for the living room, to be more relevant than the thermal benefits (Patterson 2012, Tweed 2013).

Wallenborn and Wilhite (2014) mention physicality as an aspect not sufficiently explored in domestic energy use. They claim that technical issues have been the focus for understanding energy consumption patterns, while sensory and physical experiences are often not considered.

Wilson et al. (2015, p. 12) point out that the current understanding of renovation decision-making emphasizes 'houses but not homes', and 'energy efficiency but not home improvements'. Energy efficiency renovation is considered an isolated issue and is often unpopular among households (Wilson et al. 2013).

Based on studies of energy efficiency renovation of dwellings in the United Kingdom, Wilson et al. (2013) conclude that energy efficiency measures are three times more likely to be included as part of an amenity-based renovation than when considered alone. Only one in ten renovations would aim at improving energy efficiency alone (Wilson et al. 2013). Most of the costs of renovation in dwellings in the United States are related to amenities to improve comfort and spatiality (JCHS 2009). Amenities can cost more than five times the costs of energy efficiency measures (JCHS 2009). Judson and Maller (2014) illustrate that energy efficiency measures often happened in connection with expansions, for example additional bathrooms.

3.1.5 Development of the spatial quality definition and assessment

The last group consists of authors whose work was relevant for the development of the spatial quality definition and assessment in specific areas: Chermayeff and Alexander (1966), Hopkinson et al. (1966), Altman and Wohlwill (1976), Alexander, Ishikawa, and Silverstein (1978), Ashihara (1981), Kaplan (1987), Goulding et al. (1992), Weber (1995), Baker and Steemers (1996, 2002), Hartig (2003), Indraprastha and Shinozaki (2012), Patterson (2012), Tweed (2013), Matusiak (2006, 2008, 2014, 2015), and CEN (2015). The work of Lynch (1960), Rapoport (1970/1971, 1977), Uytenhaak (2008) and Gehl (2010, 2011) is also relevant for specific areas of the spatial quality assessment.

Lynch (1960) proposes the principle of complexity, which consists of surface contrast, form simplicity and dominance, to describe physical features of the building block. Surface contrast, form simplicity and dominance are included in the spatial quality determinant of (4) perceived density, built and human densities, principle (A) (Table 4, Chapter 2. Objectives of the research work). The definition of Lynch's (1960) principle of complexity is described in Section 8.1.4 'Perceived density, built and human densities'.

Chermayeff and Alexander (1966) consider privacy to be the most critical and urgent need in the world of mass culture. Privacy is 'particularly relevant where people live' (Chermayeff & Alexander 1966, p. 37). Boundaries, which define privacy, are physical elements that protect, insulate, and control interactions between public and private domains.

Visual privacy is the selective control of visual access to oneself by others (Altman & Wohlwill 1976). Rapoport (1971/1994) discusses privacy levels and psychological effects of unwanted sensory interaction with other people, which is equivalent to loss of privacy. Gehl (2010, 2011) refers to degrees of privacy and reasonable viewing distances to protect privacy. Chermayeff and Alexander (1966) refer to degrees of sight protection, and distances to protect privacy. Degrees of sight protection consist of how much control the user has, to allow or avoid visual contact with others. The transparency and flexibility of the facade to adjust to users' preferences determine visual privacy and allow the desired freedom of choice to open or close for social interaction (Chermayeff & Alexander 1966, Altman & Wohlwill 1976). For example, Chermayeff and Alexander (1966) mention the relevance of the entry-lock zone (hall) to the dwelling, where the resident has the possibility to see arriving visitors and the entrance, without being seen (Figure 15). Visual privacy is included in the spatial quality determinant of (1) view, principle (C), and in (3) transition between public and private spaces, principle (A) (Tables 1 and 3, Chapter 2).

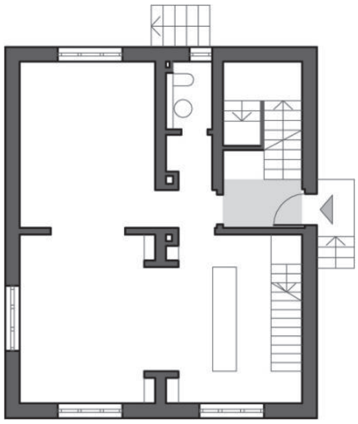


Figure 15. Inner hall, the entry-lock zone. Ground floor plan, private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL. Figure: Fernanda Acre.

Privacy within the dwelling is as important as privacy in relation to neighbours and strangers (Chermayeff & Alexander 1966). Physical boundaries within the dwelling are boundaries among different family groups and functions in the dwelling, for example, the interaction among children and parents, and the division between living and working in the dwelling (Figure 16). Chermayeff and Alexander (1966) propose separate domains within the dwelling, such as 'children and adult areas' complemented with gathering areas (p. 215). These boundaries define the hierarchical structure in the plan, and appropriate boundaries work as a connection between the different groups and functions in the dwelling (Chermayeff & Alexander 1966, p. 213). Privacy within the dwelling is considered in (2) internal spatiality and spatial arrangements, principle (D) (Table 2, Chapter 2).

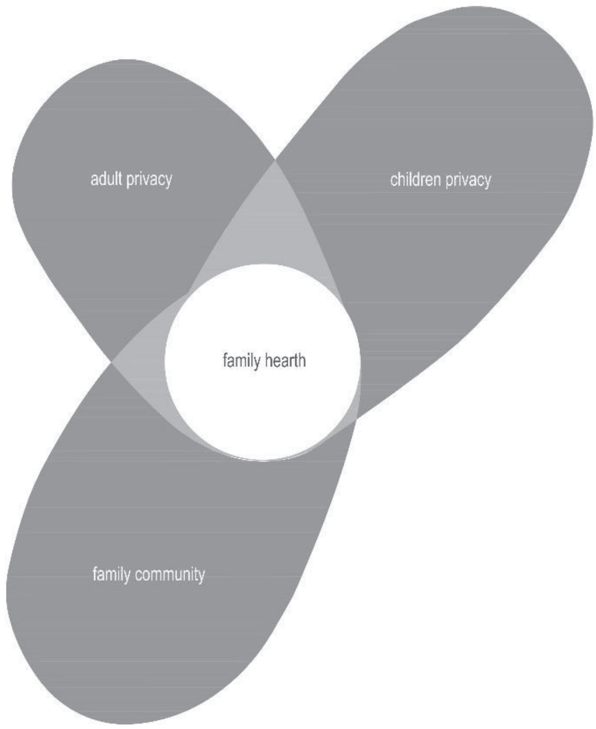
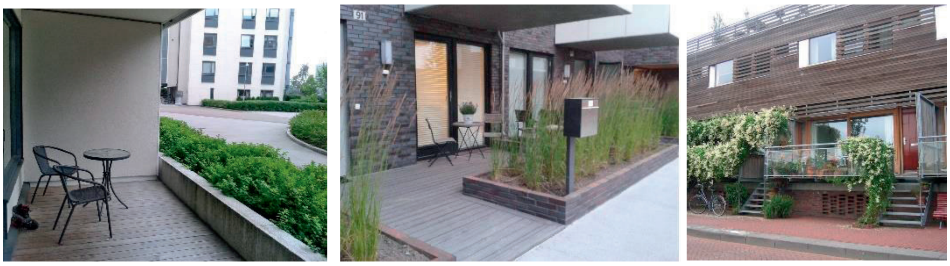


Figure 16. ‘Anatomy of dwelling: people’ (Chermayeff & Alexander 1966, p. 210).

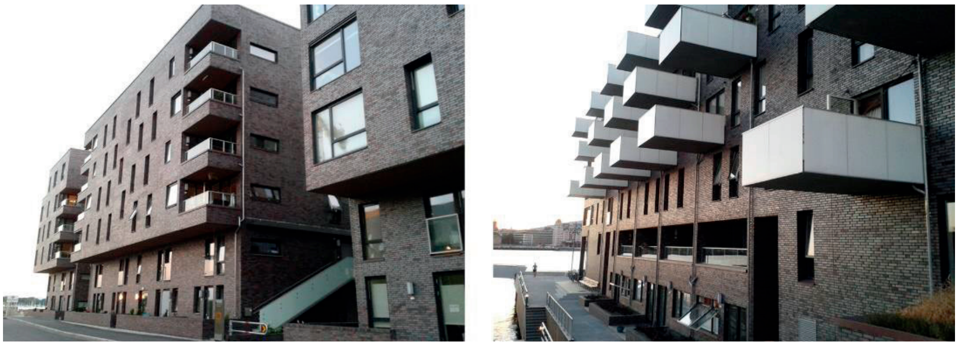
The balance between facade transparency and daylighting access versus visual privacy needs to be adjusted to achieve desired outcomes for each case. Spatial quality in dwellings is determined by how much daylight the rooms get and by the possibility to see the sky, which depends on facade transparency (Uytenhaak 2008). The higher the transparency of the facade is, the lower the privacy in the dwelling. Therefore, Uytenhaak (2008) emphasizes the relevance of searching for the optimal balance between density, the transparency of the facade and privacy. Facade transparency is mainly considered in (1) view, principle (A) (Table 1, Chapter 2).

Rapoport (1971/1994), Chermayeff and Alexander (1966), Alexander, Ishikawa, and Silverstein, (1978) and Gehl (2010, 2011) emphasize the relevance of private outdoor spaces as buffers between private and public domains (Figures 17a, 17b and 17c).



Figures 17(a), 17(b) and 17(c). Outdoor private spaces and gradual and physically clear transition between private, semi-public and public domains. Residential building, Skøyen, Oslo, Norway (17a). Residential building, Søringa, Oslo (17b). Dwellings, Borneo, Amsterdam, the Netherlands (17c). Figures: Fernanda Acre.

Uytenhaak (2008) uses the placement of balconies to exemplify the effect of the floor plan on privacy (Figures 18a and 18b). Balconies placed on top of each other provide more privacy than staggered balconies. Instead, staggered balconies have more space above, which also improves daylight access (Uytenhaak 2008).



Figures 18(a) and 18(b). Balconies placed on top of each other (18a) and staggered balconies (18b). Residential building, Oslo, Norway. Figures: Fernanda Acre.

Chermayeff and Alexander (1966), Ashihara (1981), Rapoport (1970/1994, 1971/1994) and Gehl (2010, 2011) highlight the importance of spaces with clear character (public, semi-public, semi-private or private) to create spatial order (Figure 19). Transitions between public and private domains need to be clear and gradual (Ashihara 1981, Gehl 2010). Gehl (2010) calls soft edges the gradual transition between public and private (Figures 17a to 17c, and 20a to 20d). Soft edges are necessary on the lower floors of buildings, mainly on the street level, where indoor and outdoor interact. Gehl (2010) emphasizes the potential of mixing functions to smooth transitions between public and private, for example by locating retail and offices in the lower floors and dwelling in upper floors of buildings (Figure 21a). Function is included in the spatial quality determinant of (4) perceived density, built and human densities, in principle (E) (Table 4, Chapter 2).

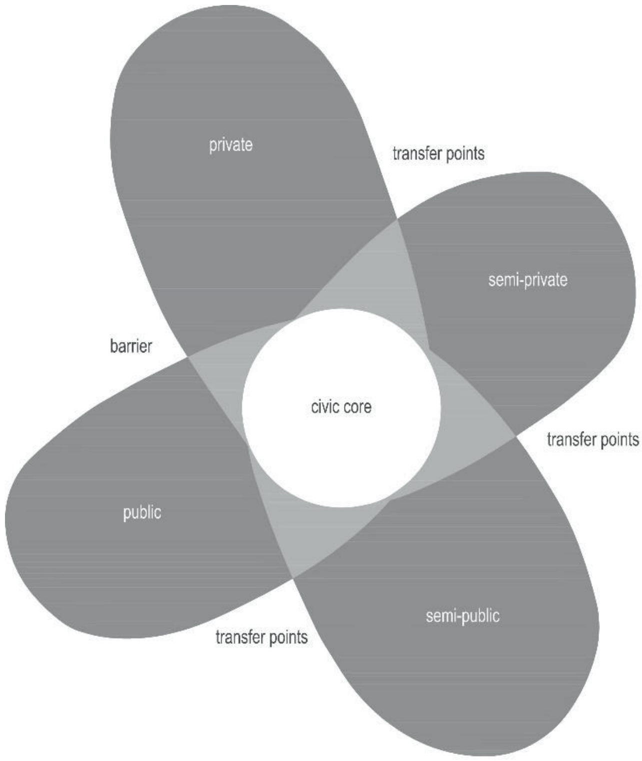


Figure 19. 'Anatomy of urban realms: areas of responsibility' (Chermayeff & Alexander 1966, p. 211).

Figures 20(a) and 20(b). Gradual and physically clear transition between private, semi-public and public domains. Private dwellings, Amsterdam, the Netherlands. Figures: Fernanda Acre.

Figures 20(c) and 20(d). Gradual and physically clear transition between private, semi-public and public domains. Residential buildings, Søringa, Oslo, Norway. Figures: Fernanda Acre.

Buildings are considered by Gehl (2010) to have soft edges, when activities inside the buildings can move out into the common space of the city; where there are opportunities for sitting and standing outside. Gehl (2010) emphasizes the importance of semiprivate front yards and staying zones to smooth transitions between public and private in residential contexts. Spaces with a clear character (public, semi-public, semi-private or private) strengthen natural surveillance, and give a greater feeling of security and a stronger sense of belonging and responsibility (Gehl 2010). Transitions should be gentle zones, which are physically indicated but flexible boundaries rather than firm demarcations (hard edges) that avoid contact with the outside world (Gehl 2011). Transitions between public and private spaces are the focus of the spatial quality determinant (3) (Table 3, Chapter 2).

Figure 21(a) and 21(b). Mixing functions to smooth transitions between public and private domains. Retail, offices and dwellings, functions with high human presence. Amsterdam, the Netherlands (21a). Storage spaces and parking located on the street level, functions with low human presence. Residential building, Rotterdam, the Netherlands (21b). Figures: Fernanda Acre.

A) Lynch (1960, 1990), Hopkinson et al. (1966), (Rapoport 1982/1994, 2005), Kaplan (1987), Goulding et al. (1992), Baker and Steemers (1996, 2002), Berman et al. (2008), Hartig (2003), Matusiak (2006, 2008, 2014, 2015), CEN (2015)

These authors are the main references in the PhD research for quality of the view, daylight access and distribution in the space. Daylight access and distribution in the space, and the internal zoning considering sun orientation, are the main factors to assess daylighting in relation to spatial quality in this research. Light affects the perception of spatiality in internal and external spaces (Ashihara 1981, Millet & Barrett 1996). The perception of size of a room is influenced by daylight (Matusiak 2008), and by windows' form and placement in the walls (Baker & Steemers 2002, Matusiak 2006). Daylight access and distribution greatly depend on the configuration of the plan and facades.

The daylight factor (DF) is the main indicator in this research to assess daylight access. DF is the ratio between internal illuminance and external unobstructed illuminance[d] (Hopkinson et al. 1966, Baker & Steemers 2002). DF consists of three components: the direct daylight from the sky (sky component), the daylight reflected from the exterior into the interior space (ERC—external reflected component), and the originally external daylight inter-reflected from interior surfaces (IRC—internal reflected component)[e] (Hopkinson et al. 1966, Goulding et al. 1992). IRC depends on surface reflectances of walls, floor and ceiling, and of objects present in the room (Matusiak 2016).

Reflectance and luminance are the main indicators in the spatial quality assessment for the analysis of light distribution in the space, while daylight factor

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[d] DF = Ei/ Eo x 100% (Baker & Steemers, 2002, p. 60).
[e] DF = SC + ERC + IRC (Hopkinson et al. 1966, Goulding et al. 1992, p. 117).

(DF) is the main indicator to assess daylight access. Increase of surface reflectance is an efficient way to increase light level and energy efficiency in building renovation (Baker & Steemers 2002). The general light level increases with the increase of surface reflectance, and the light will be distributed more even (Matusiak 2016). Reflectance represents the light reflected that gives the surface its luminance (Hopkinson et al. 1966). Luminance is the 'physical quantity of brightness' of a surface, which can be physically measured (Hopkinson et al. 1966, p. 5). Light level can be improved by increasing the ERC (external reflected component), and the IRC (internal reflected component) (Baker & Steemers 2002, Matusiak 2014). The ERC can be improved by increasing reflectance of external surfaces such as windowsills, while the IRC can be improved by increasing the reflectance of indoor surfaces (Baker & Steemers 2002, Matusiak 2014, 2015).

Daylight quality depends on daylight distribution rather than the quantity of daylight entering a room (Baker & Steemers 2002, Matusiak 2014). Baker's and Steemers's (1996) concept of the passive zone is used to calculate the percentage of floor area that benefits from daylight. The passive zone is the area 'within a maximum distance from the perimeter wall' (building envelope) that 'can receive the benefit of daylight' (Baker & Steemers 1996, p. 252). The areas outside this zone are the non-passive zones that require artificial lighting. The passive zone is the depth from the perimeter to twice the floor to ceiling height or 6 meters as a default (Baker & Steemers 1996, p. 252). The ratio between the passive zone and the non-passive zone areas represents the efficiency of the building in terms of daylight access.

Plans and facades determine daylight access in the room. In relation to facades, higher window glazing results in spaces with better daylight access, in comparison to equal lower glazing (CEN 2015). The position of the openings (windows and balcony doors) in the room, and the relation between the openings dimensions significantly impact daylight distribution (Hopkinson et al. 1966). In relation to the configuration of plans, the dimensions of the room should define the width of the view (minimum size of the glazing) and consequently the dimensions of the window (Hopkinson et al. 1966, CEN 2015).

Features of the building's surroundings affect the access of daylight in the room and views considerably (Lynch 1990, Gehl 2010). Therefore, improving daylighting in dwellings should focus on not only the plans and facades, but also consider the immediate surroundings (Lynch 1990). Examples of features of the surroundings that affect the access of daylight and views in buildings are heights of the surroundings buildings and the distance between them. Daylight is included in the spatial quality determinants of (1) view, in principle (D), and in (2) internal spatiality and spatial arrangements, principle (E) (Tables 1 and 2, Chapter 2. Objectives of the research work).

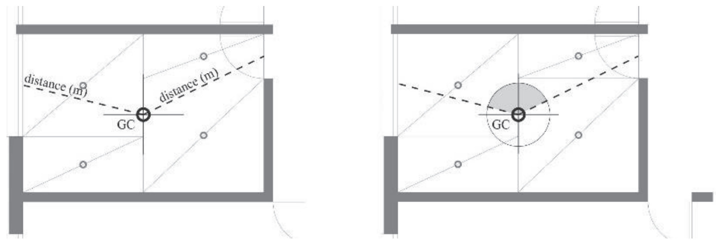
The quality of a view is determined by nature (Berman et al. 2008, Hartig 2003), mystery (Kaplan 1987), coherence (Lynch 1960, 1990, Kaplan 1987, Weber 1995), and lighting in the room (CEN 2015, Matusiak 2014). CEN (2015) recommends that a view should have 'a layer of sky, a layer of city or landscape, and a layer of ground', and that the view is distant enough (p. 10). The element of surprise, the mystery, attracts the observer because of the promise of additional information, for example 'the trail that disappears around a bend' (Kaplan 1987, p. 8). Mystery is a result of overlaps and the articulation of elements that increase the depth of vision (Lynch 1960). 'Symmetry, repeating elements and unifying textures' also contribute to a 'good view' (Kaplan 1987, p. 10). Lynch (1960, 1990), Kaplan (1987), and Weber (1995) define this potential as 'coherence', which is the 'capacity to predict within the scene' (Kaplan 1987, p. 10).

Rapoport (1982/1994), Wohlwill (1983), Nasar (1992/2000) and Berman et al. (2008) emphasize the importance of natural elements in the view. The presence of trees is appreciated because trees evoke the rural environment (Rapoport 1982/1994). People consider natural scenes more orderly and coherent than man-made ones (Rapoport 1982/1994, 2005). The quality of the view is included in determinant (1) view, in principle (B) (Table 1, Chapter 2).

B) Indraprastha and Shinozaki (2012)

Indraprastha and Shinozaki (2012) assess visual openness and visual privacy through indexes, which consist of a CAD-based mapping model, and a mathematical model, using distances (in metres) and viewing angles. These indexes are not included in the spatial quality assessment proposed in this research, as developing the mathematical model would require an additional skill set and resource use beyond the scope of this PhD. Only the definitions of visual openness and visual privacy from Indraprastha and Shinozaki (2012) are considered in the spatial quality determinant of (1) view, principle (B) (Table 1, Chapter 2. Objectives of the research work). The CAD-based mapping model and the mathematical model are included in Appendix A.

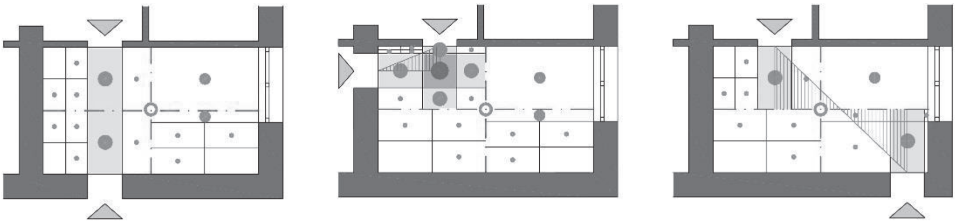
The goal of the analysis of visual openness and visual privacy is to assess the exposure of a point seen from external spaces. To simplify the analysis, only the geometrical centre point of the room is the point considered in the spatial quality assessment (Figures 22a and 22b). Visual openness and visual privacy are analysed by the distance and the viewing angle from the geometrical centre point of the room to the windows. Considering that an observer is placed on the geometrical centre point of the room, the more windows covered by the viewing angle from this point, the greater the visual openness and the lower the visual privacy. A greater distance (in metres) from the geometrical centre point of the room to the windows, gives lower visual openness and higher visual privacy.



Figures 22(a) and 22(b). Distance (m) from the geometrical centre point (GC) to the midpoint of the openings (22a) and maximum viewing angle of 100º at the GC (22b). Bedroom in Boa Vista house, Porto, Portugal, architect Alvaro Siza. Figures: Fernanda Acre.

The considerations about centricity and the configuration of entrances of spaces in Indraprastha and Shinozaki (2012), are also relevant for the spatial quality definition and assessment proposed in this research. The number and placement of entrances affect visual privacy and openness, and centricity (Indraprastha & Shinozaki 2012). Indraprastha and Shinozaki (2012) define two types of pass-through spaces for rooms with more than one entrance, namely the linear and angular paths (Figures 23a, 23b and 23c). The circulation path is linear if two entrances are 'connected by a straight line', and angular if two entrances are 'connected by an angular line' (p. 71-72). Multiples entrances in a room result in more space used for circulation in comparison to a single entrance.

Indraprastha and Shinozaki (2012) define zones of influence of the openings (windows and doors) in a room based on the geometrical centre of the room (Appendix A, and Pacheco & Wyckmans 2013). The zones of influence of doors may overlap in the angular path type of pass-through spaces (Figure 23b), which results in more compact circulation in comparison to the linear path type (Figure 23a). More space is used for circulation in the angular path type of pass-through spaces in comparison to the linear path type, when zones of influence of doors do not overlap (Figure 23c).



Figures 23(a), 23(b) and 23(c). Linear (23a) and the angular (23b and 23c) path types according to the placement of entrances (Indraprastha & Shinozaki 2012). Figures: Fernanda Acre.

3.2. Experts and laypersons

The results of this research, which are the spatial quality definition and assessment framework, can support design teams to explore the potential of energy efficiency renovation to improve spatial quality in dwellings. In this PhD work, architects, engineers and other technicians in the design team are considered the experts, and the users the laypersons. This section presents the definitions of experts and laypersons.

There are significant differences between how experts (in this research, architects and engineers for example) and laypersons (end users) perceive the built environment (Cold 1995). The conflict between experts and laypersons experienced in architecture has its roots in the Modern Architecture movement

(Hackney 1988). Users were often considered to disturb the design, as for example in Mies van der Rohe's project of the Seagram Building in New York. Van der Rohe was concerned that the facade composition would be disturbed if people in different rooms pulled down blinds to different levels (Hackney 1988). People working inside of the building thus had no possibilities to control the blinds.

Cold (1995) considers that architects' aesthetical education and professional experience are the reasons behind the distance between expert and layperson in architecture. Cognitive aspects such as emotional experiences and feelings mostly guide the perception of spatial quality by a layperson (user) (Kaplan 1992, Cold 1995). The expert's (architect's) understanding of spatial quality on the other hand, is a result of qualitative parameters learnt during a career (Cold 1995). The lack of professional knowledge about spatiality from the layperson eventually causes disinterest in experts such as architects.

Experts see beyond what laypersons see (Styhre 2016). However, the good professional is able to shift from the 'insider professional's view' to the 'layperson's perception' (Styhre 2016, p. 137). In order to minimize the distance between the expert and layperson, the expert needs to accept the layperson as a valuable source of information during building processes (Cold 1995). The challenge is to translate experts' professional knowledge to best fulfil laypersons' needs.

4. The ZenN Project and the PhD research

This PhD research contributes to the ZenN project ‘Near Zero Energy Neighbourhoods’ (7th Framework Programme, Grant Agreement number 314363), and Work Package 4 on Non-Technical Drivers. The ZenN project aims to demonstrate ‘the advantages and affordability of energy efficiency renovation, and to create the right context to replicate this experience around Europe’ (ZenN 2012, Part B, p. 43). The ZenN project has demonstrators – demonstrating the renovation of existing residential buildings and blocks in urban areas – in Malmö (SE), Oslo (NO), Grenoble (FR) and Eibar (ES). The demonstrators are renovated in between 2013 to 2017. The ZenN project is funded through EU's Seventh Framework Programme (FP7), and involves 12 partners from five countries. The partners consist of research and educational institutions, governmental representatives and consultants from the European and Nordic countries involved in the project.

The demonstrators consist of residential neighbourhoods with several stakeholders, diverse ownership structures and ambitious energy efficiency targets. The residential buildings in the demonstrators are renovated to increase energy efficiency between a 10% to 50% reduction in energy consumption in comparison to their current demands. For example, the Arlequin demonstrator in Grenoble, France, has an energy consumption target of 96 kWh PE/m²/year for all the building blocks, for heating, domestic hot water (DHW), ventilation, auxiliaries and lighting. This target represents a reduction of 50 % of the current energy consumption level. The renovation is currently in the conclusion phase, after 2 years of project development and execution.

The optimization of energy-efficiency in buildings that improves technical performance along with well-being concerns is a current challenge for the European society (ZenN 2012, Part A). In this context, non-technical drivers are instruments to generate innovation in building renovation (ZenN 2012, Part A). NTNU is responsible for Work Package 4 Non-Technical Drivers (WP4). The aim of WP4 is to propose an overall approach to achieve context related high quality near-zero energy efficiency renovation at the district level considering four non-technical drivers (ZenN 2012, Part A):

- Architectural and Cultural Heritage
- Stakeholder Awareness and Behaviour
- Economic and Ownership Structures
- Legislation, Governance and Policy

According to ZenN's project description, the results of WP4 'will be summarized in a holistic design methodology for nZEB renovation' (2012, Part A, p. 17).

The ZenN demonstrators, among them the Arlequin demonstrator in Grenoble, France, are an opportunity to develop and test a spatial quality assessment. Spatial quality is not considered by the ZenN demonstrators. However, spatial quality is included in the non-technical driver of Architectural and Cultural Heritage in WP4. The ZenN Project, particularly WP4, offered the right context for the development of the PhD research. This is because WP4 aims at an innovative synergy between energy efficiency renovation and improvements on well-being concerns.

The PhD author participated in project meetings and reporting on the spatial quality analyses of the Arlequin demonstrator, in Task 4.1 Architectural Values and Cultural Heritage. The Arlequin demonstrator in Grenoble, France, is used to test the spatial quality definition and assessment proposed in the PhD research. Arlequin also influenced the results of this PhD research, namely the spatial quality definition and assessment (7.1 Impact of energy efficiency renovation of dwellings on spatial quality). The spatial quality assessment framework was presented in two of these meetings in 2014, and the overall reaction was positive about the potential of including the framework in the project.

The results of the spatial quality assessment of the Arlequin demonstrator were presented in a project meeting to the ZenN's partners in October 2014. The reactions were diverse due to the various backgrounds of the participants. All the renovation measures are considered in the spatial quality assessment of the Arlequin demonstrator, regardless of whether the measures were related to energy efficiency or not. The majority in the audience were engineers and their first reaction was to question the relevance of considering all the renovation measures in the spatial quality assessment. They argued that only the measures that were explicitly related to energy efficiency should be included in the assessment. In contrast, the few architects involved in the project understood the relevance of considering all the renovation measures in the assessment to find the overall effect of the renovation on spatial quality.

The overall results of the assessment indicate that the renovation improves spatial quality in the MS-1 building in Arlequin (Acre & Wyckmans 2015b), a building with 89 social housing apartments. However, if only specific energy efficiency related measures are considered in the assessment, the overall effect of the renovation on spatial quality is going to be negative. This is because these measures include lower ceiling heights, thicker walls and smaller windows in comparison to before the renovation. These measures have a negative impact on spatial quality according to the definition and assessment proposed in this PhD research. The renovation measures of the MS-1 building that have a positive impact on spatial quality are new openings in the facade and several changes in the plans of most of the apartments (Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015b).

5. Definition of indicator

Spatial quality is evaluated in this research by using indicators that translate spatial quality principles into assessable features. This section presents the definition of indicator considered in the PhD research. The use of indicators to assess spatial quality is part of the answer to the main research question: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* Indicators are intended for assessment (considering goals to reach), diagnoses (to identify affecting factors), and comparison and monitoring (impacts of changes over time) (ISO21929-1 2011). Periodic evaluation and monitoring indicate the direction of any impact (ISO21929-1 2011).

Indicators have three main functions: to quantify, simplify and communicate. Indicators are quantitative, qualitative or descriptive simplified data that enable information on a complex phenomenon, to become relatively easy to use and understand (ISO1929-1 2011). They help to set goals and indicate tendencies, which can significantly influence decision-making (ISO21929-1 2011). An ideal indicator has the following scientific characteristics (World Health Organization, WHO):

- Validity. The indicator has to measure what it is meant to measure;
- Reliability. Repeated measurements by different observers has to result in similar values of the same indicator;
- Sensitivity. The indicator can capture changes;
- Specificity. The indicator only reflects changes in a particular situation.

In practice, indicators merely approximate a real situation. Indicators are only a tool for assessment. There are no inherent positive or negative values associated with them, therefore indicators are useful to illustrate differences and similarities (ISO21929-1 2011). Indicators are generic in nature although benchmark values can be site-specific (ISO21929-1 2011). Indicators are relevant for diverse stakeholders in decision-making in building processes because they can be used to monitor and evaluate achievements over time (i.e. periodic review).

A system of indicators can be developed by choosing relevant indicators, and by finding proper methods to assess the values of individual indicators, or by developing methods if they are not available (ISO21929-1 2011). It is to be possible to clearly report the selection, development and application of the indicators, and the assessment methods (qualitative, quantitative or descriptive methods) used in the indicators (ISO21929-1 2011). The spatial quality indicators developed in this research are characterized by objective quantitative and descriptive methods and consider temporal system boundaries as before and after building renovation. Indicators can be simple or complex. For example, in the spatial quality assessment proposed in this PhD research, indicators related to light and visual privacy have a high complexity because various parameters describe them.

6. Methodology

6.1. Research strategy

The PhD research is characterized by a quantitative and descriptive research approach with a deductive process of cause and effect relations: namely the impact (effect) of energy efficiency renovation (cause) on the spatial quality in dwellings. The first step was a literature study on the quality of life in the urban environment, spatiality and spatial perception, and energy efficiency renovation of dwellings (Chapter 3. Research background). The spatial quality definition and assessment, which consist of general spatial quality determinants and principles derived from the literature study, constitute the new knowledge and main contribution of this research (Chapter 8. Spatial quality definition and assessment). The literature study led to the hypothesis that the renovation does affect spatial quality. The hypothesis was confirmed by the literature study on energy efficiency renovation of dwellings (Section 3.1.4 Energy efficiency renovation, and relevance of non-technical drivers in renovation of dwellings), the study of six actual dwelling renovation cases in Europe and Norway (Chapter 7. Energy efficiency renovation of dwellings), and the assessment of the impact of the renovation on spatial quality in the Arlequin case in Grenoble, France (Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015b). The spatial quality definition and assessment are tested in the Arlequin case that is part of the ZenN project (Chapter 4. The ZenN project and the PhD research).

This PhD research adopts a post-positivism research paradigm instead of a positivism one. The positivism and post-positivism research paradigms have often a quantitative approach (Creswell 2014). Positivism is 'a philosophical system recognizing only that which can be scientifically verified or which is capable of logical or mathematical proof (…)' (Oxford Dictionary 2016). Positivists believe in an ultimate truth and that it is possible to achieve this truth through research (Mertens 1998, Groat & Wang 2002). The difference between positivism and post-positivism is that the post-positivism recognizes that research in general can fail (Groat & Wang 2002). Post-positivists believe that objectivity is a genuine goal that may be achieved, but in an imperfect way (Groat & Wang 2002). There is no ultimate truth in the study of spatial quality. The spatial quality definition and assessment proposed in this research are fallible and imperfect, and they are one approach among many possibilities.

The post-positivism research paradigm is characterized by a reductionist approach and by the purpose of testing theory (Creswell 2014). In the reductionist approach, ideas are reduced to a 'small set of ideas to test out as variables' (Creswell 2014, Grover 2015, p. 3). This PhD research adopts a reductionist approach. The literature on the quality of life in the urban environment, spatiality and spatial perception considered in this research work is reduced to a spatial quality definition and assessment with indicators as variables. The post-positivism research paradigm is guided by 'a theory to find relationships between variables'; at the same time post-positivism aims to 'test the guiding theory in terms of relationships between variables' (Creswell 2014, Grover 2015, p. 3). The literature study is the basis of this PhD research to define the variables, as well as to find relationships between these variables. The spatial quality definition and assessment, which represent a reduced or compact version of the literature behind it, are tested in terms of the possible relationships between the variables in this PhD research, which consist of renovation measures and the spatial quality indicators.

The post-positivism research paradigm is guided by research questions and hypotheses, 'which are to be tested' (Creswell 2014, Grover 2015, p. 3). The hypothesis of this PhD research is that energy efficiency renovation does affect spatial quality in dwellings. The hypothesis was confirmed by the literature study and the study of seven actual dwelling renovation cases. The research questions of this PhD guided the development of the research. The main research question is: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* The spatial quality assessment is developed to answer this question. The first sub research question is: *What are the main spatial quality determinants for dwellings?* The spatial quality definition is developed in this PhD research to answer this question. The second sub research question is: *What potential effects are there between energy efficiency renovation and spatial quality?* The answers to this question are in the crossing between the renovation measures and the spatial quality determinants, which are exemplified in Tables 10 to 17 (Appendix C). The third sub research question is: *How can energy efficiency renovation increase spatial quality in dwellings?* The answer to this question is based on the study of energy efficiency renovation of dwellings and on the analysis of the seven renovation cases. The answer to the last sub research question is presented in Section 10. Conclusion and recommendations for further research.

Guba (1981) defines quality standards for the post-positivism research paradigm, which are similar to the scientific characteristics of the ideal indicator, namely validity, reliability, sensitivity and specificity (WHO) (Chapter 5. Definition of indicator). Guba's (1981) quality standards for post-positivism research are considered in this PhD research because the spatial quality assessment uses indicators to evaluate the effect of the dwelling renovation on spatial quality (Tables 18 to 21, Chapter 8. Spatial quality definition and assessment). The quality standards according to Guba (1981) consists of:

- Internal validity is whether the main concepts in the study truthfully represent the object of the study;
- External validity is whether the results of the study can be generalized to other studies, or whether the framework of the study where the results are valid, is clearly defined;
- Reliability is whether the findings are consistent;
- Objectivity refers to minimizing the interference of the researcher to the lowest level possible.

Internal validity in this PhD work means whether the spatial quality definition is consistent or not. The definition is based on the study of theory on the quality of life in the urban environment, spatiality and spatial perception, and energy efficiency renovation of dwellings (Chapter 3. Research background). The literature study is the starting point to answer the sub research question of: *What are the main spatial quality determinants for dwellings?* The authors, whose work are relevant for defining spatial quality, are categorized in five groups (Chapter 3. Research background):

- Authors that call attention to the relevance of spatial quality related issues;
- Authors who define universal principles about the perception of the physical environment;
- Authors who study physical characteristics of space that are fundamental to spatial perception;
- Authors that technically describe energy efficiency renovation of dwellings, and that emphasize the relevance of non-technical drivers to promote user acceptance of building renovation;
- Authors whose work was relevant to specific topics in the spatial quality definition and assessment.

Regarding external validity, the framework of the study is clearly defined, which consists of the spatial quality definition and assessment. The results of a particular case cannot be generalized to other cases because the assessment compares the spatial quality of a case prior to the renovation, with the spatial quality of the same case after the renovation. This comparison is to find whether the spatial quality improves because of the renovation in the dwelling. However, design teams can apply the spatial quality framework to other cases of renovation of dwellings to evaluate the impact of the renovation on spatial quality.

In terms of reliability, the spatial quality assessment evaluates the impact of the energy efficiency renovation on spatial quality through the analysis of physical changes in the building components of windows, external and internal walls, mechanical services and control, floors and built area. It is expected that other design teams could achieve similar results of the spatial quality assessment for a same case, as long as the assessment, the weighting and the scale (whether an entire building or only a single apartment unit is evaluated) remain the same. However, reliability is not consistently verified in this research because the assessment is not performed by others than the author of this PhD work (Chapter 8. Spatial quality definition and assessment).

In terms of objectivity, the spatial quality assessment is designed to minimize the interference of the individual performing the assessment. This is pursued by straightforward questions related to spatial quality according to the definition proposed in this PhD research, for example whether the ceiling height is at least 2.40 metres (TEK10 The Norwegian Agency for Building Quality) or higher after the renovation (Chapter 8. Spatial quality definition and assessment).

6.2. Correlational research strategy

This PhD research adopts characteristics of the correlational research strategy, which aligns with the post-positivism research paradigm. The correlational research strategy is of a quantitative type (Groat & Wang 2013), and it is appropriate to study complex phenomenon using variables in a rational and an objective manner, which characterize the post-positivism research paradigm (Creswell 2014). The correlational research strategy is particularly appropriate when the researcher wants to have a general understanding of a circumstance or a naturally occurring pattern (Mertens 1998, Groat & Wang 2013). Naturally occurring patterns are for example how people use a public square every day, or how people experience civic qualities in a neighbourhood (Groat & Wang 2013). The characteristics of the correlational research strategy are (Groat & Wang 2013, p. 206):

- The search for ‘patterns of relationships’ between two or diverse variables;
- The measurement of specific variables that can be measured somehow;
- The ‘focus on naturally occurring patterns’;
- The use of statistics to clarify naturally occurring patterns.

The present PhD research identifies ‘patterns of relationships’ between spatial quality and energy renovation of dwellings. The goal is to clarify these relationships and predict the outcome of the renovation, that is, the impact of the renovation on spatial quality, which answers the sub research question of: *What potential effects are there between energy efficiency renovation and spatial quality in dwellings?* In terms of measuring specific variables, the spatial quality assessment evaluates changes in the variables, which consist of physical features of the building components. Some examples of these specific and measurable variables are the glazing area of the facade, apartment area, ceiling height, built and human densities.

The correlational research strategy is used in the PhD work, even though the focus in this PhD research is not on naturally occurring patterns, and statistics are not used. Namely, energy renovation of dwellings is not a naturally occurring pattern, that is, an ordinary and constant process in people’s everyday life (Groat & Wang 2013). Statistics are not used to clarify patterns of relationships between spatial quality and the renovation, because the goal of this PhD research is not to identify trends in energy efficiency renovation of dwellings, such as which renovation measures affect spatial quality most significantly. The goal is to create an assessment framework to evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings. Statistical methods can be useful to compare the outcomes of the assessment among several cases, or in the same case among the apartments in a same building, if the assessment is run for each apartment individually.

6.3. In-depth case and the study of cases of energy efficiency renovation of dwellings

This PhD research uses seven cases of energy efficiency renovation of dwellings. These cases cannot be considered as case studies. The case study research strategy is characterized by the study of 'some present circumstance' considering users, and the social and physical contexts of the case (Yin 2009, p. 4). The contexts (or 'dynamics') of the seven cases from which they are 'inseparable' (Groat & Wang 2013, p. 421) are not included in this PhD. The cases of energy efficiency renovation of dwellings included in this PhD work are considered as discrete objects, unconnected to their social and physical contexts.

An in-depth case is used to test the results of this PhD research, namely the spatial quality definition and assessment. The spatial quality assessment is applied to the Arlequin case in Grenoble, France, to evaluate the impact of the energy efficiency renovation on spatial quality in the MS-1 building (Chapter 8. Spatial quality definition and assessment, and Acre & Wyckmans 2015b). Arlequin is used to test whether the assessment is able to predict and represent the impact of the renovation on spatial quality. The particular results of the spatial quality analysis for the Arlequin case are specific to Arlequin and therefore cannot be generalized to theory. The main reasons for choosing Arlequin as an in-depth case is that it is an actual example of energy renovation of dwellings, and it is one of the demonstrators of the ZenN Project (Chapter 4. The ZenN Project and the PhD research).

Data from six cases of energy efficiency renovation of dwellings are analysed to gather technical information about the renovation (Chapter 7. Energy efficiency renovation of dwellings). The cases are also helpful to exemplify topics of the spatial quality definition, which are included in the spatial quality assessment. These six cases are used to explore, describe and explain the impact of energy efficiency renovation on spatial quality in dwellings. The cases are instrumental, that is they are of secondary relevance (Stake 1998) to the spatial quality framework developed in the PhD.

The criteria for selection of the six cases are that they should be cases of renovation of dwellings with the aim of improving energy efficiency. From the data collected about the cases, only the renovation measures are considered in the study. Social, management and economic related issues are not included in this study. All renovation measures associated or not to energy efficiency in these cases are considered to develop the spatial quality definition and assessment (Chapter 8. Spatial quality definition and assessment). None of the six cases are used to test the spatial quality assessment as the Arlequin (in-depth) case is.

7. Energy efficiency renovation of dwellings

This chapter presents the description of technical measures of energy efficiency renovation considered in this PhD research. Energy efficiency renovation is among the core elements of the research. The technical measures presented in Tables 5 to 9 in Appendix B, are the ones considered for the analysis of the impact of the renovation on spatial quality. The knowledge on energy renovation was a support to answer the sub research questions: *How can energy efficiency renovation increase spatial quality in dwellings?* And *what potential effects are there between energy efficiency renovation and spatial quality?*

The work of Baker (2009) and Burton (2012) are the starting point for the study of energy efficiency renovation in the European context. Burton (2012) describes the majority of the technical measures in the renovation of dwellings considered in this research for floors, walls, roofs, windows, and mechanical services (Tables 5 to 9, Appendix B). The usual technical measure for the building component of internal walls consists of the addition of insulation, which is not considered relevant in terms of spatial quality and therefore is not described in Appendix B. Changes in the plan are the only measures considered in relation to internal walls. Changes in the built area of the block consist of the addition of new buildings and demolition of existing ones (Giebeler et. al 2009). Possible measures in terms of renewable energy options in building renovation consist of the use of photovoltaic re-cladding panels and roof tiles, and opaque PV used as shading devices (Baker 2009).

Baker (2009) describes energy efficiency renovation for non-domestic buildings. Measures that are often applied to energy efficiency renovation of non-domestic buildings can also be applied to the renovation of dwellings (Giebeler et al. 2009, Retrokit 2014, ZenN 2012). Such measures are for example: green roofs, changes in the placement of windows on the facade, implementation of shading elements on facades, and the use of photovoltaic elements as cladding on facades and roofs (Baker 2009).

Several measures in energy efficiency renovation of dwellings that affect spatial quality, are not taken in order to improve energy efficiency. However, they have the potential to affect energy efficiency as for example the addition of green roofs, changes in the plan of apartment units, and the addition or demolition of buildings in the block (Acre & Wyckmans 2014).

Green roofs can contribute to cooling, and changes in the plan improve zoning regarding sun orientation and space use. This may decrease the use of artificial lighting and heating. The demolition of poorly insulated buildings can lower energy demands in the block. These measures are not energy issues directly; however, they could be. This kind of measures may increase end users' receptiveness towards energy efficiency renovation. This is because these measures can result in benefits other than energy efficiency. For example, users could get a green terrace with the new green roof, and the changes in the plan could improve spatiality in the apartments. The addition or demolition of buildings in the block could for example, improve semi-public spaces and daylight conditions in the apartments.

7.1. Impact of energy efficiency renovation of dwellings on spatial quality

This section consists of the references for energy renovation, which are Baker (2009) and Burton (2012), and actual cases of energy efficiency renovation of dwellings. The European context is the starting point for the selection of the literature, and of the cases of energy efficiency renovation of dwellings considered in the PhD research. The availability of detailed technical information regarding the energy efficiency renovation was also a criterion for the selection of the cases. Initially the intention was to use the ZenN demonstrators as reference cases. However, the majority of the ZenN demonstrators were not in an advanced stage of project development at the time the research was carried out, excepting for the Arlequin Neighbourhood in Grenoble, France. A detailed description of the renovation of the MS-1 building in the Arlequin demonstrator was available, including the master plan for the neighbourhood, and technical specifications and construction drawings as for example, plans, sections, facade drawings and several construction details.

The work of Baker (2009) and Burton (2012), and the renovation cases affected the results of this PhD, which are the spatial quality definition and assessment. This is because the renovation, which was intended to improve energy efficiency only, affects several spatial quality related issues in the dwellings (Acre &Wyckmans 2014, 2015b). The renovation cases are used to exemplify principles of the definition and assessment of spatial quality in Acre and Wyckmans (2014, 2015a). The crossing between building renovation and spatial quality is presented in Tables 10 to 17 in Appendix C. The cases presented in this section, are located in Switzerland, Germany and Norway:

- Residential block in Chur, Switzerland
- Residential blocks in Zürich, Switzerland
- Residential block in Freiburg, Germany
- Residential building in Cologne, Germany
- Private dwelling in Bochum, Germany
- Apartment building in Trondheim, Norway

The renovation for energy efficiency may affect several building components (Tables 5 to 9, Appendix B). Measures for floors consist of adding insulation to the floor to improve thermal performance on the ground floor, and to improve acoustics in the intermediate floors. Measures for external walls and roofs consist of adding insulation to improve thermal performance, and adding or removing balconies on the facade for external walls. The addition of insulation and internal changes in the plan are usually how the renovation influences internal walls. Measures for windows consist of improvements to thermal and acoustic performances, and light and view conditions, such as the reduction or increase of framing, changes in glazing and aperture areas, and the use of shading devices. The renovation of mechanical services consists of measures to improve heating, domestic hot water (DHW) and lighting. The renovation may also influence the built area, such as when parts of or entire buildings are added or demolished.

- **Residential block, Chur, Switzerland**

The residential block is designed in 1942 by Karl Beer and renovated in 2000 by Dieter Jüngling and Andreas Hagmann (Giebeler et al. 2009). The complex has a central location in front of the Chur station. The building has a block shape with a courtyard. The u-shape of the original block had the potential to accommodate new buildings, which would create a perimeter block. These were the main reasons why the owners decided to preserve the complex. However, the original apartments were small and the intention was therefore to enlarge them. The main changes brought by renovation are: the existing staircases were demolished and new ones were built outside of the building, the balconies were enlarged, external thermal insulation was added to the facades, and three new buildings were added to the block to strengthen the perimeter block.

The renovation in Chur is a case in which principles of the definition and assessment of spatial quality in this PhD research can be illustrated (Acre & Wyckmans 2014, 2015a). The case is relevant to illustrate changes in the boundaries and area of the block (Figures 24a and 24b) (Figures 10a to 10d, Section 3.1.3 Physical characteristics of space relevant to spatial perception). It is also relevant to exemplify how changes in the plan of the apartments affect spatial hierarchies (subordinated spatial relationships) (Figures 7a and 7b, Section 3.1.3).

Figures 24(a) and 24(b). Residential block, Chur, Switzerland. Residential block before and after the renovation with the addition of a new building (24a and 24b). © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.

- **Residential blocks, Zürich, Switzerland**

This renovation case consists of three residential blocks: a 19-storey tower and two six-storey buildings, built in 1970 and renovated in 2005 (Giebeler et al. 2009). The architectural office responsible for the renovation is Urs Primas Architects. The internal organization of the plan underwent changes with the creation of maisonettes and new apartment types. The energy performance of the complex increased to achieve the Swiss Minergie standard[f]. The Minergie standard sets the target for renovation projects so that the energy consumption should not be higher than 80kWh/m². The strategy for the renovation is based on cross ventilation and heat recovery systems. The main renovation measures were: addition of external insulation with new cladding in corrugated aluminium in a bronze colour, changes on the internal organization of the plan, installation

[f] Minergie, the Swiss Sustainable Building Standards. Minergie is the quality label for new and renovated energy efficient buildings (accessed in September 2016).

for controlled ventilation for the apartments, and conversion of some terraces into conservatories.

The renovation case in Zürich is also used in this research to exemplify the definition and assessment of spatial quality. This renovation case is particularly relevant to illustrate the impact of changes on facade composition before and after the renovation (Figures 25a and 25b) (Acre & Wyckmans 2014, 2015a).

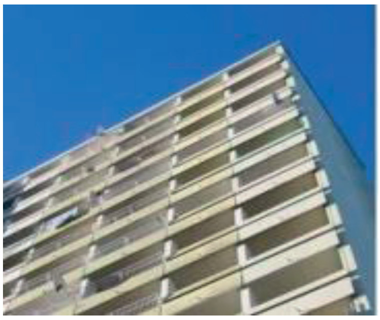
Figures 25(a) and 25(b). Changes in materialization of facades and windows' size and composition. Residential blocks, Zürich, Switzerland. Residential block after renovation (25a) © [Andrea Helbling, Arazebra]. Reproduced by permission of Andrea Helbling, Arazebra, Zürich. Residential block before renovation (25b) © [Schneider Studer Primas GmbH]. Reproduced by permission of Schneider Studer Primas GmbH.

- **Residential block, Freiburg, Germany**

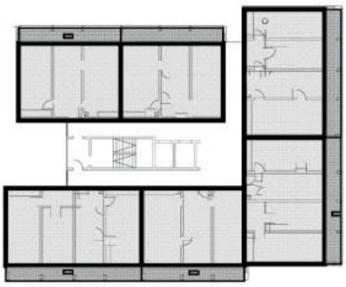
The residential block in Freiburg is located in the western part of the Weingarten district. The block consists of four high-rise buildings in concrete, with low priced apartments constructed between 1965 and 1968. The whole area is going to be modernized from 2007 until 2018. The buildings will remain social housing after the renovation.

The goals of the renovation in 2009 and 2010 were to reduce energy consumption using passive strategies, and to increase the number of housing units. One of the buildings with 16 stories, built in 1968, was renovated first. The experience gained with the first building helped to shape the renovation strategy for the rest of the complex. Some of the existing apartments in this first building were subdivided into more units, and the number of apartments increased from 90 to 144 after the renovation. The compact shape of the building eased the reduction of heating energy demands.

All apartments had a large balcony without thermal separation. Therefore, the refurbishment concept was to integrate the old balconies into the new thermal building envelope. This represented an increase of around 5.2 % in the area of the apartments. The Freiburg case was used in the spatial quality definition and assessment to illustrate how changes in the internal division of space can affect facade composition (Figures 26a to 26d) (Acre & Wyckmans 2014, 2015a).



a



b

c d

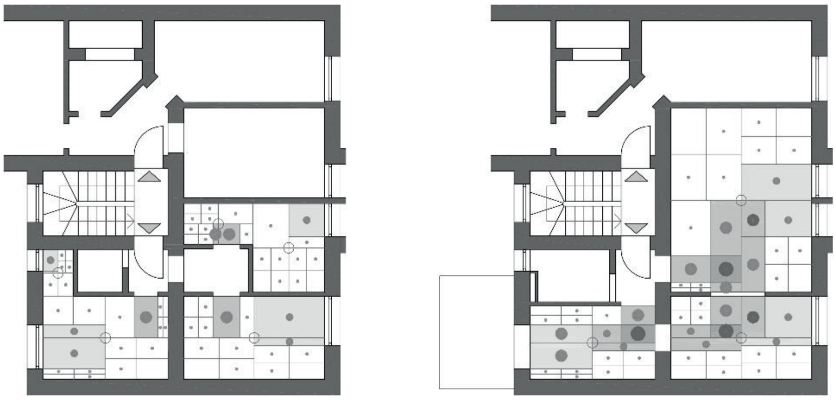
Figures 26(a), 26(b), 26(c) and 26(d). Changes in the internal division of space due to dwelling renovation affect the facade composition. Residential block, Freiburg, Germany, plan and facade before (26a and 26b) and after (26c and 26d) renovation. © [Florian Kagerer]. Reproduced by permission of Florian Kagerer.

- **Residential building, Cologne, Germany**

The residential building in Cologne, Germany, was built in 1900 and renovated in 2005 by architect Boris Enning (Giebeler et al. 2009). The building was intended to accommodate carpenters, and was initially a combination of small apartments and rooms for workshops. The workshops were turned into apartments or added to existing apartments because of the renovation.

The renovation brought about many changes to the internal organization of the plan with new apartment units of diverse sizes. The roof, facade, and building services were renewed. There was the addition of steel balconies, insulation on the roof, and damp proofing to the semi-basement, which created additional living areas. Internal insulation was added behind the existing facade to keep the original facade intact; in other parts of the facade, external thermal insulation was added.

The residential building in Cologne illustrates how the placement of entrances and the changes in the plan, affects centrality and concavity of spaces in the apartments (Figures 27a and 27b) (Acre & Wyckmans 2014, 2015a).



Figures 27(a) and 27(b). Placement of perceptual centres according to Indraprastha and Shinozaki (2012) (Appendix A, and Pacheco & Wyckmans 2013). Plans of the first floor before (27a) and after (27b) the dwelling renovation. Residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL. Figures: Fernanda Acre.

- **Private dwelling, Bochum, Germany**

The residential building in Bochum, Germany, was constructed in 1950 and then totally renovated in 2001 by the architect Anja Köster (Giebeler et al. 2009). The building had two apartments, which after the renovation, were combined into one house. The main renovation measures were changes on the internal organization of the plan, addition of external thermal insulation, new windows with low E glazing, and enlarged window openings to optimize daylighting and views.

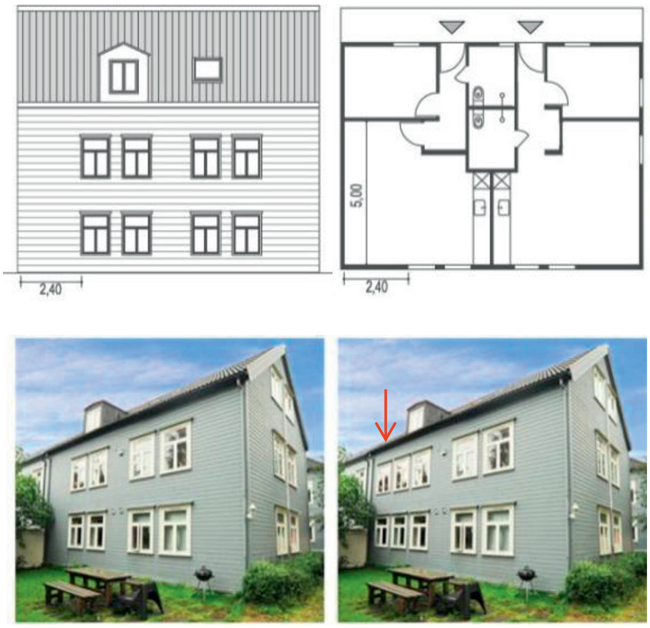
The renovation of the Bochum house illustrates changes in facade transparency and visual privacy (Figures 28a and 28b), and in spatial hierarchies (coordinated spatial relationship) (Figures 6a and 6b, Section 3.1.3 Physical characteristics of space relevant to spatial perception) in the present research.

Figures 28(a) and 28(b). Changes in windows' size, after (28a) and before (28b) the dwelling renovation. Private dwelling, Bochum, Germany, © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.

- **Apartment building, Trondheim, Norway**

The two buildings of the condominium in Møllenberg in Trondheim, Norway were built in 1888 and fully renovated in the early 1980s. The buildings were partially renovated in 2015 and 2016. The renovation measures from 2015 and 2016 consisted of an upgrade of electrical installations, painting of facades, renovation of the existing outside stairs and addition of a window on the facade of one of the buildings to improve daylighting condition, ventilation and view. The internal organization of the apartments, which was left to the owners, also changed with the renovation. The drainage of the foundation and renovation of the roof tiles had to be postponed because of budget constraints and were also not considered urgent.

The building that got the new additional window, is used in the research to exemplify when lighting demands are overlooked in advantage of facade composition (Figures 29a to 29d). The apartment that got the additional window (the apartment on the left of the Figure 29b), had prior to the renovation, a deep living room with a dark area on the left side of the plan (Figure 29b). This is because the priority was to maintain the symmetry of the facade composition, with a group of four windows on both sides of the axis of vertical symmetry.



Figures 29(a), 29(b), 29(c) and 29(d). Existing facade (29a) and plan of the apartment building (29b). Existing facade (29c) with eight windows and proposal for the addition of two extra windows (29d). Trondheim, Norway. Figures: Fernanda Acre.

8. Spatial quality definition and assessment

This section is the answer to the sub research question: *What are the main spatial quality determinants for dwellings?* Spatial quality consists of a combination of diverse physical, perceptual and social features. The present research focuses on physical features of spatial quality only. The literature study demonstrates that spatial quality can be understood via common determinants, which are assessable and concrete. Spatial quality is defined in this research by the analysis of the four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces and (4) perceived density, built and human densities (Acre & Wyckmans 2014). The determinants result from the literature study, which is presented in Chapter 3 'Research background'. The material collected from the literature study is categorized and organized in the spatial quality definition and assessment that are presented in this section (Tables 18 to 21).

8.1. Spatial quality determinants

The four spatial quality determinants of (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces, and (4) perceived density, built and human densities (Acre & Wyckmans 2014, 2015a) are described in this section. Each determinant has three main topics, which are represented by five principles from A to E. Each principle has three sub-principles (Tables 18 to 21, reviewed version, the first version is in Acre & Wyckmans 2015a). Each sub-principle may have three quantitative or descriptive indicators related to specific physical features to assess spatial quality as indicated in Tables 18 to 21. The spatial quality determinant of (2) internal spatiality and spatial arrangements, and the principle of '(E) Lighting' can exemplify the relationships between determinant/ principle/ sub-principles/ indicators in the spatial quality assessment (Table 19):

(2) Spatial quality determinant of 'Internal spatiality and spatial arrangements':

(E) Principle of 'Lighting':

(E3) Sub-principle of 'Internal zoning of the diverse functions and daylight access', which is represented by the following three indicators:

'(a) Internal zoning considers optimal sun orientation (yes or no question)'

'(b) Minimum of 80% of the floor area of the room is lit by daylight (yes or no question)'

'(c) Daylight access in living areas (yes or no question)'

8.1.1. View

> 'In their home, people want to relax and be able to shut themselves away from the city. At the same time, they want to maintain the view over their world' (Uytenhaak 2008, p. 80).

The spatial quality determinant of view embraces the scales of the building and the block. The main three topics of view are:

- View from the inside (private domain) to the outside (public domain) of dwellings, and from outside to inside, (visual privacy)
- Distances between public and private domains
- Quality of the view

The main topics are represented by five principles, which are listed in Table 18:

(A) Facade transparency. It consists of the relationship between the external walls' areas, glazing areas, and the properties of the glazing. (Baker & Steemers 2002, Uytenhaak 2008, Matusiak 2014, CEN 2015) (Section 3.1.5 Development of the spatial quality definition and assessment);

(B) Depth of vision (Lynch 1960). It consists of the analysis of view quality, room and window dimensions, and direct surroundings that impact views, visual openness and visual privacy (Lynch 1960, Chermayeff & Alexander 1966, Gehl 2010, 2011, Indraprastha & Shinozaki 2012, Matusiak 2014, CEN 2015) (Section 3.1.5);

(C) Distance and degree of sight protection (Gehl 2010). It consists of visual privacy and the protection of the private domain. That is, how much the user can control visual interaction with others, and how entrances and private outdoor spaces contribute to visual privacy and protection of the private domain. (Chermayeff & Alexander, 1966, Rapoport 1970/1994, 1977, Uytenhaak 2008, Gehl, 2010, 2011, SBTool 2012) (Section 3.1.5);

(D) Lighting. The focus is on the daylight access and how much daylight the facade allows to enter the rooms. (Baker & Steemers 2002, Uytenhaak 2008, Matusiak 2014, CEN 2015) (Section 3.1.5);

(E) Closure, enclosure and peripheral density (Weber 1995). This principle refers to the configuration of the block that affects views (Lynch 1960, Weber 1995, Gehl 2010, 2011) (3.1.3 Physical characteristics of space relevant to spatial perception).

Table 18. Spatial quality assessment for view (revised version)

Spatial quality assessment – Determinant 1: View (Building and block scales)
(A) Facade transparency[a,b]
1. Ratio between facade area and apertures (windows and doors) area
2. Ratio between apertures (windows and doors) area and glazing areas
3. Glazing properties of transmittance[c,d]
(B) Depth of vision[e]
1. Visibility[f]
(a) Percentage of the total number of spaces in the dwelling with a view
(b) Visual openness[g]
(c) Visual privacy[g]

a Uytenhaak 2008
b Baker & Steemers 2002
c CEN 2015
d Matusiak 2014
e Lynch 1960
f Gehl 2010, 2011
g Indraprastha & Shinozaki 2012

2. Quality of the view (composition of the view)
(a) Distance of the view (depth) is > 6 metres[c] (yes or no question)
(b) Width of the view through window(s) is > 28° [c] (yes or no question)
(c) Presence of layers of proximity (sky, landscape and ground) and natural elements[c,d,e,f,h] (yes or no question)
3. Internal division of space and views (configuration of the plan that affects views from inside to outside, and from outside to inside)
(a) Window's length is equal to at least half of room depth (d)[c] (yes or no question)
(b) Room depth (d) ≤ 5m, minimum window area (wa) = $1.25m^2$; room depth (d) > 5m, minimum window area (wa) = $1.50m^2$ [c] (yes or no question)
(c) Visual distance increases (distance between the geometrical centre p of the space to the midpoint of the openings – windows)[g] (yes or no question)
(C) Distance and degree of sight protection (visual privacy and protection of the private domain)
1. Level of privacy and view of arriving visitors and entrance[h,i]
(a) Percentage of dwelling units whose bedroom and living areas are open to horizontal or downward views from a point within 20 metres of the exterior windows[i]
(b) Possible to see arriving visitors without being seen[h] (yes or no question)
(c) Entry-lock (hall) area to dwelling[h] (yes or no question)
2. Availability and configuration of private outdoor spaces[a,f,j]
(a) Availability of private outdoor spaces (yes or no question)
(b) Possibility of controlled visual contact with neighbour's private outdoor spaces (yes or no question)
(c) Availability of private outdoor spaces on the ground floor level (yes or no question)
3. Placement of balconies[a]
(a) Ratio between the transparent (or translucent) and the opaque parts of the handrails
(b) Balcony sticks out or is built into the facade of the building volume
(c) Balconies are on top of each other or staggered

[h] Chermayeff & Alexander 1966
[i] SBTool 2012
[j] Rapoport 1970/1994, 1977

(D) Lighting (daylight access)
1. Daylight access[a,c,d] (yes or no question)
2. Ratio between glazing and room areas[d]
3. Daylight factor (DF)[b,c,d]
(E) Closure, enclosure and peripheral density (configuration of the block that affects views)[k]
1. South-west orientation of the main living areas[e] (yes or no question)
2. Height-to-width-ratio of the enclosed space (courtyard)[e,f]
3. Difference between the height of the building and the average height of surrounding buildings (difference in height > than ⅔ of the average height of the surroundings)[f] (yes or no question)

8.1.2. Internal spatiality and spatial arrangements

> ‘The essential existence of architecture is not simply given by the shapes of which a building is composed but through the interaction of them as they segregate, bound and articulate space’ (Weber 1995, p. 132).

The spatial quality determinant of internal spatiality and spatial arrangements considers the building scale only. The main three topics of internal spatiality and spatial arrangements are:

- Articulation between space and its boundaries, and between adjacent spaces
- Privacy within the dwelling (zoning considering different groups within the family)
- Light (daylight distribution in the space, layout zoning, and sun orientation of openings)

[k] Weber 1995

The main topics are represented by five principles, which are listed in Table 19:

(A) Centricity (Weber 1995, Von Meiss 1997, Indraprastha & Shinozaki 2012) and concavity (Weber 1995) (Section 3.1.3 Physical characteristics of space relevant to spatial perception, and Section 3.1.5 Development of the spatial quality definition and assessment). Centricity consists of the perception of where the centre of a space is located, and it does not necessarily coincide with the geometrical centre of the room. Concavity consists of how concave the space appears to be. The placement of space boundaries (walls), and the number and placement of entrances, affect centricity (Weber 1995, Von Meiss 1997, Indraprastha & Shinozaki 2012) and concavity (Weber 1995) in spaces. Spaces with clear centricity and concavity present a strong figural character, and are clearly perceived by the observer (Weber 1995).

Indraprastha and Shinozaki (2012) define the linear path type of pass-through spaces for rooms with more than one entrance (Figures 23a, 23b and 23c, Section 3.1.5). The circulation path is linear when two entrances are 'connected by a straight line' (2012, p. 71). The linear path type is crossing the room from one door perpendicular to the other (cross circulation). The zones of influence of doors do not overlap in linear path type of pass-through spaces (Section 3.1.5, Appendix A);

(B) Internal division of space and spatial density (Weber 1995, Section 3.1.3). This is how a space is subdivided. Walls but also columns, stairs and differences in ceilings heights can subdivide spaces;

(C) Spatial hierarchies and system complexity (Weber 1995, Section 3.1.3). System complexity consists of the analysis of spatial hierarchies among spaces (coordinated or subordinated spatial relationships), and system complexity (balance and rhythm in spatial relationships). A coordinated spatial relationship is characterized by adjacent spaces with similar dominance (Figures 6a and 6b, Section 3.1.3). In a subordinated spatial relationship, there is a secondary space that is subordinated to a primary space, such as in the relation between a room (primary space) and a balcony (secondary space) (Figures 7a and 7b, Section 3.1.3).

(D) Privacy within the dwelling (Chermayeff & Alexander 1966, Section 3.1.5). This consists of the analysis of the dwelling's internal zoning, considering the needs of different family group members (for example a distinction between children's areas and adults' areas);

(E) Lighting (Section 3.1.5). This principle refers to internal zoning considering the access and distribution of daylight in the space, and optimal sun orientation (Hopkinson et al. 1966, Baker & Steemers 1996, 2002, BREEAM UK 2008, SBTool 2012, Matusiak 2014).

Baker and Steemers (2002) explain that daylight quality depends on light distribution rather than the quantity of light entering a room. Therefore, the ratio between glazing and room areas can be an indicator of the nature (positive or negative) of changes in the glazing and plan areas brought by building renovation (Matusiak 2014). The same is valid for the ratio between glazing and indoor surface areas (wall, floors and ceiling) (Matusiak 2016). This is considering that there are no changes in the glazing properties of transmittance, and on the reflectances of the indoor surface areas (Matusiak 2016, Section 3.1.5). For example, equal glazing area and higher room area lead to lower ratio values between glazing and room areas, in comparison to the situation prior to renovation. This means that the area of the room increased, while the glazing area remained unchanged, which may result in poorer daylight in the room. However, room and glazing areas alone are not sufficient to evaluate light distribution in the space because light distribution are also influenced by space proportions (ratio between length and width of the room), placement of windows on the walls, and surface reflectance (CEN 2015, Matusiak 2014, 2016).

Table 19. Spatial quality assessment for internal spatiality and spatial arrangements (revised version)

Spatial quality assessment – Determinant 2: Internal spatiality and spatial arrangements (Building scale)
(A) Centricity and concavity
1. Geometric centre of the space
(a) The relevance of the geometrical centre is weakened (for example as a consequence of the addition of large openings and enclosing elements)[a] (yes or no question)
(b) Shape of the room has only one geometrical centre (strong figural character)[a,b] (yes or no question)
(c) Secondary centres are symmetrically arranged (emphasis on the presence of the geometric centres of the rooms, regularity and symmetry)[b] (yes or no question)
2. Perceptual centres of the space
(a) The space has multiple entrances[b,c] (yes or no question)
(b) Liner path type of pass-through space (for spaces with multiple entrances)[c] (yes or no question)
(c) Zones of influence of doors overlap (for spaces with multiple entrances)[c] (yes or no question)
3. Placement of entrances (concavity and privacy)[b]
(a) Entrance(s) located close to the axes of the room (yes or no question)

[a] Von Meiss 1997
[b] Weber 1995
[c] Indraprastha and Shinozaki 2012

	(b) Presence of columns, niches or angular walls to enhance concavity (yes or no question)
	(c) Entrance located on the longitudinal axis to increase privacy (yes or no question)
(B) Internal division of space and spatial density[b]	
1. Placement of columns and internal walls	
	(a) Columns standing free in space (if free-standing columns are added or replaced) (yes or no question)
	(b) Spaces defined (subdivided) by columns (yes or no question, if there are free-standing columns in the room)
	(c) Ratio between the internal walls area and the room area
2. Placement of the stairs	
	(a) Free-standing stairs (detached from space boundaries) (if stairs are added or replaced) (yes or no question)
	(b) Spaces defined (subdivided) by free-standing stairs
	(c) Ratio between the area of stairs and the room area (if stairs are placed in living areas)
3. Ceiling heights	
	(a) Different heights in the same room (yes or no question)
	(b) Spaces defined (subdivided) by different heights (yes or no question, if there are differences in heights in the room)
	(c) Minimum height of 2.4 metres[d] (yes or no question)
(C) Spatial hierarchies and system complexity[b]	
1. Coordinated spatial relationship (spaces with similar dominance)	
	(a) Areas (in square metres) of adjacent spaces are similar (area difference < 30%) (yes or no question)
	(b) Direct connection between two or more coordinated spaces (yes or no question)
	(c) Coordinated spaces have direct connection with circulation areas (yes or no question)
2. Subordinated spatial relationship (primary and secondary spaces)	
	(a) Areas (in square metres) of adjacent spaces are significantly dissimilar (area difference > 30%) (yes or no question)
	(b) Direct connection between two or more subordinated spaces (yes or no question)
	(c) Function of the secondary space complements the primary space (yes or no question)

[d] TEK10

3. Spatial system complexity
(a) Parts of the spatial system are organized in orderly and balanced relationships (yes or no question)
(b) Secondary spaces are rhythmically arranged in a subordinated spatial relationship (yes or no question)
(c) Secondary spaces are coordinately arranged in a subordinated spatial relationship (yes or no question)
(D) Privacy within the dwelling (zoning according to the needs of different family group members)[e]
1. Differentiation between social and private zones (yes or no question)
2. Children's domain is directly accessible from the circulation area (yes or no question)
3. Buffer zone between the children's private domain and the parents' private domain (yes or no question)
(E) Lighting[f]
1. Daylight access
(a) Relation between wall thickness and window area
(b) Ratio between glazing and room areas
(c) Ratio between glazing and indoor surface areas (walls, floor, ceiling)
2. Light distribution in the space
(a) Reflectance of indoor surface areas[g]
(b) Luminance distribution[g]
(c) Ratio between the daylit (passive) and the non-daylit (non-passive) zones[h]
3. Internal zoning of the diverse functions and daylight access
(a) Internal zoning considers optimal sun orientation (yes or no question)
(b) Minimum of 80% of the floor area of the room is lit by daylight[i] (yes or no question)
(c) Daylight access in living areas for at least 2 hours per day[j] (yes or no question)

e Chermayeff & Alexander 1966
f Matusiak 2014
g Hopkinson et al. 1966
h Baker & Steemers 1996, 2002
i BREEAM UK 2008
j SBTool 2012

8.1.3. Transition between public and private spaces

> ‘This is where you enter and leave buildings, where indoor and outdoor life can interact. This is where city meets building’ (Gehl 2010, p. 75).

The spatial quality determinant of transition between public and private spaces considers the building and the block scales. The main three topics of transition between public and private spaces are:

- Physical barriers between public and private spaces
- Outdoor private spaces
- Facade composition and permeability (changes in facade permeability and composition, such as the size of windows and dwelling entrances)

The main topics are represented by five principles, which are listed in Table 20:

(A) The private entrance to the dwelling is a protected and sheltered standing space (Chermayeff & Alexander 1966) (Section 3.1.5 Development of the spatial quality definition and assessment);

(B) There are clear boundaries between the private and semi-public domains, and between private, semi-public and public domains (Chermayeff & Alexander 1966, Rapoport 1970/1994, 1977, Gehl 2010, 2011) (Section 3.1.3 Physical characteristics of space relevant to spatial perception, and Section 3.1.5 Development of the spatial quality definition and assessment);

(C) Outdoor private spaces are effective staying areas, that is they are actually used by the residents (Rapoport 1970/1994, 1977, Gehl 2010, 2011) (Sections 3.1.3 and 3.1.5);

(D) Uniformity and coherence of boundaries (Weber 1995) (Section 3.1.3). This is the analysis of facade composition in terms of similarity and rhythm, and facade roughness (Weber 1995, Serra 1997).

The indicator D.1c analyses whether symmetry and coherence of boundaries are achieved in facade composition after renovation, but lighting and view demands are overlooked (Acre & Wyckmans 2015b). That is when considerations about the facade composition prevail above other demands, for example, a large room with a little window, which provides insufficient lighting and view;

(E) The impact of changes on the plan on the facade composition (Acre & Wyckmans 2015b). This principle consists of the analysis of whether changes in the plan as consequence of the renovation, affect facade composition in terms of similarity, rhythm and facade roughness.

Table 20. Spatial quality assessment for the transition between public and private spaces (revised version)

Spatial quality assessment – Determinant 3: Transition between public and private spaces (Building and block scales)
(A) Private entrance to dwelling is a protected and sheltered standing space (yes or no question)[a]
(B) Clear boundaries between private, semi-public and public domains[a,b,c]
1. Clear boundaries within the private and semi-public domains (neighbour to neighbour, and interaction between dwelling and front yard (yes or no question)
2. Clear boundaries between private, semi-public and public domains (relation between front yard and street) (yes or no question)
3. Use of materials to indicate different domains (yes or no question)

a Chermayeff & Alexander 1966
b Rapoport 1970/1994, 1977
c Gehl 2010, 2011

(C) Outdoor private spaces[a,c]		
	1. Presence of outdoor private spaces (yes or no question)	
	2. Outdoor private spaces are actually used (yes or no question)	
	3. Outdoor private spaces on street level (yes or no question)	
(D) Uniformity and coherence of boundaries (single building)[d]		
	1. Similarity in facade composition	
		(a) Similarity of architectural elements (similarities in scale and proportion) (yes or no question)
		(b) Similarity of facade decoration and materials (yes or no question)
		(c) Symmetry and coherence of boundaries are achieved; however, lighting and view demands are overlooked (yes or no question)
	2. Rhythm of facade composition	
		(a) Ordered repetition of architectural elements to achieve an overall unified effect (yes or no question)
		(b) Differences of formats and sizes of architectural elements (yes or no question)
		(c) Proportion considered in the figure (window) and ground (wall) articulation (yes or no question)
	3. Facade roughness[e]	
		(a) Presence of projected bounces on the facade (such as balconies and bay windows) (yes or no question)
		(b) Ratio between the area of projected bounces and the facade area
		(c) Similarity of decoration and materials between projected bounces and the facade (yes or no question)
(E) The impact of changes in the plan on facade composition[f]		
	1. Changes in the plan impact similarity in the facade composition (yes or no question)	
	2. Changes in the plan impact the rhythm in the facade composition (yes or no question)	
	3. Changes in the plan impact the roughness in the facade composition (yes or no question)	

[d] Weber 1995
[e] Serra 1997
[f] Acre & Wyckmans 2015b

8.1.4. Perceived density, built and human densities

> 'The study of density is not so much about maximizing density in terms of floor space or people in general, as it is about optimizing and guiding the mixture of the elements above' (Uytenhaak 2008, p. 10).

The spatial quality determinant of perceived density, built and human densities considers the block scale only. The main three topics of perceived density, built and human densities are:

- Block physical boundaries (closure and peripheral density)
- Height-to-width ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure
- Functions, and built and human densities

The main topics are represented by five principles, which are listed in Table 21:

(A) Spatial complexity (Lynch 1960). It consists of the study of surface contrast, form simplicity and dominance in the building block. Surface contrast is whether there is physical continuance of the edges of the block, nearness of parts (such as a cluster of buildings), and harmony (similarity) of surface and form among the buildings in the same block. Harmony in the facade composition of a building block can be achieved by building materials and use of common signs such as repetitive pattern of windows (Lynch 1960). Form simplicity is the analysis of the shape of the block in terms of compactness and porosity (Lynch 1960, Serra 1997). Dominance consists of the analysis of the visual impact of one part over the whole by means of size and proportion, and the interplay between vertical and horizontal dimensions of the block. The placement of vertical elements in the shape of the block is particularly relevant in relation to symmetry and the main focus (the centre point) of the facade (Weber 1995);

(B) Closure, enclosure and peripheral density of the block (Weber 1995) (Section 3.1.3 Physical characteristics of space relevant to spatial perception). This principle consists of features of the block such as physical or perceived continuity of space boundaries (closure) (Figures 10a to 10d, Section 3.1.3), the height-to-width ratio of the enclosed space (enclosure), and the articulation of space boundaries. Physical or perceived continuity is the continuance of the perimeter of the block (Weber 1995). Height-to-width ratio of the enclosed space is the relation between the dimensions of the courtyard and the heights of the peripheral buildings (Rapoport 1970/1994, 1977, Weber 1995, Gehl 2010, 2011). Articulation of space boundaries is the contrast between the heights of the peripheral buildings, which is the peripheral density (Weber 1995);

(C) Built density, which is measured in square metres (Rapoport 1977, 1982/1994, Uytenhaak 2008, Gehl 2010, 2011) (Section 3.1.1 Spatial quality relevance and research gap, Section 3.1.3 Physical characteristics of space relevant to spatial perception);

(D) Human density, the number of people per square metre of block area (Rapoport 1970/1994, 1977, Uytenhaak 2008) (Sections 3.1.1 and 3.1.3);

(E) Functions. This principle consists of the analysis of changes in the use of space that follow the dwelling renovation (Rapoport 1970/1994, 1977, Gehl 2010) (Section 3.1.3).

Table 21. Spatial quality assessment for perceived density, built and human densities (revised version)

Spatial quality assessment – Determinant 4: Perceived density, built and human densities (Block scale)	
(A) Spatial complexity	
1. Surface contrasts[a]	
	(a) Physical continuance of the edges of the block (quality of continuity) (yes or no question)
	(b) Similarity of surface and form of the boundaries of the block (yes or no question)
	(c) Similarity among the different facade compositions of the different buildings of the block (building materials and use of common signs such as repetitive pattern of windows) (yes or no question)
2. Form simplicity[a,b]	
	(a) Geometry and compactness of the block shape (relation between the external block surface and its volume)
	(b) Porosity of the block shape (presence of exterior spaces within the external perimeter of the block, such as courtyards) (yes or no question)
	(c) Ratio between the area of exterior spaces within the block's perimeter, and the area of the block (porosity of the block shape)
3. Dominance[c]	
	(a) Slenderness of the block shape (relation between the vertical and the horizontal volumes of the block)
	(b) Presence of strong vertical accents at the position of the main focus (yes or no question)
	(c) Presence of a vertical axis of symmetry at the position of the main focus (perceptual stability) (yes or no question)

[a] Lynch 1960
[b] Serra 1997
[c] Weber 1995

(B) Closure, enclosure and peripheral density[c]
1. Presence of physical or perceived continuity of space boundaries (stability of the block perimeter)[c] (yes or no question)
2. Height-to-width ratio of the enclosed space in relation to the 1:1 proportion (relation between the dimensions of the courtyard and the heights of the peripheral buildings)[c,d,e]
3. Articulation of space boundaries (contrast between the heights of the peripheral buildings and the proportion between the block heights and surrounding blocks in relation to the 1:1 proportion)[c]
(C) Built density (per square metre)[d,e,f]
1. Floor space index (FSI) and average number of floors (L=FSI/GSI)
2. Ground space index (GSI)
3. Open space ratio (OSR)
(D) Human density (people per square metre of block area)[d,f]
1. Percentage of residents of the total users population
2. Percentage of non-residents of the total users population
3. Relation between square metres per person and the built area according to the functions' demands
(E) Functions (use of the space)[d,e]
1. Percentage of square metres per function
2. Compatibility of functions within the block (yes or no question)
3. Functions with low human presence located on the ground and first floors (such as parking and storage areas) (yes or no question)

8.2. Spatial quality assessment method

The spatial quality assessment is a proposal to bring the theory on spatial quality closer to the practice in energy efficiency renovation of dwellings. The translation of the spatial quality definition into an assessment that can potentially be applied to practice is presented in this section. The spatial quality assessment is the

[d] Rapoport 1970/1994, 1977
[e] Gehl 2010, 2011
[f] Uytenhaak 2008

answer to the main research question: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* The assessment provided in this PhD research is applied to the Arlequin case in Grenoble, France (Figures 30 and 31). The results of the assessment were presented to the ZenN partners in project meetings in 2014 and 2015. However, architects, engineers or other technicians involved in the project have not evaluated the assessment.

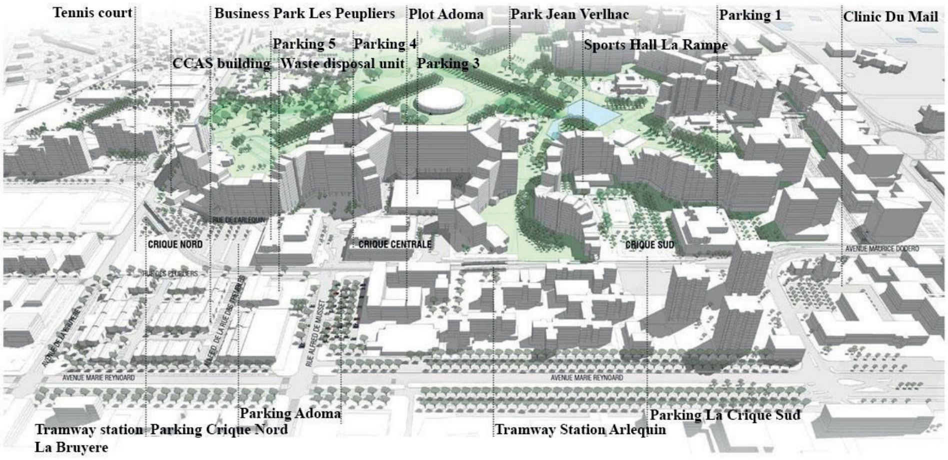


Figure 30. The Arlequin Neighbourhood and surroundings before the renovation, Grenoble, France, © [Ateliers Lion Architectes Urbanistes]. Reproduced by permission of Ateliers Lion Architectes Urbanistes.

The four spatial quality determinants are combined into a spatial quality assessment method (Acre & Wyckmans 2015a), which evaluates the impact of energy efficiency renovation of dwellings on spatial quality. At any time in the renovation process, it is possible to apply the assessment. However, the design phase of projects is the period when alternatives are explored and changes can still be made. The goals of applying the assessment are: to predict the nature of the impact of the renovation on spatial quality before the construction, and upgrade spatial quality as well as energy efficiency in dwellings. The assessment can also be performed after the renovation, to check whether the original intended impact on spatial quality is maintained.

In this PhD research, the four spatial quality determinants are equally relevant in the study of spatial quality in dwellings, and all four are evaluated in the Arlequin case. Therefore, each determinant is given a weight of 25% from the total of 100%. The weight of 25% is further equally divided among the principles, sub-principles and features of each determinant (Tables 18 to 21, Chapter 8. Spatial quality definition and assessment). Whether all determinants are equally weighted depends on each case, and should be decided by the interested parties involved in the project. However, any weighting will be subjective which may lead to a bias in the results. It has been difficult to find any guidance in the literature about what is the most important spatial quality determinant and therefore equal weights are chosen.

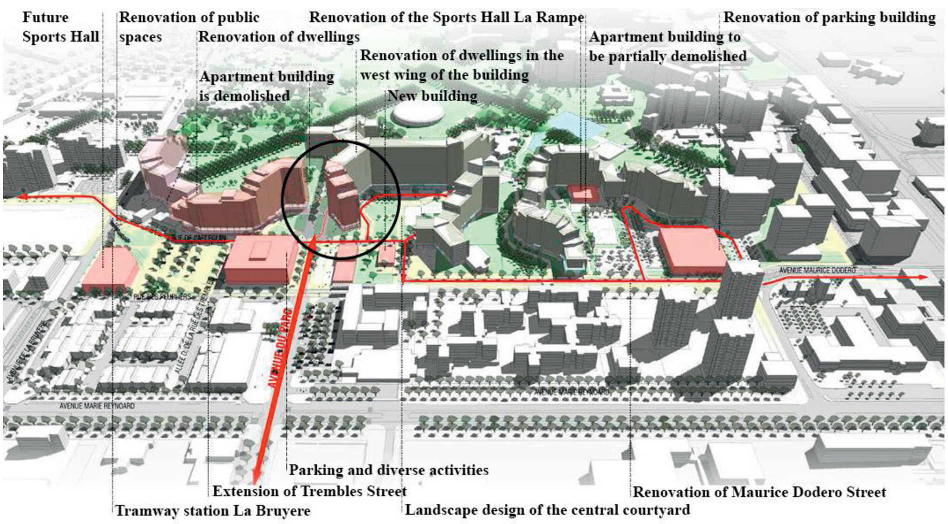
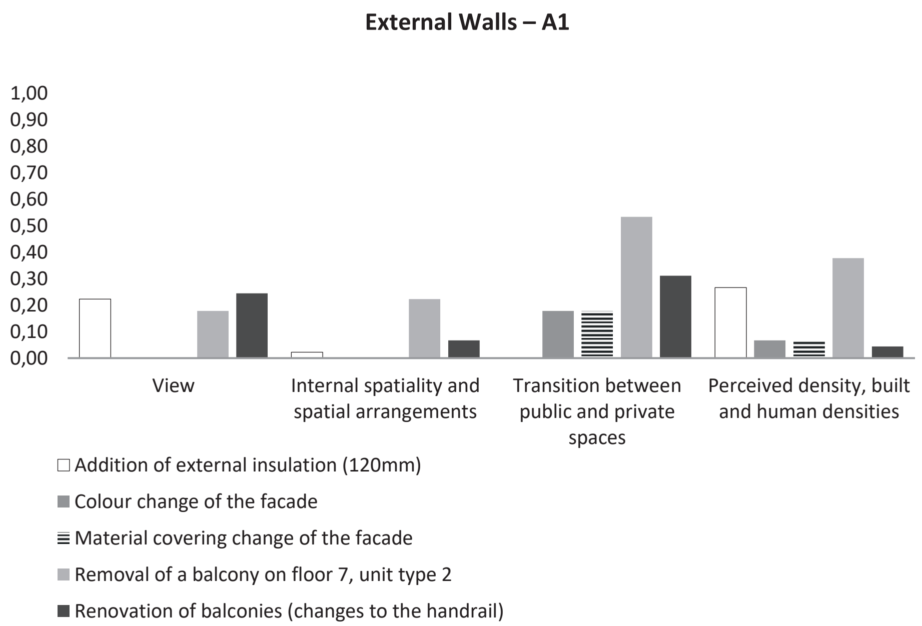


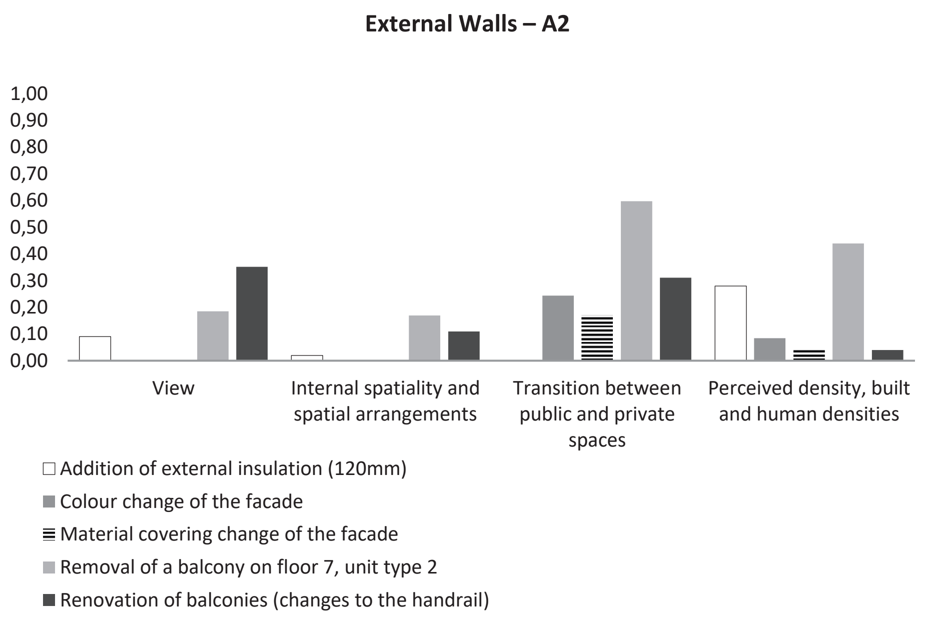
Figure 31. The MS-1 Building with 89 social housing apartments is indicated by the rectangle with a broken red line to the top. Arlequin Neighbourhood after the renovation, Grenoble, France, © [Ateliers Lion Architectes Urbanistes]. Reproduced by permission of Ateliers Lion Architectes Urbanistes.

The spatial quality assessment of the renovation is performed in two parts (A1 and A2) for all features of the spatial quality determinants. The first part of the assessment (A1) consists of answering the question: does the measure influence the spatial quality feature? This is a yes or no question (Graph 1a). The question in the second part of the assessment (A2) is: what is the nature of the impact? The answer can be positive, irrelevant or negative (+1, 0, -1) (Graph 1b). Each renovation measure in the project passes through the two parts of the assessment to determine the existence of the impact on spatial quality and the nature of it.



Graph 1a. Example of results of the spatial quality assessment part 1 (A1). The existence of the impact of the renovation of external walls on spatial quality in the MS-1 building, in Arlequin, Grenoble, France (Acre & Wyckmans 2015b).

The answers from A1 and A2 are first inserted into Microsoft Excel© sheets. The answers are given a numerical score (+1, 0, -1) and after that they are transferred to an Excel© database to generate the graphs, which express the relations between the renovation and the impact on spatial quality. The graphs are generated per building component. The graphs are only an abstract representation of the impact of the renovation on spatial quality. That is, the higher the bars are, the more significant the impact on spatial quality, namely the bars and values in the graphs do not represent quantities or dimensions (Acre & Wyckmans 2015b).



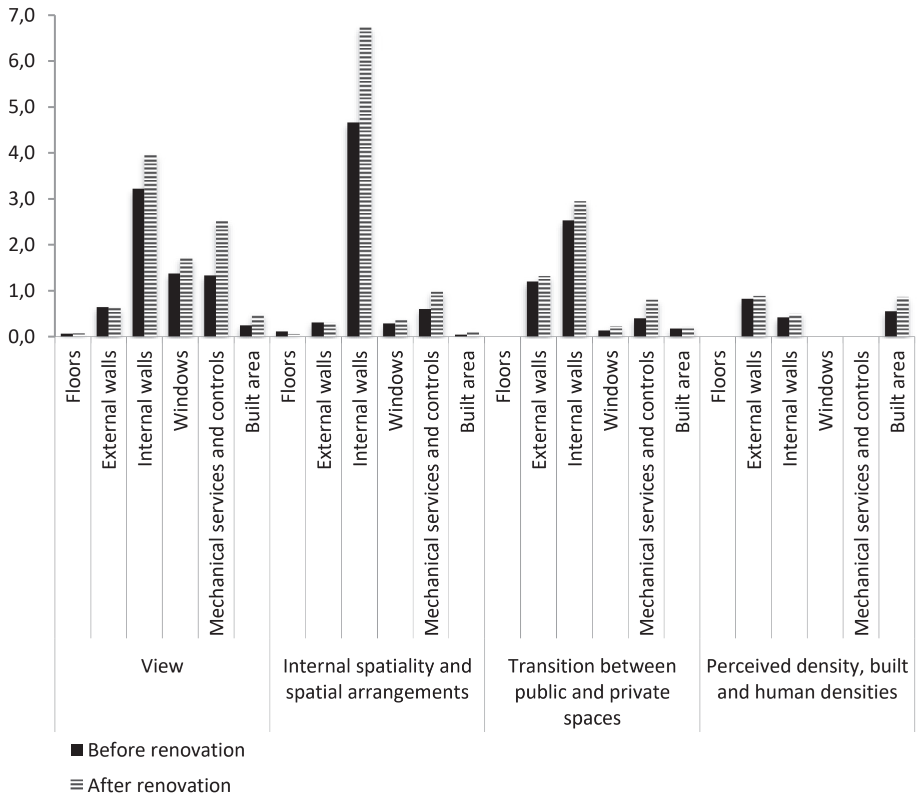
Graph 1b. Example of results of the spatial quality assessment part 2 (A2). The nature (positive, irrelevant or negative) of the impact of the renovation of external walls on spatial quality in the MS-1 building, in Arlequin, Grenoble, France (Acre & Wyckmans 2015b).

Graph 2 indicates the impact of the dwelling renovation on spatial quality for the MS-1 building in Arlequin, Grenoble, France, with all building components and measures included (Acre & Wyckmans 2015b). The results for each building component are grouped per spatial quality determinant in the graph, to give an overview of the overall impact of the renovation on spatial quality. Graph 2 also eases the comparison of the impact on spatial quality among building components and determinants. The assessment was based on technical information and drawings received from Aktis Architecture & Urbanisme, the architectural office responsible for the renovation of the MS-1 building.

The results of the spatial quality assessment of the MS-1 building in Acre and Wyckmans 2015b, are used in this section to illustrate the assessment. The assessment of the MS-1 building was carried out during the renovation of the building. The dark bars in Graph 2 represent whether and to which extent in a range from 0 to 10, the renovation is expected to affect spatial quality. The light grey bars represent the nature (positive, irrelevant or negative) of the impact on spatial quality, expected after the renovation. The upper light grey bars in comparison to the dark ones represent improvements in spatial quality, while the lower light grey bars represent deterioration in relation to spatial quality (Graph 2).

The overall impact of the renovation of the MS-1 building on spatial quality is expected to be positive, as represented in Graph 2 (Acre & Wyckmans 2015b).

The positive impact on spatial quality is a consequence of for example new openings in the facade and the area increase of several apartments in the building. Changes in the building components of floors and external walls are the ones expected to have a negative effect on spatial quality according to Graph 2. The lower light grey bars for floors and external walls in determinants (1) and (2) represent the negative impact on spatial quality. These changes are for example, the lower ceiling height (2.35 metres), and thicker external walls (addition of external insulation of 120mm) after the renovation.



Graph 2. Results of the spatial quality assessment of the MS-1 building before and after renovation (Acre & Wyckmans 2015b). Example of the graphical

representation of the impact of the energy efficiency renovation on spatial quality.

However, there are measures for other building components that also have a negative impact on spatial quality that do not clearly appear in Graph 2 with the overall results. This is because the majority of the measures for these specific components has a positive effect on spatial quality, which shadows the negative effect from the minority of the measures. This happens because the assessment is performed for the whole building. The assessment can be performed for all apartment units separately to increase the level of detail of the results, which would then be specific for each unit. The negative effect of the renovation on spatial quality will be more visible in the results for a single unit, in comparison to the assessment performed for the whole building. Examples of the measures that affect spatial quality negatively but that are not clear in the overall results in Graph 2 are: the decrease in area of several apartments, smaller windows with more robust framing and deep rooms (Figures 32a, 32b and 32c), and spatial relationships in the some of the apartments (Figures 33a, 33b, and 33c), in comparison to before the renovation (Acre & Wyckmans 2015b).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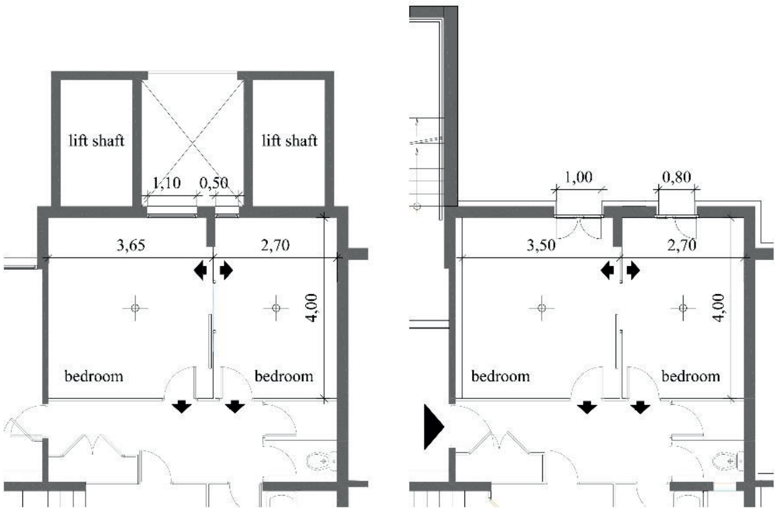
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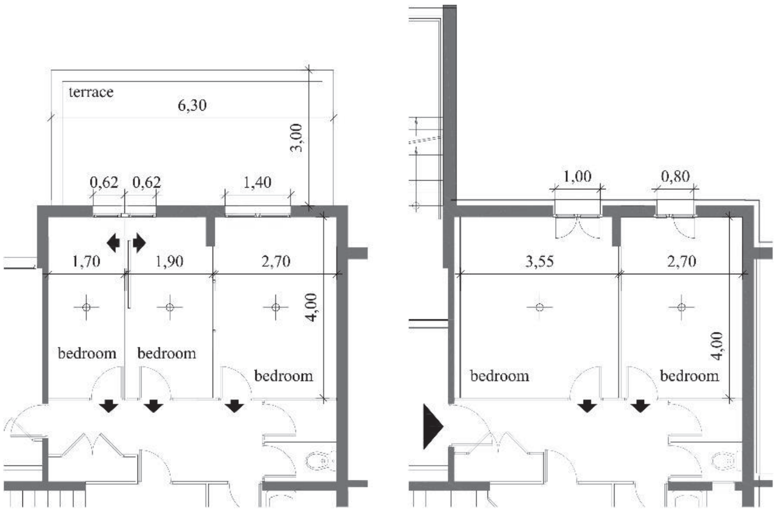
b

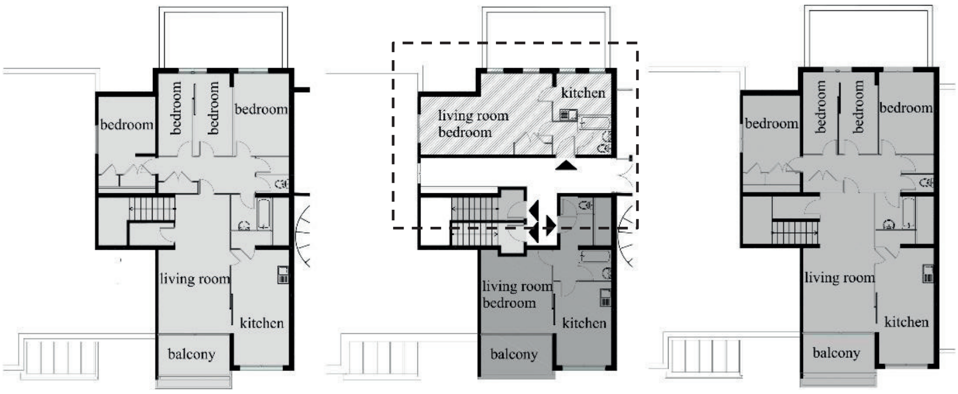


c

Figures 32(a), 32(b) and 32(c). Small windows and deep rooms. North-west facade before and after the renovation (32a). Drawings of bedrooms of an apartment on the 3rd floor before and after the renovation (32b). Drawings of bedrooms of an apartment on the 7th floor before and after the renovation (32c). These apartments are indicated in Figure 32(a). Figures: Fernanda Acre.

Figures 33a, 33b and 33c illustrate spatial relationships in the some of the apartments, specifically in the apartment on the 14th floor indicated in detail in Figure 33c. This specific unit increased in area with the addition of the former corridor to the apartment, which is indicated in Figures 33a (before the renovation) and 33b (after the renovation).

The structural plan (Figure 33c) indicates that the wall between the apartment and the corridor prior to renovation, is not part of the structure and therefore could be removed with the renovation. This wall is not removed and the former corridor is attached to the apartment after the renovation (Figures 33a, 33b and 33c). Part of the corridor on the right becomes a bathroom, while the left part becomes a narrow and long room (1.42m x 3.80m) resulting from the corridor area. The main room in the apartment is both the living area and bedroom. The former corridor could be fully integrated to the living area, and the kitchen could be moved into the living area in order to create a bedroom.



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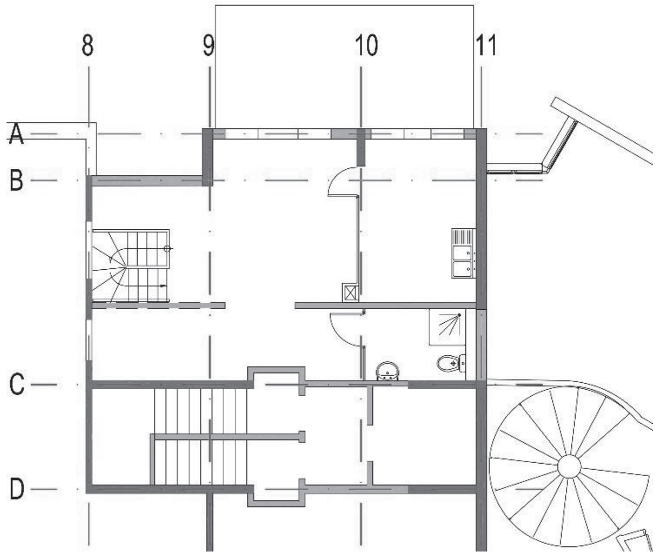

c

Figures 33(a), 33(b) and 33(c). Fragments of the 13th, 14th and 15th floors before (33a) and after (33b) the renovation. Structural plan of one of the apartments on the 14th floor, which increased in area with the addition of the former corridor (33c). The wall located beside the stairs between the apartment and the former corridor is not part of the structure and could be removed with the renovation (33c). The location of this specific apartment is indicated in Figures 32(a), 33(a) and 33(b). Figures: Fernanda Acre.

8.3. Data source for the assessment of spatial quality

Two sources of information are necessary to perform the spatial quality assessment in a renovation case: data from the renovation project that is the measures categorized per building component, and the input of the evaluators who fill in their answers in the Excel© sheets in the database. The engineering and architectural firms involved in the project provided the data regarding the renovation. Visiting the project under assessment is desirable in this method. Once the information about the renovation is gathered, the measures are categorized per building component (Tables 5 to 9, Appendix B, with descriptions of the technical measures per building component). After the renovation measures are classified, the assessment is carried out as described in Section 8.2 'Spatial quality assessment method'. The assessment is intended to be performed by experts for example, architects and engineers involved in the renovation. This is because the majority of the principles and indicators in the assessment are not commonly known by laypersons such as end users.

9. Scientific articles and peer reviewed conference papers

This PhD research consists of three parts that complement each other. The results of each part have been published in three scientific articles. The first part consists of proposing a definition of spatial quality for dwellings, which is presented in Acre and Wyckmans (2014). The second part of the research is the development of the spatial quality assessment, and it is published in Acre and Wyckmans (2015a). The third part is the evaluation of an actual energy efficiency renovation case using the assessment and is published in Acre and Wyckmans (2015b). The idea behind developing a spatial quality assessment is to provide architects, users and decision makers with a tool to improve spatial quality along with energy efficiency, which at the same time promotes building renovation, and fosters sustainable built environments. The three articles are presented in chronological order, and commented in the sections below.

The conference papers are working papers. The goal was to explore possible indicators to assess spatial quality. The conferences were an opportunity to present and discuss these indicators. The lessons learnt with these papers were relevant for developing the spatial quality definition and assessment in Acre and Wyckmans (2014) and (2015a).

9.1. Spatial Quality Determinants for Residential Building Renovation: A Methodological Approach to the Development of a Spatial Quality Assessment

2014/06 International Journal of Sustainable Building Technology and Urban Development, SUSB (ISSN 2093-761X). Co-author: Professor Annemie Wyckmans.

DOI: 10.1080/2093761X.2014.923793

This article presents the spatial quality definition that is the basis for the PhD research. The gap this research addresses is the lack of a clear definition of spatial quality on the building scale, which is also presented in this article. The four spatial quality determinants that define spatial quality in dwellings brought together in this article are: (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces and (4) perceived density, built and human densities. The article also describes and illustrates the principles of each determinant.

The conclusion of this article has two main parts. The first part is the four spatial quality determinants resulting from the literature study. Second, more research is needed to extend the spatial quality definition in this little-developed field of research. There is still a significant amount of information that can be included in the definition, which can lead to new spatial quality determinants. A strength of the spatial quality definition is the inclusion of building and block scales. Also, this work calls attention for alternatives in building renovation that do not consider technical performance only. The spatial quality checklist in this article is the starting point for the development of the spatial quality assessment.

The content of the article got minor revision but it had to be restructured to align with the requests from the editor and reviewers. The article was originally written as a literature review on spatial quality. However, the reviewers and the editor of the SUSB Journal were not interested in publishing this type of article for that issue. The reviewers and the editor requested an extra section with an initial crossing between energy efficiency renovation of mechanical installations and spatial quality.

9.2. Dwelling Renovation and Spatial Quality, The Impact of the Dwelling Renovation on Spatial Quality Determinants

2015/04 International Journal of Sustainable Built Environment, IJSBE (ISSN: 2212-6090). Co-author: Professor Annemie Wyckmans.

DOI: 10.1016/j.ijsbe.2015.02.001

The focus of this article and the main result is the development of the spatial quality assessment to evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings. The article describes technical measures of dwelling renovation using literature on energy efficiency renovation. These measures were crossed with the definition of spatial quality proposed in Acre and Wyckmans (2014). The crossing also indicated that energy efficiency renovation does affect spatial quality in dwellings.

This article is a main contribution for the PhD research because it was the first time that the impact of the renovation on spatial quality was graphically represented. Once the renovation measures were categorized and the impact of these measures on spatial quality was analysed, it was exciting to generate Graph 2 (Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015a) and see how straightforward it was to understand why the bars in the graph got those particular shapes. That is, whether the renovation affects spatial quality and the nature of this effect. The graphical representation of the effect of the renovation on spatial quality can help laypersons such as owners and end users, understand this effect.

The main conclusion of this article is that energy efficiency renovation affects spatial quality in dwellings. The main contribution of the work is the revealing of the 'whole underlying facet of building renovation that has not been clearly brought to the surface in the current literature and practice' (Acre & Wyckmans 2015a, p. 36). The direct contribution of this article is the spatial quality assessment, which enables the evaluation of the impact of energy efficiency renovation on spatial quality. The assessment consists of a proposal of guiding principles to help stakeholders to integrate spatial quality in energy efficiency renovation of dwellings. Interviews with end users and design professionals are not performed in this research. The assessment is particularly valuable before the renovation starts that is, when it is easier to adjust technical measures and eventually the renovation strategy.

Two other relevant findings in this article are worth pointing out. First, the article suggests that the whole-building-renovation approach (BPIE 2013) has the potential to improve both technical issues along with spatial quality in dwellings. This is contrary to the punctual interventions approach (BPIE 2013). In the whole-building-renovation approach, the renovation may affect the whole building and not a few building components only. This approach aligns with the European deep renovation strategy to reach Europe's 2050 aspirations for energy savings and CO_2 emissions reduction (BPIE 2011).

Second, the analysis of cases of renovation of dwellings indicates that there is an opportunity in energy efficiency renovation strategies. Measures such as changes in the size of windows to increase solar gain and natural ventilation, and the use of vegetation to avoid overheating, are gradually being implemented in energy efficiency renovation of dwellings. These low maintenance measures are becoming alternatives instead of the use of technical installations only. This opens up a range of alternatives and possibilities to improve spatial quality, for example, changes in the size of windows might provide opportunities to improve facade composition. The use of vegetation as shading device can be a possibility to create outdoor private spaces. This development can promote the exploration of alternatives in building renovation, in which the focus is the end user rather than technical issues only.

The reviewers and the editor of the IJSBE Journal required minor adjustments to the article. Adjustments were for example to reduce the number of keywords provided because it exceeded the maximum allowed by the journal, and to check the reference list because there were references in the text that were not included in the reference list.

9.3. Spatial Quality Assessment of Dwelling Renovation, The Impact of the Dwelling Renovation on Spatial Quality, Case of the Neighbourhood of Arlequin in Grenoble, France

2015/11 Smart and Sustainable Built Environment Journal, SASBE (ISSN: 2046-6099). Co-author: Professor Annemie Wyckmans. DOI: 10.1108/SASBE-05-2015-0008

This article presents the impact of an energy efficiency renovation on spatial quality in an actual renovation case. The MS-1 building in the neighbourhood of

Arlequin in Grenoble, France, is the first building case that is evaluated using the spatial quality assessment. The Arlequin case is one of the demonstrators of the ZenN Project (grant agreement number 314363) (Chapter 4. ZenN Project and the PhD research).

The results indicate both the positive and the negative impacts of the renovation on spatial quality in the MS-1 building. The impact is mostly negative when the measures considered for the assessment are the ones intended to improve energy efficiency only. The positive impact of the renovation on spatial quality results mainly from measures that are not directly related to energy efficiency. This indicates the potential of including non-technical drivers such as spatial quality, in the predominant technical context of energy efficiency renovation of dwellings. The potential benefits are to improve the overall result of the renovation and create arguments to convince stakeholders to undertake renovation in dwellings.

The article has three main findings. First, the energy efficiency renovation of the MS-1 building affects spatial quality and the general impact of the renovation on spatial quality is expected to be positive. Second, some main points in the renovation of the MS-1 building could be re-evaluated in terms of their effect on spatial quality. The analysis brings the conclusion that some energy efficiency measures worsen existing negative spatial quality related conditions. The goal should be to find alternatives, which may not consider energy efficiency only, to improve these existing negative conditions in the MS-1 building. Examples of such existing negative conditions are small windows, deep rooms and low ceiling height. Measures that worsen these conditions are: the increase in the framing area of the windows and smaller openings, the decrease in the glazed area of the windows, the lower ceiling height, thicker external walls and deep and narrow rooms.

The spatial quality assessment consists of two parts, A1 and A2 (Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015a). The question answered in the first part of the assessment (A1) by the individual performing the assessment is: does the measure influence the spatial quality feature? This is a yes or no question. The question answered in the second part of the assessment (A2) is: what is the nature of the impact? The answer can be positive, irrelevant or negative. In Graph 2 in Acre and Wyckmans 2015b, the dark bars represent whether the renovation affects spatial quality, while the light grey ones represent the nature of this impact that is, whether it is positive, irrelevant or negative.

The third finding in the article is a limitation of the assessment. The spatial quality assessment is sensitive to negative effects, but this depends on weighting and the scale of the assessment, which is whether it is run for a single apartment unit or for the whole building. For example, the building component of windows in Graph 2, the overall result for the impact of the renovation of windows on spatial quality is positive. This is mainly because new windows were added to the facade, and because symmetry and coherence of the facade composition is achieved (Acre & Wyckmans 2015b). However, the new windows remain too small considering the dimensions of the bedrooms (Figures 32b and 32c, Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015b). Despite the new windows being small, the overall result for the impact of the renovation of windows on spatial quality is positive. The reason is that equal weighting is given to all renovation measures in the assessment performed for the MS-1 building in Arlequin. Also because the assessment is performed for the whole building. The negative effect of the renovation on spatial quality would appear clearer in the results for a single apartment unit, in comparison to the assessment performed for the whole building.

The reviewers commented that the article has little detail on the spatial quality definition and assessment. The reviewers' expectations on the content of the article were fulfilled by including an extra section to explain the spatial quality definition and assessment.

9.4. Spatial Quality Indicators for Energy Renovation of Residential Buildings

2013/06 Peer reviewed conference paper and oral presentation at the CESB13 Conference, Central Europe towards Sustainable Buildings 2013, Sustainable Building and Refurbishment for next Generations, Prague, Czech Republic (ISBN 9788024750156). Co-author: Professor Annemie Wyckmans. Funding source: European COST-TUD Conference Grant for Early Stage Researchers.

The goals of this paper are two: to find the impact of renovation of windows on spatial quality particularly on views, and to find indicators in building performance assessment tools that can assess this impact. A short analysis of three building performance assessment tools is performed to find indicators that are appropriate to assess this impact. The tools are SBTool 2012, BREEAM 2008 and LEED 2009, but the emphasis is on the SBTool 2012.

The results indicate that there are spatial quality related indicators for views in these tools. However, their indicators need to be improved to fulfil to the scientific characteristics of an indicator, namely validity, specificity, sensitivity and reliability (World Health Organization, WHO) (Chapter 5. Definition of indicator). The paper is not developed into a journal article, but the study of building performance assessment tools was relevant background exercise to the development of the spatial quality assessment, which is published in Acre and Wyckmans (2015a).

The scientific commission considered the topic relevant and accepted the paper with minor changes. The commission requested that the paper should be shorter, so that only the main topics and findings should be published in the conference proceedings.

9.5. Spatial Quality Assessments for Building Performance Tools in Energy Renovation

2013/11 Peer reviewed conference paper and oral presentation at the SB13 Conference, Contribution of Sustainable Building to Meet EU20-20-20 Targets, Guimaraes, Portugal (ISBN 9789899654372). Co-author: Professor Annemie Wyckmans. Funding source: UNIFOR.

The paper presents the method developed by Indraprastha and Shinozaki (2012) to calculate visual openness and visual privacy indexes. The content of the paper contributed to the definition and assessment particularly of the spatial quality determinant of views, in which visual openness and visual privacy are the main issues. The content of the paper was relevant to the articles Acre and Wyckmans (2014) and (2015a).

The scientific commission accepted the paper with minor changes. The commission requested more information about the visual openness and visual privacy indexes. Therefore, the mathematical model and the steps to calculate the indexes were included in the appendices of the conference paper.

9.6. Spatial Quality in Building Performance Assessment Tools, The case of Dwelling Renovation for Energy Efficiency

2014/10 Peer reviewed conference paper and oral presentation at the WSB14 Conference, World Sustainable Building 2014, Barcelona, Spain (ISBN: 978-84-697-1815-5). Co-author: Professor Annemie Wyckmans. Funding source: UNIFOR, Norges tekniske høgskoles fond.

The paper consists of a short analysis of two building performance assessment tools to find indicators that were related to spatial quality. The tools are studied for indicators for the four spatial quality determinants. This differs from the CESB13 paper mainly because the emphasis of the CESB13 paper is on the spatial quality determinant of views. The tools are SBTool 2012 and BREEAM UK 2008, but the emphasis is on the SBTool 2012.

The results indicate that there are spatial quality related indicators in SBTool 2012 and BREEAM UK 2008. However, the indicators need to be improved to fulfil to the scientific characteristics of an indicator according WHO (validity, specificity, sensitivity and reliability). The indicators in both tools lack definitions and consist mainly of recommendations, for example 'rooms should have an adequate view out' (BREEAM UK 2008, Hea 2), and 'visual quality' (SBTool 2012, F 3.7). As the CESB13 paper, the WSB14 paper is not further developed into a journal article, but this paper was important to the development of the spatial quality assessment in Acre and Wyckmans (2015a).

The scientific commission considered the exploration of how assessment tools can be improved by including non-technical drivers, relevant for the conference. The commission requested that the paper should be shorter, and narrowed to the main findings.

10. Conclusion and recommendations for further research

‘If one can get the other person to see the issue in a new way, perhaps by reframing a problem to trigger new intuitions, then one can influence others with one's words’ (Haidt 2001, p. 823).

10.1. Conclusion

The present research proposes a systematic description of the impact on spatial quality when buildings are renovated for improving energy efficiency. Patterns of how the renovation of dwellings affects spatial quality are identified and represented in the spatial quality assessment proposed in this PhD work. The study of the literature and the analysis of cases of energy efficiency renovation of dwellings considered in this PhD, indicate that the renovation may have a substantial impact on spatial quality and hence should be taken into account in the planning of energy efficiency measures (Acre &Wyckmans 2015a, 2015b). However, the significance of the impact of the renovation on spatial quality can vary considerably according to the extent of the renovation in each case. Namely, the more changes occurring in the building as consequence of the renovation, the higher the possibility for the renovation to impact spatial quality in the dwellings.

The main goal in the PhD research is: *To create an assessment framework to evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings.* The main research question is therefore: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* The sub-goals in the PhD research are: *To define spatial quality for dwellings, with measurable determinants; to evaluate and predict the impact of energy efficiency renovation on spatial quality in dwellings;* and *to explore the potential of dwelling renovation to improve spatial quality*. Consequently, the sub-questions are: *What are the main spatial quality determinants for dwellings? What potential effects are there between energy efficiency renovation and spatial quality?* And *how can energy efficiency renovation increase spatial quality in dwellings?*

Starting with the main research question: *How can design teams assess and predict the impact of energy efficiency renovation on the spatial quality in dwellings?* The spatial quality assessment is proposed to answer this question. The assessment is a translation of the spatial quality definition that has the potential to be applied to practice in renovation of dwellings. Equal weighting is given to all renovation measures in the assessment performed in the example of the MS-1 building in Arlequin in Grenoble, France (Acre & Wyckmans 2015b). However, users and design professionals are free to decide which spatial quality issues are relevant according the specific context, available time and resources.

Considering the sub research question: *What are the main spatial quality determinants for dwellings?* The spatial quality determinants for dwellings proposed in this PhD research are (1) views, (2) internal spatiality and spatial arrangements, (3) the transition between public and private spaces and (4) perceived density, built and human densities. The determinants are based on the literature study on the quality of life in the urban environment, spatiality and spatial perception.

What potential effects are there between energy efficiency renovation and spatial quality? The analysis of the literature and cases of energy efficiency renovation of dwellings indicates the renovation affects spatial quality. It also indicates that several measures, which affect spatial quality, are not taken in order to improve energy efficiency. However, they can potentially affect energy efficiency. They might also have encouraged end users' receptiveness towards energy efficiency renovation. Some examples mentioned in Acre and Wyckmans (2014) are: the addition of green roofs, changes in the plan of apartment units, and the addition or demolition of buildings in the block.

The analysis of the literature and cases of energy efficiency renovation also indicates that potential improvements on spatial quality are not a priority in dwelling renovation. That is exemplified in Graph 2 (Section 8.2 Spatial quality assessment method, and Acre & Wyckmans 2015b), with the overall results of the spatial quality assessment of the MS-1 building in Arlequin, Grenoble, France. The dark bars represent the existence of the impact of the renovation on spatial quality, in a range from 0 to 10. The dark bars are relatively low, except for the building component of internal walls (Graph 2, Section 8.2, and Acre & Wyckmans 2015b). This seems to contradict the previous assumption that several measures, which affect spatial quality, are not taken to improve energy efficiency. However, the non-energy efficiency related measures in dwelling renovation are neither taken to intentionally and consistently improve spatial quality. This indicates the opportunity to gather non-energy efficiency related improvements to a certain extent, under the term spatial quality. Once there is a clear definition of spatial quality, there is room for improving the synergy between dwelling renovation and spatial quality.

The last sub research question is: *How can energy efficiency renovation increase spatial quality in dwellings?* Energy efficiency renovation can increase spatial quality in dwellings when the renovation is considered an opportunity to improve spatial quality as well as energy performance. Energy renovation becomes attractive when renovation decision-making emphasizes homes instead of houses, and home improvements instead of primarily energy efficiency. The research indicates that there are plenty of possibilities to improve spatial quality along with energy efficiency. For example, by changing plans and windows in the facade on the building scale, and changing the configuration of the block, on the block scale. The way to improve spatial quality along with energy efficiency in dwellings is to consciously and consistently direct the renovation to both achieve energy performance as well as improve spatial quality.

The assessment for the MS-1 building is performed for the whole building. The assessment can be performed for each apartment unit individually in order to increase the level of detail of the results. That is, the negative effect of the renovation on spatial quality will be clearer in the results for a single apartment, in comparison to the assessment performed for the whole building.

10.2. Recommendations for further research

I consider the work done as the foundation for a holistic understanding of the search for sustainability, in which energy efficiency renovation of buildings plays a central role. The research gave me a basis to develop the topic of spatial quality in diverse directions and scales. During this PhD research, I gained substantial knowledge on the topics of spatial quality and energy efficiency renovation of dwellings. Expanding the scale of the study from the building to the neighbourhood scale would come as a natural sequence of the work.

There are several possibilities to develop the work further. The spatial quality definition and assessment can be developed for other scales than the building scale. They can also be used as guidelines for new houses and residential buildings. Additional research can also consist of expanding and developing further the spatial quality determinants and the assessment. However, this may lead to difficulties in applying the assessment method. In any model, there is a trade-off between complexity, accuracy and implementation strength. Complex methods many need parameters, which can only be estimated with great uncertainty so the end prediction is not necessarily more accurate.

Another possibility to explore this PhD work further is to change the focus of the study from the renovation, to renovation processes and decision making, or to end users' motivation and satisfaction, considering spatial quality. The definition and assessment can be tested and improved by interviews with users and practitioners in actual cases of energy efficiency renovation of dwellings. The results of this PhD can be a starting point for the development of qualitative based research on spatial quality. Once there is a definition of spatial quality for dwellings, the next step can be to translate the assessment into surveys and workshops for end users. The goal can be to find out how users experience the renovation in terms of its impact on spatial quality. Additional research can also be exploring how spatial quality concerns can actually affect energy renovation, instead of looking at how renovation affects spatial quality.

The spatial quality assessment could be performed for each apartment in the Arlequin case building for example. Statistical methods could be used to compare the impact of the renovation on spatial quality among the apartments. This is expected to give results that are more detailed. However, this is not performed here because the focus of the research is on developing the spatial quality definition and assessment. Running the assessment for each of the apartments is considerably time consuming, and requires knowledge of statistical methods to interpret the results for the whole building. Once there is specific data for each apartment, statistical methods can be used in collaboration with experts trained in applied statistics, to obtain and interpret results with a high level of detail.

The spatial quality assessment can be developed for different scales such as neighbourhoods and city scales. Energy efficiency renovation of dwellings is one of the scales among several in which spatial quality can be assessed. Renovation for energy efficiency in existing built environments consists mainly on improvements on the building scale. This opens up the discussion on how energy efficiency can also be improved on the neighbourhood scale complementing the achievements on the building scale. In addition, how these improvements on neighbourhood scale can have a positive effect on spatial quality for its users? If the perspective is shifted to spatial quality on the neighbourhood scale, the methodology developed in the PhD could be the same, but the spatial quality determinants and principles would change to embrace the complexity of the analysis of spatial quality on this scale.

This research work gives indications to believe that spatial quality may influence building renovation. The research deals with how the renovation influences spatial quality only, and not with: how does spatial quality influence building renovation? Nor with how does spatial quality encourage energy awareness of users? Different approaches would be necessary to answer these questions. The path in order to answer the first question would be to analyse renovation processes to find whether the decisions taken were motivated by spatial quality concerns. In order to answer the second question, the study would consider end user motivation to undertake dwelling renovation, and satisfaction after the renovation is completed.

11. Duty work

11.1. Research projects

Project: ZenN, Demonstration of nearly Zero Energy Building Renovation for Cities and Districts (EU 7th Framework Programme grant agreement no: 314363)

The ZenN project's goal is to demonstrate 'the advantages and affordability of energy efficiency renovation, and to create the right context to replicate this experience around Europe' (ZenN 2012, Part B, p. 43). The ZenN Project supports the success of energy efficiency strategies by optimizing synergies between technical and non-technical dimensions such as social, economic and policy issues (ZenN 2012). Workload: 272 hours. Funding source: European 7th Framework Programme. My contribution was participation in project meetings and reporting on the spatial quality analyses of the Arlequin case (ZenN's demonstrator in Grenoble, France) in Task 4.1 Architectural Values and Cultural Heritage. NTNU is responsible for Work Package 4 Non-Technical Drivers. I worked in ZenN in 2014, 2015 and in November 2016.

Project: RAMSES, Reconciling Adaptation, Mitigation and Sustainable

Development for Cities. Strategies, costs and impacts of adaptation to climate change (EU 7th Framework Programme grant agreement no: 308497)

The RAMSES project's goal is to define strategies for adaptation to climate change. Workload: 382 hours. Funding source: European 7th Framework Programme. My contribution was to evaluate and map strategies, costs and impacts of adaptation measures to climate change and mitigation in policy documents of the cities of Antwerp, Bilbao, Bogota and Rio de Janeiro. I have also worked on a comparison among the city cases. My work contributed to the deliverables D2.1 Synthesis review on resilient architecture and infrastructure indicators, and D2.4 Adaptation measures and corresponding indicators for resilient architecture and infrastructure. I worked in RAMSES in 2014.

Project: IDES-EDU Project, Master and Post Graduate Education and Training in Multidisciplinary Teams (Intelligent Energy Europe grant agreement no: IEE/09/631/SI2.558225)

The IDES-EDU project's goal was to indicate how different institutions are implementing energy performance of buildings (EPBD) in Master and Post Graduate education. Workload: 15 hours. My contribution was to transcribe several survey results in the deliverable D6.1 Monitoring of results, report on internal and external monitoring of results, in October and November 2013.

11.2. Teaching activities

Teaching activities at the Department of Architecture and Technology, at the Faculty of Architecture and Design, Norwegian University of Science and Technology, NTNU (September 2013/ June 2015). Responsible persons: Associate Professors Aiofe Houlihan Wiberg and Luca Finocchiaro. Total workload: 150 hours. See the description below for information on these activities:

February/ June 2015. Co-supervisor of two Master's theses in the Master of Science in Sustainable Architecture. Workload: 25 hours.

'Sustainable neighbourhood and housing development: Integration of renewable energy production and energy efficiency behavioural strategies'. Students: Viridiana Acosta Leon and Stergios Chatzichristos. Main Supervisor: Per Monsen. Co-supervisors: Fernanda Acre, Gabriele Lobaccaro and Thomas Berker.

'Refurbishment of Flatåsaunet Borettslag'. Student: Laurina Felius. Main Supervisor: Luca Finocchiaro. Co-supervisors: Fernanda Acre and Ferry Smits (Link Arkitektur).

January/ June 2014. Guidance of approximately 25 master's students divided into groups in the courses AAR 4817 ZEB Zero Emissions Design Theory (5 hours), and AAR 4546 ZEB Design of Zero Emissions Buildings (30 hours). Workload: 35 hours.

September/ December 2013. Guidance of approximately 25 master's students divided into groups in the courses: AAR 4883 Concepts and Strategies for Sustainable Architecture (50 hours), AAR 4832 Energy Theory I, and AAR 4532 Energy Project I (40 hours). I developed a lecture on concepts and strategies for sustainable architecture using material from my previous experience as an architect, for the course AAR 4883. Workload: 90 hours.

12. Other activities

Newsletter no. 2 for the ZenN Project, article: Improving People's Well-being – The Key to Renovation Acceptance.

The article 'Improving People's Well-being – The Key to Renovation Acceptance' presents the PhD research and how the research contributes to the ZenN Project. The research focus on the potential of spatial quality as an argument to secure acceptance and support by building owners to the energy efficiency renovation. A dwelling renovation completed in 2010 in Newport, South Wales (Tweed 2013) is mentioned in the article to illustrate how spatial improvements can promote energy efficiency renovation to users.

Newsletter no. 3 for the ZenN Project, article: Examining the influence of renovation options on architectural values and cultural heritage.

The article briefly summarizes the non-technical drivers presented in the Deliverable 4.1 of the ZenN Project. Non-technical drivers are stakeholder awareness and behaviour, economic and ownership structures, legislation, policy and governance, and architectural values and cultural heritage. Spatial quality is related to the non-technical driver of architectural values and cultural heritage. The influence of the energy efficiency renovation on spatial quality in the Arlequin case is also mentioned in the article. The findings indicate that the renovation has a positive impact on spatial quality.

Journal Helserådet, article: Helsefremmende boligmiljø i et ressursperspektiv.

The article illustrates research topics at NTNU's Faculty of Architecture and Design that can contribute to a health-promoting built environment. The research topics are health, welfare and technology; energy; sustainable development; and smart cities.

Peer reviewed conference, presentation and poster: Density and Spatial Quality, High-density and spatial quality. The fourth CIB Smart and Sustainable Built Environments–SASBE2012 Emerging Economies, Sao Paulo–SP, Brazil.

The main argument of the paper is that spatial quality is a key aspect in the sustainability of urban environments. Spatial quality is considered on the scales of the block and neighbourhood in this paper. Economic and technical matters are often central in the discussion regarding sustainability. However, quality of architectural and urban design solutions plays a central role in fostering user satisfaction and acceptation. The paper presents the analysis of diverse cases in high-density urban contexts. These issues are for example building typology, daylight incidence, mixed usage, the relationship between a building's street level and its direct surroundings, transitions between public, collective and private spaces, and privacy levels.

DION Organization for doctoral candidates at NTNU. Board member from June 2014 until June 2015.

My main activities as a board member in DION were the revision of the PhD handbook and of the university's web site for doctoral candidates. The auditing team led by Ragnhild Lofthus, started the revision in October 2014. The revised version of the PhD handbook was published in 2015. I also participated in the discussion for improving the university's web site for doctoral candidates in November 2014.

13. Complete list of papers and other dissemination activities

2015/11 Scientific article: Spatial Quality Assessment of Dwelling Renovation, The Impact of the Dwelling Renovation on Spatial Quality, Case of the Neighbourhood of Arlequin in Grenoble, France. Smart and Sustainable Built Environment Journal, SASBE (ISSN: 2046-6099). Co-author: Professor Annemie Wyckmans. DOI: 10.1108/SASBE-05-2015-0008

2015/04 Scientific article: Dwelling Renovation and Spatial Quality, The Impact of the Dwelling Renovation on Spatial Quality Determinants. International Journal of Sustainable Built Environment, IJSBE (ISSN: 2212-6090). Co-author: Professor Annemie Wyckmans. DOI: 10.1016/j.ijsbe.2015.02.001

2015/05 and 2014/10 Deliverables RAMSES Project, grant number: 308497: WP 2: Taxonomy of architecture and infrastructure indicators. Deliverable 2.4 Adaptation measures and corresponding indicators for resilient architecture and infrastructure. Authors: Kallaos, James, et al. Deliverable 2.1 Synthesis review on resilient architecture and infrastructure indicators. Authors: Kallaos, James, et al.

2014/12 Deliverable ZenN Project, grant number: 314363: Task 4.1 Taxonomy of near-zero energy renovation options and their influence on architectural and cultural heritage. Authors: Carmel Lindkvist, Fernanda Acre, Kari Sørnes and Annemie Wyckmans.

2014/10 Peer reviewed conference and presentation: Spatial Quality in Building Performance Assessment Tools, The case of Dwelling Renovation for Energy Efficiency. Conference proceedings, WSB14 Conference, World Sustainable Building 2014, Barcelona, Spain (ISBN: 978-84-697-1815-5). Co-author: Professor Annemie Wyckmans. Funding source: UNIFOR, Norges tekniske høgskoles fond.

2014/06 Scientific article: Spatial Quality Determinants for Residential Building Renovation: A Methodological Approach to the Development of Spatial Quality Assessment. International Journal of Sustainable Building Technology and Urban Development, SUSB (ISSN 2093-761X). Co-author: Professor Annemie Wyckmans. DOI: 10.1080/2093761X.2014.923793

2014/04-11 Newsletters 2 and 3 European Project ZenN, Nearly Zero Energy Neighbourhoods: Newsletter 2: Improving People's Well-being – The Key to Renovation Acceptance. Co-author: Annemie Wyckmans. Newsletter 3: Examining the influence of renovation options on architectural values and cultural heritage. Authors: Carmel Lindkvist, Fernanda Acre and Annemie Wyckmans.

2013/10–2014/04 Diverse presentations in meetings of the European project ZenN: 2014/10 Architectural values, cultural heritage and spatial quality analysis of the ZenN case of Grenoble, France. 2014/04 How does energy renovation of residential buildings affect spatial quality? Framework for Spatial Quality

Evaluation of the ZenN Demonstrators. 2013/10 Framework for Spatial Quality Evaluation of the ZenN Demonstrators. 2013/10 Work Package 4 Social and Financial Sustainability.

2013/12 Journal article: Helsefremmende boligmiljø i et ressursperspektiv. Journal Helserådet (ISSN 0806-7457). Authors: Annemie Wyckmans, Karin Tømmerås, Geir Arild Espnes, Gøril Thomassen, Stig Larssæther, Solvår Irene Wågø, Barbara Szybinska Matusiak, Fernanda Acre, Karin Høyland and Bendik Manum.

2013/11 Peer reviewed conference and presentation: Spatial Quality Assessments for Building Performance Tools in Energy Renovation. Conference proceedings, SB13 Conference, Contribution of Sustainable Building to Meet EU20-20-20 Targets, Guimaraes, Portugal (ISBN 9789899654372). Co-author: Professor Annemie Wyckmans. Funding source: UNIFOR.

2013/10 Deliverable IDES-EDU Project, grant number: IEE/09/631/SI2.558225: Deliverable D6.1 Monitoring of results, report on internal and external monitoring of results. WP6 IDES-EDU Project, Master and Post Graduate education and training in multidisciplinary teams implementing EPBD and beyond. Authors: Annemie Wyckmans, Kristian Stenerud Skeie, Matthias Haase, Fernanda Acre, Marie-Claude Dubois and Per Veld.

2013/06 Peer reviewed conference and presentation: Spatial Quality Indicators for Energy Renovation of Residential Buildings. Conference proceedings, CESB13 Conference, Central Europe towards Sustainable Buildings 2013, Sustainable Building and Refurbishment for next Generations, Prague, Czech Republic (ISBN

9788024750156). Co-author: Professor Annemie Wyckmans. Funding source: European COST-TUD Conference Grant for Early Stage Researchers.

2012/06 Peer reviewed conference, presentation and poster: Density and Spatial Quality, High density and spatial quality. Conference proceedings, the 4th CIB Smart and Sustainable Built Environments, SASBE2012 Emerging Economies Sao Paulo–SP, Brazil (ISBN 978-85-65823-05-0).

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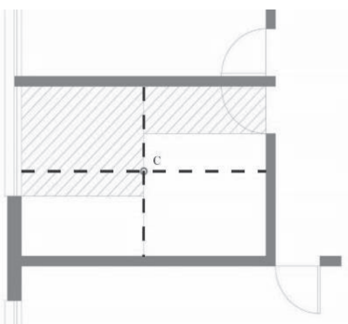
Appendices

Appendix A: CAD based mapping model, and mathematical model (Indraprastha & Shinozaki 2012)

The CAD based mapping model, and the mathematical model in Indraprastha and Shinozaki (2012), are summarized below. They are references for the visual openness and visual privacy definitions considered in the PhD research.

- **CAD based mapping model for the analysis of visual openness and visual privacy**

The first step in the CAD based mapping model is placing a Cartesian grid on the geometrical centre point of the room (Figure a). Subsequently the edges of the doors and windows (openings) are projected perpendicular to the vertical (y) and horizontal (x) axial lines of the grid, to define the zones of influence of the openings in the room. The space of the room is subdivided in enclosed spaces. The geometrical centre of each enclosed space is defined and numbered. The next step is to calculate visual openness and visual privacy indexes.



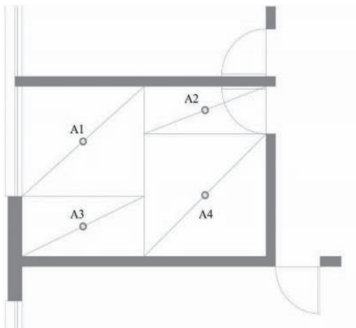


Figure a. Enclosed spaces and their respective geometrical centre A1, A2, A3 and A4. Figures: Fernanda Acre.

The placement and number of windows and doors, and centricity of the room, have an important influence on visual openness and visual privacy (Indraprastha & Shinozaki 2012). This method distributes the effect of the windows and doors to each of the enclosed spaces (enclosed spaces A1 to A4 in Figure a). The dynamics in the interaction between the boundaries of a room (walls) and its openings (windows and doors) define the perceptual centres of the room (Weber 1995).

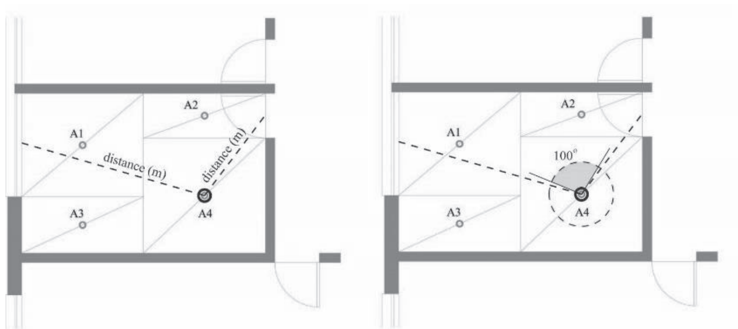


Figure b. Distance (m) from the point A4 to the midpoint of the openings and maximum viewing angle of 100º at the A4. Figures: Fernanda Acre.

Visual openness consists of three variables:

- Visual distance. The distance between the geometrical centre point p of an enclosed space to the midpoint of the openings (doors and windows).
- Transparency ratio. The ratio between the area of the openings and the area of the wall where the opening is placed.
- Viewing area. The ratio of viewing area from the geometrical centre p of an enclosed space considering a maximum viewing area of 100º.

Visual openness index: The greater the average distance from a geometrical centre p to the windows, the lower the visual openness index. The more windows covered by the viewing angle at p, the greater the visual openness index.

Visual privacy is calculated with two distinct methods:

- By using distance. The distance from a point p to a window determines the level of privacy.
- By viewing area. The number of windows and doors that are covered by the view angle determines the level of privacy. The more openings covered, the lower the privacy.

Visual privacy index: The greater the average distance from a geometrical centre p to the windows and doors, the higher the visual privacy index. The more windows covered by the viewing angle at p, the lower the privacy. The visual privacy index assesses the degree of exposure of a point p being seen from external spaces.

The results can be used to explore design alternatives to building renovation. Average visual openness and visual privacy indexes are calculated for each room, which gives an overview of possible deficiencies in terms of privacy and visual openness. For example, the plan can be changed, and doors and windows can be relocated to increase privacy or visual openness according to desired outcomes.

According to Indraprastha and Shinozaki (2012), their model has limitations. The model does not consider ceiling heights, and visual openness and visual privacy are assessed from interior spaces only. The impact of physical transitions from private to public spaces and the configuration of the block are not taken in account in the assessment. However, the efficiency of their method is in defining geometrical centres to enclosed spaces considering the openings of the room.

This method results in reliable outcomes and shorter time dedicated to the analysis in comparison to the use of a raster method (Indraprastha & Shinozaki 2012). The raster method consists of placing a virtual mesh of several points in the room. The shorter the distance between the points in the mesh is, the more accurate the result of the analysis.

- **Mathematical model for the analysis of visual openness and visual privacy**

VO: Visual openness

1. Calculate the average distance (D) between point *p* and the windows:

$$\bar{D}_p^{vo} = \frac{\sum_{i=1}^{n} dW_{ip}^{vo}}{n} \quad (1)$$

2. Calculate the visual openness strength of influence at point *p* using the distance method:

$$\bar{VO}_p = Exp \frac{-\bar{D}_p^{vo2}}{\bar{D}_p^{vo}} \quad (2)$$

3. Calculate the visual openness level using the distance method considering the transparency index of the window:

$$VO\bar{D}p = VO\bar{D}p(tr) \quad (3)$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{vo} = \frac{\theta_p}{100\circ} \quad (4)$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$VO_{\omega_p} = Exp \frac{\omega_p^{vo2}}{\omega_p^{vo}} \quad (5)$$

6. Normalize the VO level (3) and strength of influence values (5).

7. Combine the VO level (3) and strength of influence values (5) to obtain the arithmetic average:

$$VO_p = \frac{1}{2}(VO_{\bar{D}p} + VO_{\omega_p}) \quad (6)$$

PR: Visual privacy

1. Calculate the average distance (D) between point *p* and the windows and doors:

$$\bar{D}_p^{pr} = \frac{\sum_{i=1}^{k} dD_{ip}^{pr}}{k} \oplus \frac{\sum_{i=1}^{n} dW_{ip}^{pr}}{n} \quad (7)$$

2. Calculate the visual privacy strength of influence at point *p* using the distance method:

$$PR_p = Exp \frac{\bar{D}_p^{pr2}}{\bar{D}_p^{pr}} \quad (8)$$

3. Calculate the visual privacy level using the distance method, considering the transparency index of the window:

$$PR_{\bar{D}p} = PR_{\bar{D}p}(\bar{tr}) \quad (9)$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{pr} = \frac{\theta_p}{100^\circ} \quad (4)$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$PR_{\omega_p} = Exp \frac{-\omega_p^{pr2}}{\omega_p^{pr}} \tag{10}$$

6. Normalize the PR level (3) and strength of influence values (5).
7. Combine the PR level (3) and strength of influence values (5) to obtain the arithmetic average:

$$PR_p = \frac{1}{2}(PR_{Dp} + PR_{\omega_p}) \tag{11}$$

Where:

dWp = distance from the geometrical centre point p to the midpoint of the window;

dDp = distance from the geometrical centre point p to the midpoint of the door;

aWi = area of window i; aWLi = area of the wall where window i is placed;

aDi = area of door i; aWDi = area of the wall where door i is placed;

n = number of windows; k = number of doors;

trwi = (aWi/ aWLi) = transparency index of window i;

trdi = (aDi/ aWDi) = transparency index of door i;

θvo = visual angle at the geometrical centre point p having all windows covered;

ωvo = visual openness ratio of the covered angle;

θpr = visual angle at the geometrical centre point p having all windows and doors covered;

ωpr = privacy ratio of the covered angle;

Appendix B: Technical measures of building renovation in Barker (2009) and Burton (2012)

Tables 5 to 9. Technical measures of building renovation according to Barker (2009) and Burton (2012), for the building components of floors, walls, roofs, windows, and mechanical services. These measures were considered for the analysis of the impact of the renovation on spatial quality.

Table 5. Technical measures for the building component of floors.

Renovation of dwellings/ building component of floors		
Technical measures		**Technical characteristics**
Solid concrete ground floors[a]	Insulation applied above existing concrete floors	Insulation on the top of the slab, timber battens at thresholds with metal nosing, vapour-control layer on the insulation, chipboard flooring and floor
	Insulation applied above new concrete floors	Damp-proof membrane, rigid insulation on the top of the slab, chipboard flooring and floor
	Insulation applied below new concrete floors	Sand bedding, damp-proof membrane, rigid insulation, concrete floor slab, floor and floor
Suspended timber ground floors[a]	Insulation applied to the upside of the floor boards	Flooring joints sealed, floor, insulation, netting to support insulation, timber joists
	Insulation applied to the underside of the floor boards	Floor, insulation, timber joists, plasterboard in the basement
	Insulation applied between the joists	Floor, insulation between timber joists, plasterboard in the basement
Intermediate floors[b]	Insulation is not relevant	Insulation is not relevant considering heat losses. However, acoustic insulation might be needed

[a] Burton 2012
[b] Barker 2009

Table 6. Technical measures for the building component of external walls.

Renovation of dwellings/ building component of external walls		
Technical measures[a]		Technical characteristics
External solid walls with external insulation	Wet render system	Consists of insulant, fixings, base coat render with glass fibre plastic or metal mesh, and a top-coat render with or without a finish
	Dry cladding system	Consists of supporting framework or cladding fixing system fixed to the wall, ventilated cavity, breather membrane and cladding material. Useful where existing appearances need to be maintained
External solid walls with internal insulation	Laminated insulation board fixed directly to the wall	Plasterboard laminated to insulation board, rigid closed cell insulation fixes with special fastening and adhesive
	Rigid insulation between battens fixed to the wall	Plasterboard, vapour check, rigid or semi-rigid insulation boards between the battens
	Frame with insulation leaving an 30mm air gap between insulation and the wall	Plasterboard, vapour control layer, insulation and 30mm min. air gap
	Cavity fill for existing brick and block cavity walls	Insulation injected into the wall cavity
Addition, extension or removal of balconies Risk of cold bridging	Cantilevered balconies can result in cold bridges. Using insulated windows frames, applying some insulation to reveals, returning insulation along party walls, and insulating any mechanical fixings will overcome this problem	Where good insulation levels are applied in a house, uninsulated areas such as window frames and reveals and party walls can become cold bridges and attract condensation when internal humidity is high, which can lead to damp and mould growth

Table 7. Technical measures for the building component of roofs.

Renovation of dwellings/ building component of roofs		
Technical measures		**Technical characteristics**
Roof insulation at ceiling level[a]		Plasterboard ceiling, insulation between joists, insulation above joists, cables lifted above insulation
Roof insulation at rafter level[a]		Plasterboard ceiling, vapour barrier, insulation between rafters, rigid insulation, 50mm air gap
Insulation of flat roofs[a]	External roof insulation: Insulation above the roof structure (warm roof system)	Known as warm roof system, in order to avoid interstitial condensation. It consists of vapour check, rigid insulation, waterproof layer with reflective paint
	External roof insulation: Insulation above the roof structure (inverted warm roof system)	Known as inverted warm roof system, in order to avoid interstitial condensation. It consists of water proof layer, rigid insulation, vapour check and structural roofing (gravel or concrete tiles)
	Internal roof insulation: Insulation below the roof structure (cold roof system)	Known as cold roof system, where it is not possible to construct a warm roof system. It consists of insulation applied under the roof structure, vapour barrier and ceiling. External water-proof membrane applied on the roof structure
Insulation of flat roofs[b]	Green roofs	Green roofs add thermal mass and evaporative cooling but considering that they are not a good thermal insulation, they should only be used as an option for the replacement of the original vegetation replaced by the refurbishment

Table 8. Technical measures for the building component of windows.

Renovation of dwellings/ building component of windows		
Technical measures		**Technical characteristics**
Reduction or increase of framing[a]		Reduction or increase of framing to improve light and view conditions
Installation of a secondary glazed screen (second skin)[b]		It consists of high performance glazing screen and thermally insulated framing inside or outside (weathering layer). It affects the appearance either from inside or outside or in both sides
Replacement of the glazing and the framing system[b]		Existing elements replaced by high performance glazing and thermally insulated framing
Reduction or increase of existing aperture/glazed area[a]		Changes of the aperture area to improve daylight conditions, as for example reduction of heat loss and unwanted solar gain, provision of more wall space for furnishings and equipment[2]. Changes of aperture area is applied as a last option. Before other causes for poor daylight performance should be eliminated first, e.g. low transmission of glass, obstruction due to framing or poorly designed fixed shading devices, low reflectance of interior surfaces or internal obstructions
Changing the distribution of glazing by making new apertures to improve daylight distribution[b]		
Implementation of shading[b]	Implementation of external shading	It can be fixed, adjustable or retractable, e.g. overhangs, louvres, vertical fins, blinds and perforated screens (superior thermal performance)
	Implementation of internal shading	It consists mostly of louvres (venetian blinds) and roller blinds (translucent or opaque)
	Implementation of integrated shading	It addresses daylight distribution function as well as selective shading

Table 9. Technical measures for the building component of mechanical services.

Renovation of dwellings/ Mechanical services and controls		
Technical measures[a]		**Technical characteristics**
Improving the airtightness of the structure in order to reduce air leakage		Repair mortar joints, fill holes in the external walls, apply sealant materials to fill gaps around windows and doors and frames. Block off existing unused chimneys
Provision of adequate/ controllable ventilation	Passive ventilation	Fitting the ductwork into an existing house may be difficult, depending upon space and the level of renovation being carried out
Increasing solar gain	Sun entering a dwelling through east, south and west windows, as well as roof lights, assisted by thermal storage in floors and other thermal mass	As with daylighting, adding south-facing windows in an east-west-facing house can provide useful solar gain, and this can be optimized by a heat recovery ventilation system which will distribute the heat around the house
Heating	Gas and oil boilers, heat pumps, biomass systems and micro CHP systems	Gas and oil boilers. If a combination boiler is used, this will be sized for hot water production and thus quite possibly oversized for space heating needs in a well-insulated house. Smaller and/or fewer radiators than in the pre-renovation dwelling, or under-floor heating can be used
		Heat pumps. Air-sourced heat pumps can provide low-carbon space and water heating in low-energy housing, particularly where solar water heating is fitted
		Biomass systems. Biomass heating can provide a low-carbon heat supply either as a stand-alone room heater or as a central heating boiler. Room-heating stoves may be appropriate as the only space-heating system for small dwellings with low heat demand, and they are available with back boilers to provide hot water.
Domestic hot water (DHW)	Efficient provision of DHW	Solar systems supplying around 50% of annual demand

	Solar water systems	Solar collector panels can be retrofitted to any dwelling with south or even east and west facing roofs. Space for hot water storage is necessary, sized according to the collector size and number of dwelling occupants. In some countries, stand-alone systems incorporating collectors and storage are used, mounted on rooftops.
	Gas and boilers	Where gas is available, a modern room-sealed as condensing boiler will provide efficient domestic hot water
	Heat pumps	
	Storage cylinders	In conventional systems, the hot water storage cylinder should ideally be located close to both the boiler and the bathroom and kitchen to reduce heat loss from pipes
Avoiding overheating that could require active cooling	External heat gains	Solar gain entering the house through windows can be reduced by providing external shading over south and west facing windows, planned to cut out sun during the summer. Horizontal shading is effective on south windows and vertical shading is effective on west windows. Moveable external shading is more complex but more effective in providing solar gain and additional daylighting when required
	Planting and vegetation	Trees can provide shadow to the lower floors of a dwelling, and replacing hard surfaces by planting around the dwelling can lower external temperatures, thus reducing the temperature of the air entering the house
Avoiding overheating that could require active cooling	Ventilation for cooling	The designer should provide opening windows with variable openings at high and low levels, as well as windows that enable cross-ventilation. Large openings which stimulate large air movements can also provide effective cooling
Lighting installations	Maximize the use of daylight by architectural means in order to minimize artificial lighting energy[b]	Increasing daylight in rooms and corridors will reduce the use of artificial lighting, but it has to be balanced against greater heat loss and unwanted solar gain. High-level windows possibly facing south if solar gain is required, can give good daylighting, as can roof lights and light tubes. Opening up windows between rooms and into corridors or halls, and using glazed doors, can provide useful light.

Appendix C: Crossing between building renovation and spatial quality

Tables 10 to 17. Crossing between building renovation described by Barker (2009) and Burton (2012), and the spatial quality determinants (SpQD), to find the impact of the renovation on spatial quality.

Table 10. The impact of the renovation of floors on the spatial quality determinants.

Building component of floors/ Spatial quality				
Technical measures	**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Addition of insulation on solid concrete ground floors[a]	Changes on the thickness of the floors and ceiling heights may lead to changes on: D. Lighting	B. Internal division of space and spatial density (B.3) E. Lighting	No impact is found	No impact is found
Addition of insulation on suspended timber ground floors[a]				
Addition of insulation on intermediate floors[b]				

Table 11. The impact of the renovation of external walls on the spatial quality determinants.

Building component of external walls/ Spatial quality				
Technical measures[a]	**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Addition of external insulation **Addition of internal insulation**	Changes on the thickness of the external walls may lead to changes on: B. Depth of vision (B.1b, B.1c, B.2b) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.1)	No impact is found	No impact is found
Addition, extension or removal of balconies	A. Facade transparency B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.2, C.3) D. Lighting	A. Centricity and concavity (A.1a) C. Spatial hierarchies and system complexity (C.2, C.3) E. Lighting (E.1b, E1c, E.2b, E.2c, E.3b, E.3c)	B. Clear boundaries between the private and public domains C. Outdoor private spaces D. Uniformity and coherence of boundaries E. The impact of changes in the plan on facade composition	A. Principle of complexity (A.1c) C. Built density (C.1, C.3)

Table 12. The impact of the renovation of internal walls on the spatial quality determinants.

Building component of internal walls/ Spatial quality				
Technical measures	**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Internal changes in the plan[a,b]	The measure can lead to changes on: B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity B. Internal division of space and spatial density (B.1, B.2c) C. Spatial complexity D. Sense of privacy E. Lighting	E. The impact of changes in the plan on facade composition	No impact is found

Table 13. The impact of the renovation of roofs on the spatial quality determinants.

Building component of roofs/ Spatial quality				
Technical measures	**SqQD1**	**SqQD2**	**SqQD3**	**SqQD4**
External roof insulation: insulation above the roof structure (inverted warm roof system)[a]	No impact is found	No impact is found	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1, C.3)
Internal roof insulation: insulation below the roof structure (cold roof system)[a]		Measures can lead to changes on: B. Internal division of space and spatial density (B.3)	No impact is found	No impact is found
Green roofs[b]		C. Spatial hierarchies and system complexity	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1)

Table 14. The impact of the renovation of windows on the spatial quality determinants.

Building component of windows/ Spatial quality					
Technical measures		**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Reduction or increase of framing to improve light and view conditions[a]		Measures can lead to changes on: A. Facade transparency (A.2) B. Depth of vision (B.1b, B.1c) D. Lighting	E. Lighting (E.1b, E.1c, E.2b)	D. Uniformity and coherence of boundaries	A. Spatial complex. (A.1c)
Replacement of the glazing and the framing system[b]					
Reduction or increase of existing glazed area[a]		A. Facade transparency (A.1, A.3) B. Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity (A.2) E. Lighting (E.1b, E.1c, E.2b, E.2c, E.3b, E.3c)		
Changing the distribution of glazing by making new apertures to improve daylight distribution[b]					
Installation of a secondary glazed screen[b]		A. Facade transparency (A.1, A.3) B. Depth of vision (B.1, B.2) C. Distance and degree of sight protection D. Lighting	A. Centricity and concavity (A.1a, A.2,A.3a, A.3c) C. Spatial hierarchies and system complexity (C.2, C.3) E. Lighting (E.1b,E.1c, E.2b, E.3b, E.3c)	B. Clear boundaries between private and public C. Outdoor private spaces D. Uniformity and coherence of boundaries	
Use of shading (This can result in extra outdoor spaces such as balconies)[b]	External shading				
	Internal shading				
	Integrated shading				

Table 15. The impact of changes on mechanical services on the spatial quality determinants.

Building renovation and mechanical services/ Spatial quality					
Technical measures		**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Heating[a]	Efficient space heating	No impact is found	Measures can lead to changes on: C. Spatial hierarchies and system complexity	No impact is found	No impact is found
	Gas and oil boilers, heat pumps, biomass systems and micro CHP systems				
Domestic hot water (DHW)[a]	Efficient provision of DHW				
	Solar water systems				
	Gas and boilers, heat pumps and storage cylinders				
Increasing solar gain[a]	New openings: sun entering a dwelling through east, south and west windows, as well as roof lights, assisted by thermal storage in floors and other thermal mass	A. Facade transparency B. Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	E. Lighting (E.1b, E.1c, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Spatial complex. (A.1c)
Lighting installations[b]	New openings: maximize the use of daylight by architectural means in order to minimize artificial lighting energy				
Avoiding overheating[a]	Natural ventilation for cooling through opening windows				
	The use of shading to avoid external heat gains				
	The use of planting and vegetation to avoid external heat gains	B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.2b, E.3b, E.3c)	B. Clear boundaries within private and public C. Outdoor private spaces	No impact is found

Table 16. The impact of changes on built area on the spatial quality determinants.

Building renovation and built area/ Spatial quality				
Measures[c]	**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Addition of new buildings and demolition of existing ones	Changes on built area can lead to changes on: B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.2.) D. Lighting (D.1, D.3) E. Enclosure and peripheral density (E.2, E.3)	E. Lighting (E.3b, E.3c)	B. Clear boundaries between the private and public domains C. Outdoor private spaces (C.1, C.3)	A. Spatial complexity B. Enclosure and peripheral density C. Built density D. Human density E. Functions

Table 17. The impact of renewable energy options on the spatial quality determinants.

Building renovation and renewable energy options/ Spatial quality				
Technical measures[b]	**SpQD1**	**SpQD2**	**SpQD3**	**SpQD4**
Photovoltaic Re-cladding panels and roof tiles	Measures can lead to changes on: A. Facade transparency (A.1) B. Depth of vision (B.1b, B.1c, B.3a) C. Distance and degree of sight protection (C.1a, C.1b, C.2) D. Lighting	E. Lighting (E.1, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Spatial complexity (A.1c)
Photovoltaic Opaque PV used as shading devices (This can result in extra out-door spaces such as balconies)				

[c] Giebeler et. al 2009

Appendix D: Dissemination

Spatial Quality Assessment of Dwelling Renovation, The Impact of the Dwelling Renovation on Spatial Quality, Case of the Neighbourhood of Arlequin in Grenoble, France

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Dwelling renovation and spatial quality
The impact of the dwelling renovation on spatial quality determinants

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Abstract

Renovation of dwellings for energy efficiency has further implications other than only technical and economic dimensions, such as performance and cost reduction. This paper demonstrates how the renovation of dwellings for energy efficiency impacts spatial quality by crossing technical measures of dwelling renovation with the definition of spatial quality proposed in Acre and Wyckmans (2014). The results of this crossing are developed further into a spatial quality assessment. Spatial quality consists of the interaction between four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built and human densities (Acre and Wyckmans, 2014). There are two main challenges in this work: first to demonstrate that energy renovation of dwellings affects spatial quality and second, to create a clear and generic way to indicate and assess this effect that also allows comparability between before and after renovation. The current state of the art in building renovation emphasizes technical performance and efficiency, costs and user responses to technology. However, there is a facet that is hardly explored in the current literature, which is how building renovation affects spatial quality.

This paper contributes both to the theory and practice in building renovation. First it emphasizes the relevance of non-technical dimensions such as spatial quality and of the need for a cross-disciplinary approach in energy renovation of dwellings. Second, the paper indicates that energy renovation indeed affects spatial quality in dwellings. The main contribution to practice that this article aims to bring forward consists of the spatial quality assessment for dwelling renovation. The technical measures of energy renovation for the building components of floors, internal and external walls, roofs, windows, mechanical services and controls, built area and the use of renewable energy options are considered in this study in relation to their impact on spatial quality. The aim is to identify and strengthen the connection between energy renovation and people's well-being through spatial quality. The inattention to the potential of non-technical dimensions such as spatial quality, by stakeholders involved in the energy renovation of dwellings, constitutes a lost opportunity to increase occupants' receptiveness to energy renovation. This receptiveness can be extended by strengthening the connection between renovation of dwellings for energy efficiency and benefits to occupants' well-being. This work follows the current European tendency of fostering energy deep renovation to reach Europe's 2050 aspirations (BPIE, 2011). Deep renovation is an ambitious building renovation strategy that encourages high energy savings measures and the whole building approach (BPIE, 2013). The paper is intended to benefit design professionals, and building owners such as individuals, corporate entities, public sector or real estate portfolio holders,

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because it points out underlying relations between energy renovation and spatial quality that are often not clearly considered in the renovation of dwellings.

Keywords: Spatial quality assessment; Dwelling renovation; Energy efficiency; Whole building approach; Existing residential buildings

1. Introduction

The paper explores the interaction between two components of sustainable development: dwelling renovation for energy efficiency and spatial quality. A spatial quality assessment is developed to assess the impact of energy renovation on spatial quality in dwellings. The goal is to contribute to connecting the benefits of energy renovation with improvements in people's well-being by improving spatial quality. This work is an answer to European incentives to deep renovation. Deep renovation consist of a strategy that aims to reduce energy demand and fossil fuel import dependency by high levels of energy efficiency achieved in the renovation of building stocks (Bettgenhäuser et al., 2014). Most of the actual renovations achieve around 20–30% of energy savings while deep renovations aim to make savings of at least 60% (BPIE, 2013). This strategy has a holistic approach in which the measures are interdependent and may affect the whole building and its context instead of only punctual interventions. Deep renovation is among the actions to reach Europe's 2050 aspirations (BPIE, 2011).

The article is organised in three main parts. First, the article starts by briefly introducing the spatial quality definition (Acre and Wyckmans, 2014) and presenting the assessment for the analysis of the impact of energy renovation in spatial quality. Second, current technical measures of building renovation for the diverse building components (Baker, 2009; Burton, 2012) are presented and their impact on spatial quality is analysed per building component. The questions to be answered here are whether spatial quality is affected by energy renovation and whether spatial quality concerns influence energy renovation in dwellings. Third, the results of the impacts' analysis are summarised and the framework for the spatial quality analysis is consolidated.

This paper indicates that dwellings renovation (technical dimension) considerably affects spatial quality (non-technical dimension). Therefore this work explores the potential of spatial quality to bridge technical and non-technical dimensions. The paper proposes that spatial quality can be an argument to increase stakeholders' openness towards energy renovation of dwellings because it has the potential to increase people's well-being.

Spatial quality is a complex concept to define due to the widespread definition of the both 'space' and 'quality'. However, Acre and Wyckmans (2014) found similarities among several authors in the definition of spatial quality for dwellings. A range of common determining factors for spatial quality was identified in the research literature: view, privacy, lighting, spatiality, spatial arrangements, the transition between public and private spaces, and perceived, built, and human densities.

There is a general awareness of the relevance of non-technical drivers such as organizational, social and behavioural issues, and of the need for a cross-disciplinary approach (Burton, 2012, Schweber & Leiringer, 2012, Patterson, 2012; ZenN, 2012, and Tweed, 2013). Schweber and Leiringer (2012) point out an increase in the number of publications on the topic of non-technical dimensions from 2003 to 2010. However the tendency is to concentrate research on occupant's behaviour, satisfaction, thermal comfort, and the users' potential to influence energy consumption and CO_2 emissions (Tweed, 2013). Schweber and Leiringer (2012) use the example of the social dimension of design that is primarily considered relating to thermal comfort, to argue that the limitation of the scope might be a consequence of the complexity of adopting a cross-disciplinary approach. The weak point of a primarily technical approach in dwellings renovation is that it emphasises energy efficiency, however many relevant issues remain untouched because they are not directly relevant to energy efficiency improvements (Tweed, 2013). The current challenge to reduce energy consumption and CO_2 emissions is an argument for promoting cooperation among technical and non-technical disciplines and diverse stakeholders.

The result of this work underlines the need for a joint effort among diverse stakeholders involved in dwelling renovation and it proposes a possibility of including non-technical dimensions in dwelling renovation. The spatial quality assessment presented can be particularly relevant to building performance assessment tools. This is because the assessment addresses issues that are not commonly considered in the tools such as spatiality and transition between public and private spaces. However, these issues influence the user's well-being and therefore the acceptance and success of the built environment.

2. Methodology and materials

2.1. Research strategy

The research strategy presents characteristics of two research types, namely the deductive research approach (Delanty and Strydom, 2003), and the correlational research (Groat and Wang, 2013). The deductive approach is characterized by an initial theoretical study, the development of hypotheses from the theory, and the collection and analysis of data to test the hypotheses (Delanty and Strydom, 2003). The hypothesis that energy renovation of dwellings indeed affects spatial quality is developed from prior research and theories on the topics of spatial quality and energy renovation (Acre and Wyckmans, 2014). The hypothesis is tested by analysing data on energy renovation of dwellings and by crossing this data with the spatial quality definition proposed in Acre and Wyckmans (2014). The spatial quality definition is summarized in the spatial quality assessment presented in this paper.

Correlational research is characterized by the attempt to identify 'patterns of relationships' (Groat and Wang, 2013, p. 206) between two or diverse variables. However, the present study does not fit precisely in the correlational research definition by Groat and Wang (2013) because it does not focus on naturally occurring patterns, and it does not use statistics to clarify the patterns of relationships. The focus of the spatial quality assessment proposed is the relationships between spatial quality and energy renovation of dwellings, and the measurement of these relationships. The study presents the relationships between the physical features of space and technical measures in actual energy renovation. These physical features are context dependent and are also likely to affect user acceptation of energy renovation of dwellings (Tweed, 2013).

2.2. Research strategy applied to the study

This study presents an overall assessment to include spatial quality in the scope of energy renovation. There is no obvious relationship between the two elements of the study. However, the study demonstrates that energy renovation indeed affects spatial quality in dwellings. The spatial quality assessment started with the definition of a framework on spatial quality through literature review, considering residential use and the building and block scales (Acre and Wyckmans, 2014). Typical technical measures of renovation of dwellings for energy efficiency in Europe are presented and analysed in this paper. The range of measures considered for this study is a result of both the literature review on energy renovation of dwellings and the analysis of cases of energy renovation of dwellings in Europe. The authors considered for the selection and analysis of technical measures of energy renovation are Baker and Steemers (2002), Giebeler et al. (2009), Burton (2012), Patterson (2012) and Tweed (2013). The technical measures of energy renovation imply changes in the building components of floors, walls, roofs, windows and mechanical services.

The analysis of dwelling renovation cases of the last 10 years indicates that technical measures, primarily intended for the energy renovation of non-domestic buildings, have become commonly used in the renovation of domestic buildings. The use of photovoltaics and the implementation of shading are examples of such measures. Therefore technical measures of energy renovation for non-domestic buildings described by Burton (2012) are included in this study. The cases of energy renovation of dwellings illustrated in the paper are located in Spain, France, Switzerland, Germany and Norway. The examples of existing and new dwellings from the Netherlands and Denmark are used only to illustrate topics related to the spatial quality definition. They do not consist of cases of dwelling renovation.

2.3. Spatial quality assessment and weighting

The impact of energy renovation on spatial quality is illustrated in graphs per building component and it is summarized in the results section of the paper. The departure point of the spatial quality assessment is to make possible the comparison of the impacts on spatial quality both between the diverse technical measures and among the spatial quality determinants. Therefore, each of the four spatial quality determinants is given the same weight of 25% in the total of 100%. The weight of 25% of each determinant is equally divided into its sub-principles and features. Excel© sheets and databases are used to express the relations between energy renovation and spatial quality and to generate the graphs. For example, the reduction or increase of existing glazed areas on facades during the renovation affects the ratio between facade and aperture (doors and windows) areas. The ratio between facade and aperture areas is a feature of facade transparency, which is a sub-determinant of the spatial quality determinant of views. Reduction or increase of existing glazed areas indeed affects facade transparency, therefore the crossing between this technical measure and the spatial quality feature gets its full corresponding score, if not the score would be zero. The values in the graphs only represent this impact (the higher the value, the higher the impact); that is, they do not represent quantities or dimensions. These crossings are performed for the entire assessment in the database, so that it becomes possible to represent graphically the relations between energy renovation and spatial quality. This work consists of the first step on the path to consolidate the spatial quality assessment.

2.4. Spatial quality definition and assessment

The result of the literature study on spatial quality reveals that spatial quality consists of the interrelation between four determinants: (1) views, (2) internal spatiality and spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built and human densities (Acre and Wyckmans, 2014). Three main topics were identified per determinant that can be further developed and combined into a spatial quality assessment. The assessment can be used to both explore design alternatives and to analyse spatial changes before and after dwelling renovation. The authors considered for the definition of spatial quality were Lynch (1960), Chermayeff and Alexander (1966), Rapoport (1971), Alexander et al. (1977/1978), Ashihara (1981), Russell and Snodgrass (1989), Weber (1995), Rapoport (1970), Nasar (1992/2000), Owens (2008), Uytenhaak (2008), Gehl (2010, 2011), and Moulaert (2011).

2.4.1. Spatial quality assessment for views

The three main topics of the spatial quality determinant of (1) view are: (I) view from the inside (private domain) to the outside (public domain) of dwellings and from outside to inside (visual privacy), (II) distances between public and private domains, and (III) view quality (Acre and Wyckmans, 2014). The development of these topics for the spatial quality assessment is indicated in Table 1.

Visibility analyses are part of the assessment in the sub-determinant Depth of Vision (Table 1, item B) and the focus is visual openness and visual privacy. Indraprastha (2012) defines three variables to calculate visual openness: visual distance, transparency ratio and viewing area. Visual distance is the distance between the geometrical centre point p of an enclosed space to the midpoint of the openings (doors and windows) (Fig. 1e). Viewing area is the ratio of viewing area from the geometrical centre point *p* of an enclosed space considering a maximum viewing area of 100° (Fig. 1f) (Pacheco and Wyckmans, 2013).

The assessment of visual privacy (the possibility of being viewed from external spaces) can be performed considering the average value of privacy by distance or the privacy by viewing area. The assessment of privacy by distance

Table 1
Spatial quality assessment for views.

Spatial quality assessment – determinant 1: view (Building and block scales)
(A) Facade transparency
1. Ratio between facade area and apertures (windows and doors) area
2. Ratio between apertures (windows and doors) area and glass surface areas
3. Glazing properties of transmittance and absorptance[a]
(B) Depth of vision
1. Visibility
(a) Percentage of the total number of spaces with view
(b) Visual openness index[b] (Figs. 1e and f)
(c) Visual privacy index[b] (Figs. 1e and f)
2. Quality of the view (composition of the view)[a,c]
(a) Distance of the view (depth) is >6 m (yes or no question)
(b) Width of the view through window(s) is > 28° (yes or no question)
(c) Presence of layers of proximity (sky, landscape and ground) (yes or no question)
3. Internal division of space (configuration of the plan that affects views from inside to outside, and from outside to inside)
(a) Window's length equally to at least half of room depth (d); $d \leq 5$m, window area (wa) = 1,25 m^2; $d > 5$ m, wa = 1,50 m^2[c] (yes or no question)
(b) Visual distance (distance between the geometrical centre point *p* of an enclosed space to the midpoint of the openings - doors and windows)[b] (Figs. 1e and f)
(c) Viewing area (ratio between the room and the viewing areas from the geometrical centre point *p* of an enclosed space with a maximum viewing area of 100°)[b] (Figs. 1e and f)
(C) Distance and degree of sight protection (visual privacy and protection of the private domain)
1. View of arriving visitors and entrance, and entry-lock (hall) to the dwelling
(a) Possibility to see arriving visitors (yes or no question)
(b) Possibility to see arriving visitors without being seen (yes or no question)
(c) Entry-lock (hall) area to the dwelling (yes or no question)
2. Availability and configuration of private outdoor spaces
(a) Availability of private outdoor spaces (yes or no question)
(b) Possibility of controlled visual contact with the neighbour's private outdoor spaces (yes or no question)
(c) Availability of private outdoor spaces on the ground floor level (yes or no question)
3. Placement of balconies
(a) Ratio between the transparent (or translucent) and the opaque parts of the handrail
(b) Balcony sticks out or is built into the facade of the building volume
(c) Balconies are on top of each other or staggered
(D) Lighting (access of daylight)[a,c]
1. Daylight access (yes or no question)
2. Daylight factor (DF)
3. Sky view factor (SVF)
(E) Enclosure and peripheral density (configuration of the block that affects views)
1. South/west orientation of the main living areas (yes or no question)
2. Ratio between the height and the width of the enclosed courtyard space
3. Difference between the height of the building and the average height of surrounding buildings (difference in height > than 2/3 of the average height of the surroundings) (yes or no question)

[a] Matusiak (2014).
[b] Indraprastha (2012).
[c] CEN (2014).

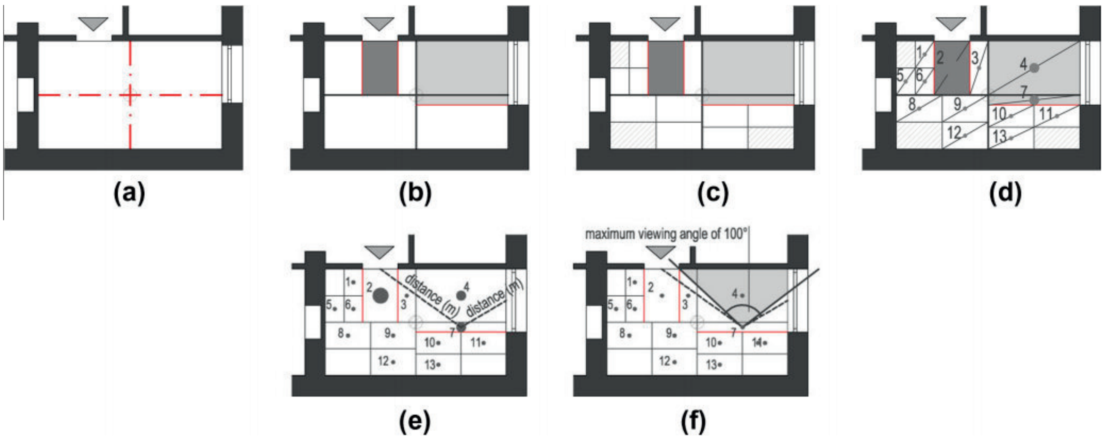


Figure 1. Placement of perceptual centres, (a–d). Distance (m) and maximum viewing angle of 100° between the geometrical centre point 7 of the enclosed space to the midpoint of the openings (e and f) (Indraprastha, 2012). Living room in residential building, Cologne, Germany. © [Detail]. Reproduced by permission of detail.

determines the level of privacy considering the distance from a point p to the opening (Fig. 1e). The assessment of privacy by viewing area considers how many windows and doors are covered by the view angle (Fig. 1f). The more openings covered, the lower the privacy. Indraprastha (2012) summarises the assessment of visual privacy in two indexes: visual privacy index and visual openness index. The visual privacy index indicates that the greater the average distance from a geometrical centre point *p* to the windows and doors, the higher the visual privacy index. The greater the angle of view at *p* covering all the windows and doors, the lower is the privacy index. The visual openness index indicates that the greater the average distance from a geometrical centre point *p* to the windows, the lower the visual openness index. The greater the number of windows covered by the angle of view at *p*, the greater is the visual openness index (Indraprastha, 2012, in Pacheco and Wyckmans, 2013).

2.4.2. Spatial quality assessment for internal spatiality and spatial arrangements

The second determinant of (2) internal spatiality and spatial arrangements considers the analysis of (I) the articulation between space and its boundaries, and between adjacent spaces, (II) the privacy within the dwelling (zoning considering different groups within the family), and (III) light (access of daylight, layout zoning, and sun orientation of openings) (Acre and Wyckmans, 2014). The development of these three topics for the spatial quality assessment is indicated in Table 2.

The placement of entrances in a room is essential for the centricity and concavity of spaces (Table 2, item A). The graphical manner of finding the perceptual centres of a room is illustrated in Figs. 1a–d (Indraprastha, 2012). The overlap areas between zones of influences within doors (if the room has more than one entrance) and within windows will have a stronger perceptual centrality than the geometric centre of the room (Fig. 2a). Fig. 3a and b consist of the plans of before (a) and after (b) the dwelling renovation; in Fig. 3b the previous four rooms were turned into two rooms connected by a large opening. The presence of overlaps between zones of influences of doors (Figs. 2a, and 3b between the two new rooms), indicates for example that there is no cross circulation in the space, which characterizes spatial efficiency. Spatial efficiency is used here to express the optimization of circulation areas, proportion of space and flexibility to accommodate different uses.

The placement of entrances determines the perception of concavity of the room. The ratio between the Cartesian distance ($x1$) from the door's middle-point, perpendicular to the geometric centre's y axis of the room, and the Cartesian distance ($x2$) from the wall to the geometric centre's y axis of the room indicates the perceived concavity of the room (Figs. 2b, 4a and b). Ratio values closer to 0 indicate high figural concavity.

The concept of passive and non-passive zones is used to calculate the percentage of the floor area that receives the direct benefit of daylight (Baker and Steemers, 1996) (Fig. 2c). The areas outside this zone (the non-passive zones) require artificial lighting. Baker and Steemers (1996) use a passive zone depth from the building envelope to twice the floor to ceiling height. The ratio between the areas in square metres of the passive and non-passive zones indicates the efficiency of the building regarding the access of daylight (Baker and Steemers, 1996).

2.4.3. Spatial quality assessment for transition between public and private spaces

The general main topics of the spatial quality determinant of (3) transition between public and private spaces

Table 2
Spatial quality assessment for internal spatiality and spatial arrangements.

Spatial quality assessment – determinant 2: internal spatiality and spatial arrangements (Building scale)
(A) Centricity and concavity
1. Geometric centre of the space (Fig. 1a)
(a) The relevance of the geometrical centre is weakened (such as consequence of the addition of large openings and enclosing elements)[a] (yes or no question)
(b) Room's shape has only one geometrical centre (figural character, regularity and symmetry) (yes or no question)
(c) Secondary centres are symmetrically arranged (enforcement of the presence of the geometric centre of the room)[b] (yes or no question)
2. Perceptual centres of the space[c] (Figs. 1a–d, 2a, 3a and b)
(a) The space has more than one entrance (yes or no question)
(b) Areas of zones of influence of door(s) overlap (yes or no question) (Fig. 2a)
(c) Areas of zones of influence of window(s) overlap (yes or no question) (Fig. 2a)
3. Placement of entrances (concavity[b]) (Figs. 2b, 4a and b)
(a) Entrance(s) located close to the axes of the room (yes or no question)
(b) Ratio between the Cartesian distance from the door's perpendicular axis to the room's axis (the axis perpendicular to the door), and the Cartesian distance from the wall to the room's axis (Fig. 2b)
(c) Entrance located on the longitudinal axis to increase privacy (yes or no question)
(B) Internal division of space and spatial density
1. Placement of columns and internal walls
(a) Columns standing free in the space (yes or no question)
(b) Spaces defined (subdivided) by columns (yes or no question, if there are free standing columns in the room)
(c) Spaces re-defined (subdivided) by internal walls (changes on the dwelling's plan) (yes or no question)
2. Placement of stairs
(a) Stair is added or replaced (yes or no question)
(b) Free standing stair (detached from space boundaries) (yes or no question, if stair is added or replaced)
(c) Ratio between stair and room areas
3. Ceilings heights
(a) Different heights in the same room (yes or no question)
(b) Spaces defined (subdivided) by different heights (yes or no question, if there are differences in heights in the room)
(c) Minimum height of 2.4 m (yes or no question)
(C) Spatial complexity (spatial hierarchies)
1. Coordinated spatial relationship (spaces with similar dominance)
(a) Areas (in square metres) of adjacent spaces are similar (area difference <30%) (yes or no question)
(b) Direct connection between two or more coordinated spaces (yes or no question)
(c) Coordinated spaces have direct connection with the main circulation (yes or no question)
2. Subordinated spatial relationship (primary and secondary spaces)
(a) Areas (in square metres) of adjacent spaces are significantly dissimilar (area difference >30%) (yes or no question)
(b) Direct connection between two or more subordinated spaces (yes or no question)
(c) Function of the secondary space complements the primary space (yes or no question)
3. Degree of space closure
(a) Ratio between the height and the width of the enclosed space (spaces of permanence)
(b) Room's width is at least the room's height (yes or no question)
(c) Ratio between the width and the length of the enclosed space (spaces of permanence)
(D) Privacy within the dwelling (zoning according to different family group members)
1. Differentiation between social and private zones (yes or no question)
2. Children's domain is directly accessible from the circulation area (yes or no question)
3. Buffer zone between the children's private domain and the parents' private domain (yes or no question)
(E) Lighting[d]
1. Access of daylight
(a) Placement of windows/balcony doors adjacent to side walls (yes or no question)
(b) Placement of windows adjacent to horizontal surfaces (yes or no question)
(c) Ratio between glazing area and indoor surface area (walls, floor and ceiling); and relation between wall thickness and window area
2. Light distribution in the space
(a) Reflectance and absorptance of indoor surface areas
(b) Luminance distribution
(c) Ratio between the daylight (passive) and the non-daylight (non-passive) zones[e] (Fig. 2c)

(*continued on next page*)

Table 2 (*continued*)

Spatial quality assessment – determinant 2: internal spatiality and spatial arrangements
3. Internal zoning of the diverse functions according to orientation (a) Internal zoning considers optimal sun orientation (yes or no question) (b) Minimum of 80% of the floor area of the room is daylit[f] (yes or no question) (c) Direct access of sunlight to living areas[f] (yes or no question)

[a] Von Meiss (2011).
[b] Weber (1995).
[c] Indraprastha (2012).
[d] Matusiak (2006, 2014)
[e] Baker and Steemers (1996/2002).
[f] SBTool (2012).

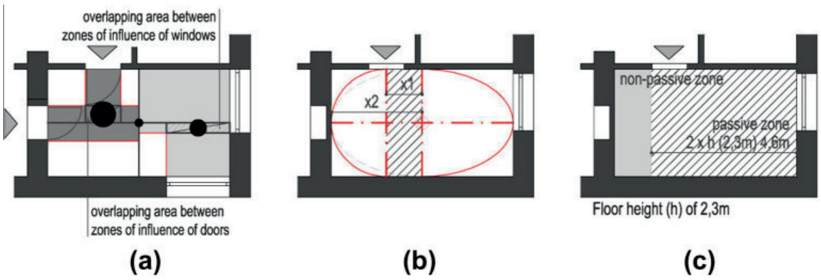


Figure 2. Overlapping zones of influence of doors and windows (a). The placement of entrances and the perception of concavity of the room (b) (Indraprastha, 2012). Passive and non-passive zones (c) (Baker and Steemers, 1996). Living room in residential building, Cologne, Germany. © [detail]. Reproduced by permission of detail.

Figure 3. Placement of perceptual centres: Plans of the first floor before (a) and after (b) the dwelling renovation. Residential building, Cologne, Germany. © [detail]. Reproduced by permission of detail.

are (I) physical barriers between public and private spaces, (II) outdoor private spaces and (III) the facade composition and permeability (changes in facade permeability and composition, such as the size of windows and dwelling entrances) (Acre and Wyckmans, 2014). The development of the main topics for the spatial quality assessment is indicated in Table 3.

Similarity, rhythm and roughness of facade composition are the topics of the sub-determinant of Uniformity and Coherence of Boundaries considered in the spatial quality assessment (Acre and Wyckmans, 2014) (Table 3, item D). In the example below (Figs. 6a and b) symmetry and coherence of the facade composition are achieved in detriment of lighting and ventilation demands. The depth of the

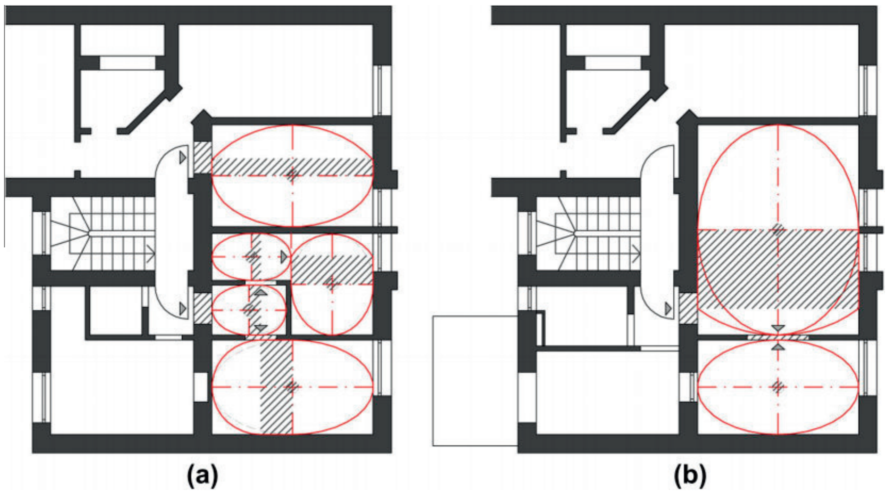


Figure 4. Concavity of the living room in a residential building. Plans of the first floor before (a) and after the dwelling renovation (b). Cologne, Germany. © [detail]. Reproduced by permission of detail.

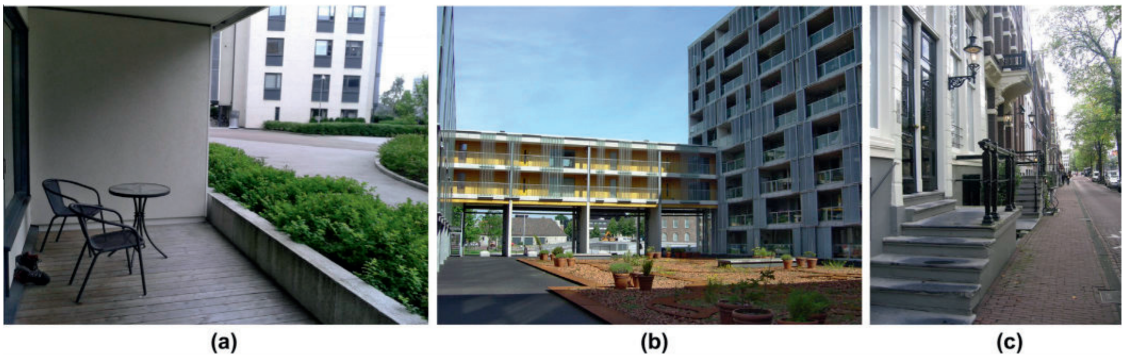


Figure 5. Clear boundaries between private and semi-public domains (a) (Oslo, Norway), between the semi-public courtyard space and the public space of the street (b) (Breda, The Netherlands), and clear boundaries between private and public domains (c) (Amsterdam, The Netherlands), pictures: Author.

living room is 5 m and the blind wall distance is 2.40 m. In the renovation an extra window is proposed on the blind wall to improve lighting and ventilation in the apartment (Figs. 6c and d).

The impact of changes in the internal division of space on the facade composition is also considered in the assessment (Table 3, item E). Figs. 7a–d illustrate a residential building before and after the energy renovation. Fig. 7b consists of the new plan after the changes in the staircase and elevators' tower. The changes in the internal division of space clearly impact the rhythm and roughness of the facade composition compared to the facade prior to renovation (Figs. 7c and d).

2.4.4. Spatial quality assessment for perceived, built and human densities

The fourth spatial quality determinant of (4) perceived, built and human densities considers (I) block physical boundaries (peripheral density and contour), (II) the height to width ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure, and (III) functions in the block, and built and human densities (Acre and Wyckmans, 2014). The development of these topics for the spatial quality assessment is indicated in Table 4.

The physical features of the block are the subject of this determinant in the spatial quality assessment. Such features are for example the compactness, porosity and slenderness of the block shape (Figs. 8a and b), and vertical accents and vertical axes of symmetry at the position of the main focus (midpoint of the facade) (Figs. 9a and b).

The relation between the proportions of the block within its boundaries and with its direct surroundings is the maximum scale that the spatial quality assessment reaches. The figure below (Fig. 10) indicates the proportion between heights of blocks and the width of the street in

Table 3
Spatial quality assessment for transition between public and private spaces.

Spatial quality assessment – determinant 3: transition between public and private spaces (Building and block scales)
(A) Private entrance to the dwelling as protected and sheltered standing space (yes or no question)
(B) Clear boundaries between the private, semi-public and public domains (Figs. 5a–c)
1. Clear boundaries within the private and semi-public domains (neighbour to neighbour, tenant to management, interaction dwelling and front yard) (yes or no question)
2. Clear boundaries between private, semi-public and public domains (relation between front yard and street) (yes or no question)
3. Use of materialisation to indicate different domains (yes or no question)
(C) Outdoor private spaces
1. Presence of outdoor private spaces (yes or no question)
2. Outdoor private spaces as effective staying areas (yes or no question)
3. Outdoor private spaces on street level (yes or no question)
(D) Uniformity and coherence of boundaries[a] (single building)
1. Similarity in facade composition
(a) Similarity of architectural elements (similarities in scale and proportion) (yes or no question)
(b) Similarity of facade decoration and materialisation (yes or no question)
(c) Symmetry and coherence of boundaries achieved in detriment of lighting and ventilation demands (yes or no question) (Figs. 6a–d)
2. Rhythm of facade composition
(a) Ordered repetition of architectural elements to achieve an overall unified effect (yes or no question)
(b) Differences of formats and sizes of architectural elements (yes or no question)
(c) Proportion considered in the figure (window) and ground (wall) articulation (yes or no question)
3. Facade roughness[b]
(a) Presence of projected bounces on the facade (such as balconies and bay windows) (yes or no question)
(b) Ratio between the total area of projected bounces and the facade area (facade roughness)
(c) Similarity of materialisation of projected bounces and the facade (yes or no question)
(E) Internal division of space and spatial density and the facade composition (uniformity and coherence of boundaries) before and after intervention
1. Internal division of space impacts similarity of the facade composition (yes or no question)
2. Internal division of space impacts the rhythm of the facade composition (yes or no question)
3. Internal division of space impacts the roughness of the facade composition (yes or no question)

[a] Weber (1995).
[b] Serra (1997).

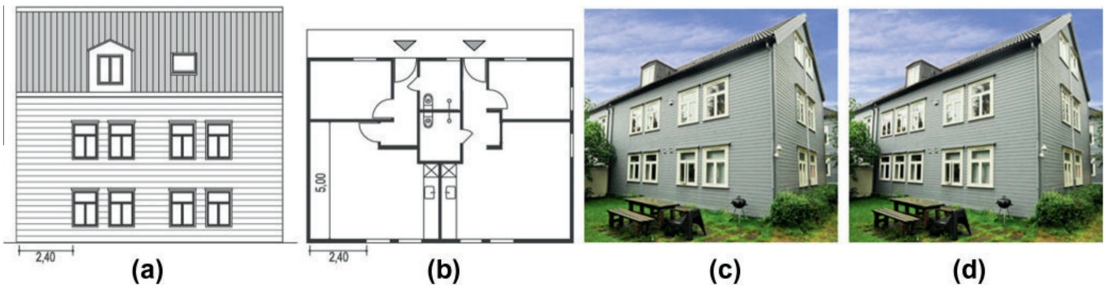


Figure 6. Symmetry and coherence of the facade composition are achieved in detriment of lighting and ventilation demands. Existing facade and plan of residential building (a and b). Existing facade (c) with eight windows and proposal for the addition of two extra windows (d). Trondheim, Norway, pictures: Author.

relation to the 1:1 ratio. This feature is used to analyse the sub-determinant of Enclosure and Peripheral Density (Table 4, item B). Fig. 11a and c illustrate a residential building block before and after renovation. Buildings 'A' are existing buildings and buildings 'B' are additions that close the perimeter of the block affecting its physical and perceived continuities (Fig. 11b) (Table 4, item B).

The analysis of the built space in a quantitative manner is also an essential feature related to spatial quality on the block scale. The measurements of density considered in this study are the floor space index (FSI), the ground space index (GSI) and open space ratio (OSR) (Uytenhaak, 2008). The FSI is the ratio between the sum of the area of all floors and the plot area, and it represents the built density. The GSI is the ratio between the area occupied by the building on the plot and the plot area, and it represents the compactness of the built volume. The ratio between FSI and GSI ($L = FSI/GSI$) indicates the average number of floors. The OSR is the ratio between the plot area excepting the footprint of the building and the sum

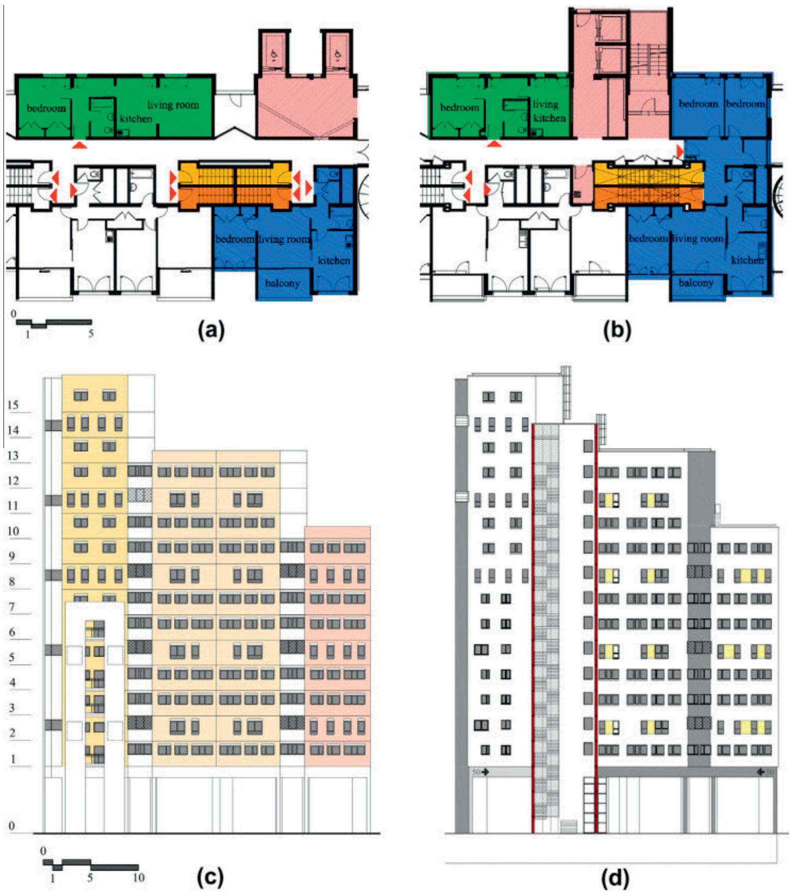


Figure 7. (a–d) Changes in the internal division of space due to the dwelling renovation affect the facade composition. Plans (a–b) and facades (c–d) before and after renovation. Residential block, Grenoble, France, pictures: Author.

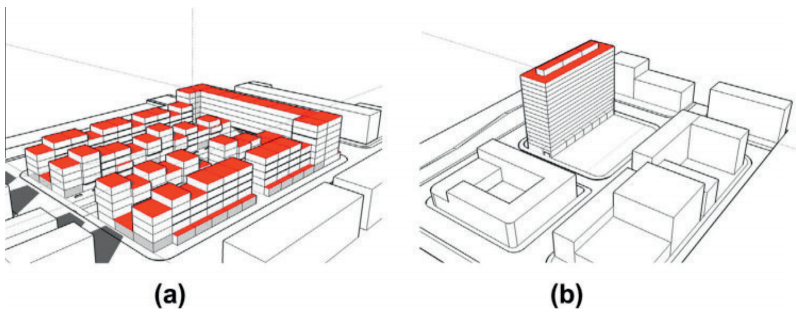


Figure 8. (a) and (b) built density. Compactness, porosity and slenderness of the block shape, pictures: Author.

of the area of all floors. The OSR indicates the openness of the built volume and the pressure on the non-built space of the plot (Uytenhaak, 2008).

These measurements provide a valuable indication about the built space. However, built density is unable to express the whole complexity of spatial quality on the block scale (Acre and Wyckmans, 2014). Therefore they consist of only part of the range of elements (Table 4, item C) for the spatial quality assessment on the block scale (see Figs. 12a–c).

Table 4
Spatial quality assessment for perceived density, built and human densities.

Spatial quality assessment – determinant 4: perceived density, built and human densities (Block scale)
(A) Principle of complexity
1. Surface contrasts[a]
(a) Continuance of edges of the block (quality of continuity) (yes or no question)
(b) Similarity of surface and form of the block's boundaries (yes or no question)
(c) Similarity of facades' composition of the block's boundaries (building materials and use of common signs such as repetitive pattern of windows) (yes or no question)
2. Form simplicity[a,b] (Figs. 8a and b)
(a) Geometry and compactness of the block shape (relation between the external block surface and its volume)
(b) Porosity of the block shape (presence of exterior spaces within the external perimeter of the block such as courtyards) (yes or no question)
(c) Ratio between the area of exterior spaces within the block's perimeter and the area of the block (porosity of the block shape)
3. Dominance[c] (impact of one part over others by means of size and proportion, and interplay between vertical and horizontal) (Figs. 9a and b)
(a) Slenderness of the block shape (relation between the vertical and the horizontal volumes of the block)
(b) Presence of strong vertical accents at the position of the main focus (yes or no question)
(c) Presence of a vertical axis of symmetry at the position of the main focus (perceptual stability) (yes or no question)
(B) Enclosure and peripheral density[c]
1. Height to width ratio of the enclosed space in relation to the 1:1 proportion (relation between the dimensions of the courtyard and the heights of the peripheral buildings)
2. Articulation of space boundaries (contrast between the heights of the peripheral buildings, and proportion between block heights and surrounding blocks in relation to the 1:1 proportion) (Fig. 10)
3. Presence of physical or perceived continuity of space boundaries (perimeter of the block) (yes or no question) (Figs. 11a–c)
(C) Built density[d] (per square metre) (Figs. 12a–c)
1. Floor space index (FSI) and average amount of floors (L = FSI/GSI)
2. Ground space index (GSI)
3. Open space ratio (OSR)
(D) Human density (people per square metre of block area)
1. Percentage of residents of the total users population
2. Percentage of non-residents of the total users population
3. Relation between square metres per person and built area according to functions' demands
(E) Functions (use of the space)
1. Percentage of square metres per function
2. Compatibility of functions within the block (yes or no question)
3. Functions with low human presence located on the ground and first floors (such as parking and storage areas) (yes or no question)

[a] Lynch (1960).
[b] Serra (1997).
[c] Weber (1995).
[d] Uytenhaak (2008).

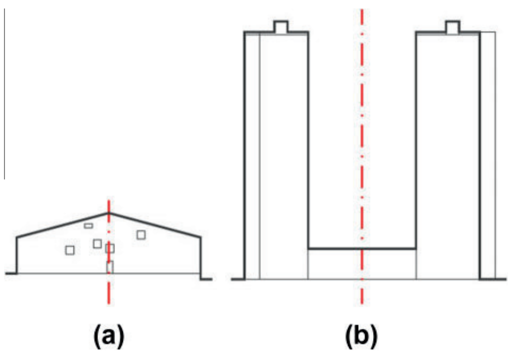


Figure 9. Presence of strong vertical accents and vertical axes of symmetry (indicated by the dashed line). Representation of dwellings, Delft, the Netherlands (a) and Hoge Heren Residential Towers, Rotterdam, the Netherlands (b), pictures: Author.

Figure 10. Proportion between heights of blocks and width of the street in relation to the 1:1 ratio, picture: Author.

2.5. The impact of technical measures for dwelling renovation on spatial quality

Post-occupancy evaluations of buildings are often used to assess the impact of energy renovation on people. However Tweed (2013) indicates that this approach fails to consider the social context properly, because many of the energy efficiency measures and technical issues in energy renovation remain abstract to the occupants. Technology allows the occupants to concentrate on their daily lives while it disappears from the occupants' perception.

Therefore, occupants often do not clearly see the improvement of energy renovation in their daily lives and well-being: "thus, it can be argued a gap exists in the treatment of socio-technical systems in that they do not address the close interaction between people, spaces and artefacts and the implications these have for energy consumption" (Tweed, 2013, p. 554). Due to the abstract nature of technical issues to occupants such as energy efficiency, non-technical issues, which are clearer to human perception, need to be addressed to improve the interface between technical dimensions and occupants.

Tweed (2013) uses a technical project report by Patterson (2012) of a dwelling renovation realized in 2010 in Newport, south Wales to demonstrate the impact of the changes made to the property as the result of the dwelling renovation. The changes affected the building components of form and space, facade, appliances and mechanical systems. Changes in form and space consisted of the addition of a sun space with roof light that functions as a buffer space for the living room, and a light tube was installed above the stairs to implement natural light. Insulation was applied to the facades and windows were changed to hardwood triple glazed windows. The dwelling got new appliances: a washing machine, a fridge-freezer and a cooker. The changes in mechanical systems consisted of the implementation of a heat pump, a whole-house mechanical ventilation and heat recovery, photovoltaic, solar thermal system located on the roof of the new sun space, the addition of time and temperature controls, low energy light bulbs and removal of the existing gas boiler (Tweed, 2013).

However, after the final visit to the property and interviews with the occupants, Tweed mentions that the dwelling renovation "was valued for the extra space" (the sun space added to the living room) "rather than any thermal benefit" (Tweed, 2013, p. 557). The exclusion of other aspects affected by energy renovation in dwellings such as spatial quality, affects the receptiveness of energy renovation by occupants. There is a contradiction between two facts in the dwelling renovation: first the "rarely discussed" role of energy, which was "not a major concern for the occupants", and second the role of the additional sun space, which "tended to dominate the conversations with the family" (Tweed, 2013, p. 559). Thus, however the relevance of the addition of the sun space, Patterson (2012) mentions the change in space and form as secondary renovation strategies in the technical report.

A spatial quality assessment for dwellings, presented in Section 2 of this article, aims to contribute to connecting the benefits of energy renovation with improvements in people's well-being (Fig. 13). In Sections 2.5.1 to 2.5.8 the paper presents how energy renovation of dwellings affects spatial quality. The impact on spatial quality of technical measures of energy renovation for the building components of floors, internal and external walls, roofs, windows, mechanical services and controls (Baker, 2009; Burton, 2012) are analysed in this study. Changes to the built area of a block (Giebeler et al., 2009) as a consequence of dwelling renovation and the use of renewable energy options are also considered in relation to spatial quality impacts (Baker, 2009).

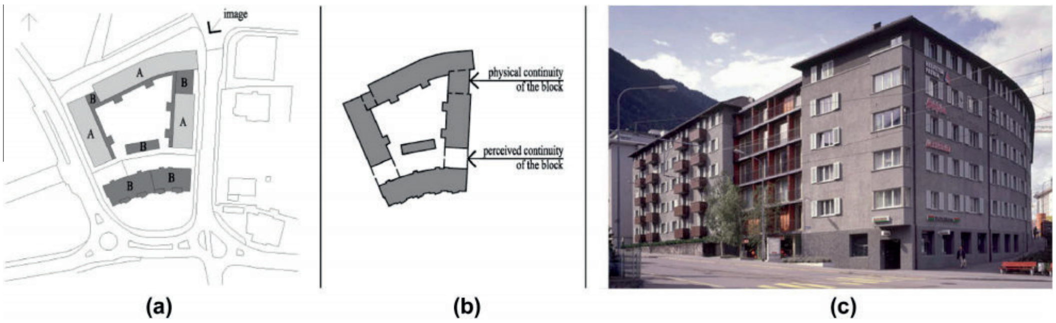


Figure 11. Residential block, Chur, Switzerland. Plan of residential block after renovation (a and b). Buildings "A" are existing; buildings "B" are additions that close the perimeter of the block. © [Detail]. Reproduced by permission of detail. Residential block after renovation with the addition of a new building (c). © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.

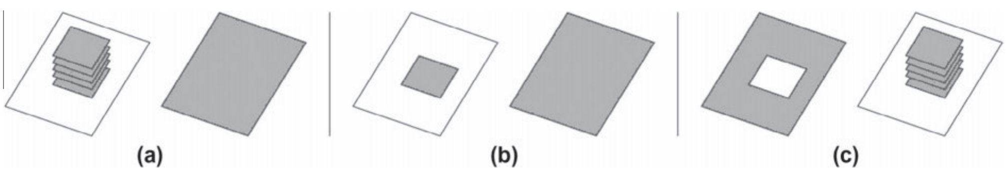


Figure 12. Built density. FSI (a), GSI (b), OSR (c), pictures: Author.

2.5.1. Building component of floors

The dwelling renovation brings changes in the building component of floors, and these changes affect the spatial quality determinants of (1) view, and (2) internal spatiality and spatial arrangements. Changes in the building component of floors are not relevant for the spatial quality determinants of (3) transition between public and private spaces and (4) perceived density, built and human densities (Graph 1). The changes brought by the renovation consist of adding insulation to the floor with thickness between 125 and 175 mm, and 250 mm for *passivhaus* standard (Burton, 2012) (Appendix 1: 'Description of technical measures and their characteristics for floors', and Table 5).

The crossing between the technical measures for floors and the spatial quality definition indicates the effects of dwelling renovation as follows: changes in the thickness of the floors and therefore ceiling heights, may affect the access of lighting in respect to views (Tables 1 and 5). Regarding the spatial quality determinant of internal spatiality and spatial arrangements (Tables 2 and 5), changes in ceiling heights may affect the spatial quality principles of:

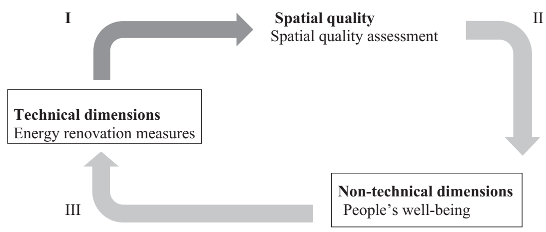
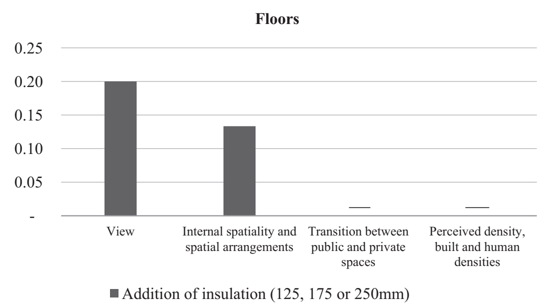


Figure 13. Spatial quality smoothes and strengthens the connection between technical and non-technical dimensions. The present study consists of the arrow 'I' in the figure, the impact of energy renovation on spatial quality in dwellings. Non-technical dimensions are Architectural Values and Cultural Heritage, Stakeholder Awareness and Behaviour, Economic and Ownership Structures, Legislation, Governance and Policy (Karlsson and Lindkvist, 2013). The non-technical driver of spatial quality belongs to the dimension of Architectural Values and Cultural Heritage.



Graph 1. The impact per technical measure of floors' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

1. (B) *Internal division of space and spatial density.* Changes in ceiling heights may affect the internal division of space because differences in ceiling heights can be used to subdivide spaces without the use of walls (Acre and Wyckmans, 2014; Weber, 1995).
2. (C) *Spatial complexity.* First by indicating spatial hierarchies through differences in ceiling heights and second, by influencing the degree of space closure that is the height to width ratio of the enclosed volume (Acre and Wyckmans, 2014).
3. (E) *Lighting.* Changes in ceiling heights affect the behaviour of the light in the space.

2.5.2. Building component of external walls

Dwelling renovation brings changes in the building component of external walls, and these changes affect all the four spatial quality determinants (Graph 2). The changes consist of adding insulation with thickness between 80 and 120 mm, and 200 mm for *passivhaus* standard (Burton, 2012) (Appendix 2: 'Description of technical measures and their characteristics for external walls', and Table 6). Balconies are also often added or removed during the renovation. The addition of balconies is meant to improve the plan of the dwelling, whereas the removal is meant to avoid the risk of cold bridges and reduce costs (Burton, 2012; Giebeler et al., 2009). The balcony area can also become an internal area of the apartment during dwelling renovation.

Regarding the spatial quality determinant of (1) view, changes in the thickness of external walls may increase the degree of sight protection, that is, the visual privacy and visual protection of the private domain. For example it can lower the possibility of view of arriving visitors and access spaces. The addition of balconies may lower the degree of visual protection instead, as it increases the percentage of apertures area, thus the facade transparency. However, that will depend on the transparency of the handrail and if the balcony sticks out of the facade or is built into the building volume (Figs. 14a and b). In addition the way balconies are placed at the facade (on top of each other or staggered) affects the degree of visual protection (Uytenhaak, 2008) (Tables 1 and 6).

Changes in the thickness of the external walls through addition of internal insulation affect the spatial quality determinant of (2) internal spatiality and spatial arrangements in two ways (Tables 2 and 6). First, the addition of internal insulation affects the degree of space closure (height to width ratio of the enclosed volume). Second, thicker walls, either as a consequence of the addition of external or internal insulation of 80, 120 or 200 mm (Burton, 2012), influence the access of daylight (Table 6).

The addition of a balcony brings a new entrance to the space. Therefore, it may lead to changes on centricity and concavity, as the placement of the entrance affects the perceptual centres of space (Figs. 2a, 4a and b) (Table 6). The addition or extension of balconies brings new spatial

Table 5
Impact of technical measures for dwelling renovation for floors on the spatial quality determinants.

Floors and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Floors					
Solid concrete ground floors[a]	Insulation applied above existing concrete floors Insulation applied above new concrete floors Insulation applied bellow new concrete floors	Changes on the thickness of the floors and ceiling heights may lead to changes on: D. Lighting (access of daylight)	B. Internal division of space and spatial density (B.3) C. Spatial complexity (C.3a, C.3c) E. Lighting (light behaviour in the space) (E.2c)	No impact is found	No impact is found
Suspended timber ground floors[a]	Insulation applied to the upside of the floor boards Insulation applied to the underside of the floor boards Insulation applied between the joists				
Intermediate floors[b]	Insulation not relevant considering heat losses. However, acoustic insulation might be needed				

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

hierarchy (Acre and Wyckmans, 2014). A balcony is a subordinated (secondary) space connected to the main (primary) space of the room. The primary space retains its figural character, but the boundary to which the secondary space was added becomes more dominant (Weber, 1995) (Figs. 15a and b). The placement of balconies in a room is particularly relevant considering that it can reinforce the main centre when placed symmetrically in relation to it. Addition of balconies to the facade also affects the access of daylight, therefore balcony placements and proportions need to be studied prior to renovation.

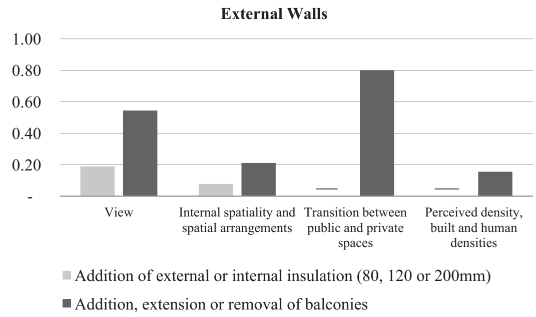
Facades bridge the inside and the outside spaces. Therefore changes in external walls clearly affect the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 6). Particularly the addition, extension and removal of balconies lead to changes on boundaries between the private and public domains (Table 6). The boundaries within the private, semi-private and semi-public domains consist of the transition within the private space of the dwelling, the semi-private front yard and the semi-public (communal) spaces for accessibility. Thus, these are the relations between neighbour to neighbour (Chermayeff and Alexander, 1966). The boundaries between semi-private, semi-public and public domains consist of the transition between the semi-private front yard, the semi-public (communal) spaces and the public space of the street. These are the relations between resident to neighbourhood (Fig. 16). The addition of balconies creates or increases outdoor private areas of effective staying in a dwelling. Therefore it increases the possibility of controlled social interaction (Alexander et al., 1978; Rapoport, 1971). In addition to the increase in floor area, balconies and loggias function as external insulation and a buffer zone, improving the "energy balance of the compact structure" (Giebeler et al., 2009, p. 234).

The addition, extension or removal of balconies affect the facade composition, thus the uniformity and coherence of boundaries in building and block scales (Table 6). However, formal strategies such as similarity, ordered repetition and articulation between figure (apertures) and ground (facade surface) can bring an "overall unified effect to facade composition" (Weber, 1995, p. 154) (Figs. 17a and b, 18a and b). Changes in the inside space of dwellings may also affect facades such as the need for new openings as a consequence of changes in the subdivision of spaces. Dwelling renovation can also mean interventions on the scale of the block and such interventions can impact the facade composition of a single building. An example is the demolition of a building from a block which frees a facade for the possibility of new openings.

On the other hand changes in the facade composition of a single building can also affect the composition of a block's facade. These changes influence the spatial quality determinant of (4) perceived density, particularly the principle of complexity (Tables 4 and 6) (Acre and Wyckmans, 2014). This principle refers to the surface contrast between diverse building facades according to the quality of steadiness and continuance of edges or surfaces (similarity, analogy, or harmony of surface and form) (Lynch, 1960). The addition, extension or removal of balconies during dwelling renovation also affects built density.

2.5.3. Building component of internal walls

Dwelling renovation often brings changes to the building component of internal walls. The changes consist mainly of the addition and removal of internal walls, and the



Graph 2. The impact per technical measure of external walls' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

addition of insulation (Burton, 2012). They affect the spatial quality determinants of (1) view, (2) internal spatiality and spatial arrangements, and (3) transition between public and private spaces. These changes are not relevant for the spatial quality determinant of (4) perceived density, built and human densities (Graph 3). Regarding the spatial quality determinant of (1) view, changes in internal walls affect the visual openness and privacy (Indraprastha, 2012) (Tables 1 and 7). They may also hinder or create the possibility of one-way view to the entrance, to general outdoor spaces and arriving visitors (Fig. 19b) (Acre and Wyckmans, 2014).

The spatial quality determinant of (2) internal spatiality and spatial arrangements is the most affected by changes in the building component of internal walls (Tables 2 and 7). The principle of centricity and concavity is affected since alterations in the internal division of space usually change geometric and perceptual centres, and the placement of entrances (Figs. 1a–d, 2b, 3a and b, 4a and b). Spatial hierarchies may also change since spatial arrangements (coordinated and subordinated spatial relations) vary (Figs. 15a and b, 20a and b). Alterations in the placement of internal walls affect the height to width ratio of the enclosed volume, changing the degree of space closure (Figs. 21a and b).

The privacy within the dwelling itself can change considerably according to the placement of internal walls. Privacy within the dwelling can be significantly improved through zoning, according to different family group members (Chermayeff and Alexander, 1966). Large openings in internal walls can also create new spatial relationships and visually increase the space (Giebeler et al., 2009). Changes in internal walls also affect the access of daylight, which may require revising the internal zoning of the diverse functions according to sun orientation and daylight demands.

Table 6
Impact of technical measures for dwelling renovation for external walls on the spatial quality determinants.

External walls and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
External walls					
External walls with external insulation[a] External walls with internal insulation[a]	Wet render system Dry cladding system Laminated insulation board fixed directly to the wall Rigid insulation between battens fixed to the wall Frame with insulation leaving an 30 mm air gap between insulation and the wall Cavity fill for existing brick and block cavity walls	Changes on the thickness of the external walls may lead to changes on: B. Depth of vision (B.1b, B.1c, B.2b) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.1c) C. Spatial complexity (C.3) E. Lighting (E.1c)	No impact is found	No impact is found
Addition, extension or removal of balconies risk of cold bridging[a]	Cantilevered balconies can result in serious cold bridges and are difficult to treat. Using insulated windows frames, applying some insulation to reveals, returning insulation along party walls, and insulating any mechanical fixings will overcome this problem	A. Facade transparency B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.2, C.3) D. Lighting	A. Centricity and concavity (A.1a) C. Spatial complexity (C.2) E. Lighting (E.1a, E1c, E.2b, E.2c, E.3b, E.3c)	B. Clear boundaries between the private and public domains C. Outdoor private spaces D. Uniformity and coherence of boundaries E. Internal division of space and facade composition	A. Principle of complexity (A.1c) C. Built density (C.1, C.3)

[a] Measures described in Burton (2012).

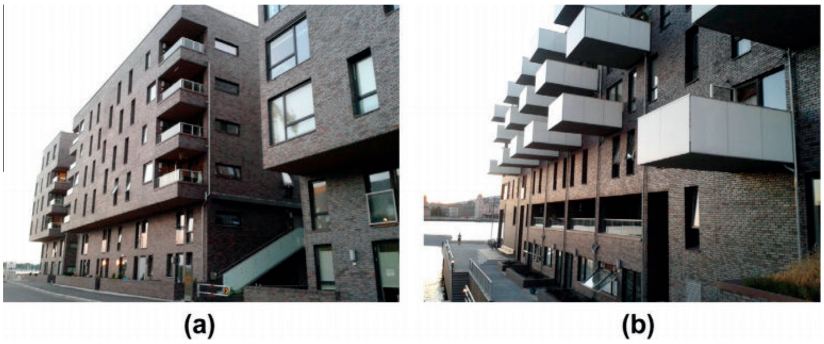


Figure 14. Balconies placed on top of each other (a) and staggered balconies (b). Residential buildings, Oslo, Norway, pictures: Author.

Adjustments to internal walls can lead to variations in facade composition, thus affecting the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 7). Internal changes in the plan can affect features of facade composition such as uniformity and coherence of boundaries, similarity, rhythm of facade composition, and figure (window) and ground (wall) articulation.

2.5.4. Building component of roofs

The building component of roofs is often affected by dwelling renovation. These changes affect the spatial quality determinants of (2) internal spatiality and spatial arrangements, and (3) transition between public and private spaces. The dwelling renovation measures for roofs considered in this study are not relevant for the spatial quality determinants of (1) view, and (4) perceived density, built and human densities (Graph 4). The renovation measures consist of adding insulation with thickness between 250 and 300 mm, and between 300 and 400 mm for *passivhaus* standard (Burton, 2012) (Appendix 3: 'Description of technical measures and their characteristics for roofs', and Table 8). Measures for the renovation of flat roofs were taken into consideration in this study as well as the implementation of green roofs in dwelling renovation (Table 8).

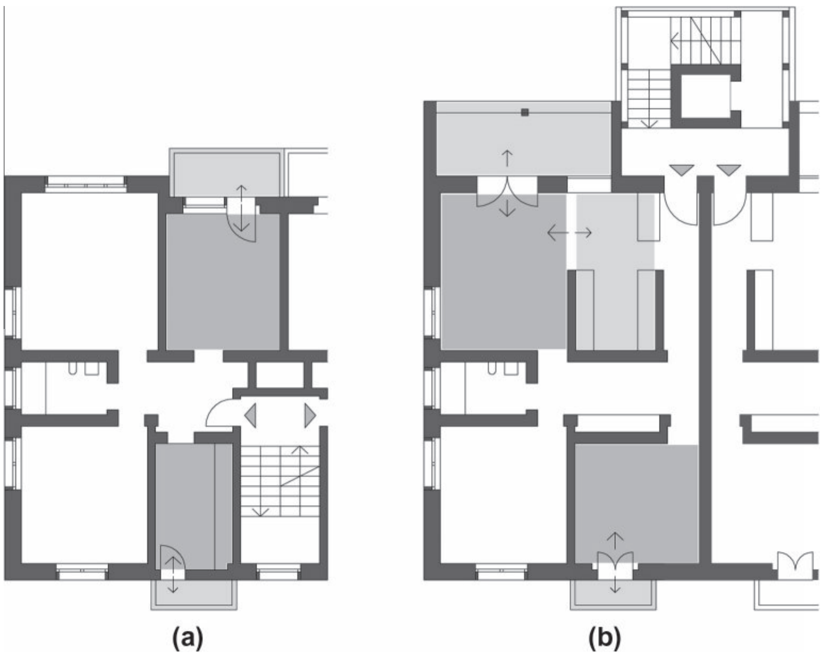


Figure 15. Plans of the first floor before (a) and after (b) the dwelling renovation. Subordinated relationship of spaces. Residential building, Chur, Switzerland. © [Detail]. Reproduced by permission of detail.

Figure 16. Gradual and physically clear transition between private, semi-public and public domains. Residential building, Amsterdam, the Netherlands, picture: Author.

Two measures are relevant for the spatial quality determinant of (2) internal spatiality and spatial arrangements: the changes in heights and the addition of new green roofs. Changes to ceiling heights may affect the principle of internal division of space and spatial density (Tables 2 and 8). Spaces can be demarcated by differences in height and these differences can be a consequence of the addition of roof insulation. The implementation of green roofs affects spatial hierarchy because the roof area becomes a usable space connected to the dwelling. Therefore the new green roof becomes subjected to spatial relations with the surrounding spaces such as coordinated or subordinated spatial relations (Figs. 15a and b, 20a and b).

The addition of terraced spaces such as flat (green) roofs affects the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 8). First, because it creates an external usable space and therefore it creates an additional boundary between a private and a public space. Second, the terrace is an outdoor private space that has the potential to be an effective staying area, which promotes social interaction and visual contact among neighbours (Acre and Wyckmans, 2014; Gehl, 2011).

2.5.5. *Building component of windows*

Dwelling renovation brings changes in the building component of windows and these changes affect all the four spatial quality determinants (Graph 5). The technical measures of dwelling renovation for windows consist of the use of double glazing or triple glazing (for *passivhaus* standard), reduction or increase of framing to improve light and view conditions (Burton, 2012), installation of a secondary glazed screen (second skin), replacement of the glazing and the framing system (Baker, 2009), reduction or increase of existing aperture and glazed area (Burton, 2012), changes in the distribution of glazing by making new apertures to improve daylight distribution, and the implementation of internal or external shading (Baker, 2009) (Appendix 4: 'Description of technical measures and their characteristics for windows', and Table 9).

All the measures mentioned lead to changes in facade transparency in relation to the spatial quality determinant of (1) view, because they affect the aperture's area (windows' and doors' areas). Therefore the ratio between the total wall area and the total aperture area changes (Tables 1 and 9). Facade transparency may also change according to the properties of reflectance, transmittance and absorptance of the new glazing. Measures such as reduction or increase of existing aperture and glazed area (Figs. 22a and b), changes in the distribution of glazing by making new apertures and the implementation of shading, affect the degree of visual protection, that is the visual

(a) (b)

Figure 17. (a) and (b) articulation between figure (apertures) and ground (facade surface). Residential building, Amsterdam, The Netherlands, pictures: Author.

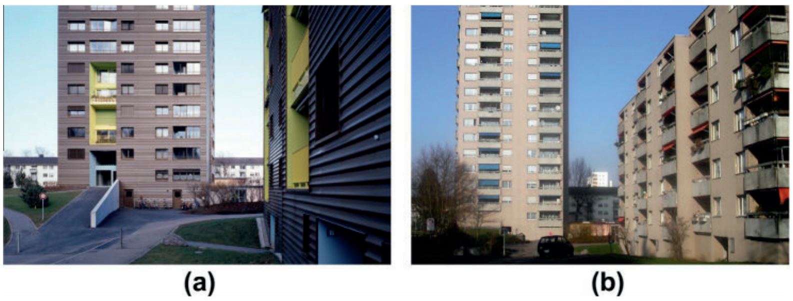
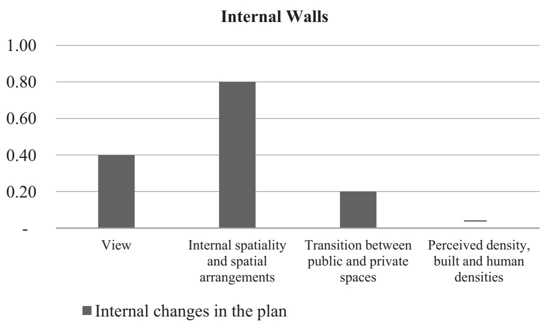


Figure 18. Changes in materialisation of facades and windows' size and composition. Residential blocks, Zürich, Switzerland. Residential block after renovation (a). © [Andrea Helbling, Arazebra]. Reproduced by permission of Andrea Helbling, Arazebra, Zürich. Residential block before renovation (b). © [Schneider Studer Primas GmbH]. Reproduced by permission of Schneider Studer Primas GmbH.



Graph 3. The impact per technical measure of internal walls' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

privacy and protection of the private domain. The one-way view of arriving visitors and access space can be gained or lost with changes in the configuration of apertures, and with the use of shading devices.

The measures considered affect the principles of lighting and spatial complexity in the spatial quality determinant of (2) internal spatiality and spatial arrangements (Tables 2 and 9). The access of daylight varies in quantity and quality of light distribution with changes in size, placement and dimensions of window framing, as well as with the use of shading. The installation of a secondary glazed screen (second skin) can create an internal or external extra space such as a sun space. The addition of an extra space can result in new spatial hierarchies, for example a sun space that functions as a buffer zone to improve energy performance (Giebeler et al., 2009) becomes a subordinated space to the room to which it is connected. The room's figural character remains, while the wall to which the sun space is attached becomes more dominant (Acre and Wyckmans, 2014).

The technical measures of dwelling renovation of reduction or increase of framing, installation of a secondary glazed screen (second skin), reduction or increase of existing aperture and glazed area, (Burton, 2012) and changes in the distribution of glazing by making new apertures (Baker, 2009) affect three principles of the spatial quality determinant of (3) transition between public and private spaces (Tables 3 and 9). First, changes in the size and configuration of windows and the implementation of shading devices affect the facade composition, which is the principle of uniformity and coherence of boundaries. Such changes

Table 7
Impact of technical measures for dwelling renovation for internal walls on the spatial quality determinants.

Internal walls and spatial quality determinants				
Building refurbishment dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Internal walls				
Internal changes in the plan[a,b] (insulation not relevant considering heat losses)[a]	Measures can lead to changes on: B. Depth of vision (B.1, B.3) C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity (A.1, A.2a, A.2b, A.3) B. Internal division of space and spatial density (B.1, B.2c) C. Spatial complexity D. Sense of privacy E. Lighting (E.2, E.3)	E. Internal division of space and facade composition before and after intervention	No impact is found

[a] Measure described in Burton (2012).
[b] Measure described in Giebeler et al. (2009).

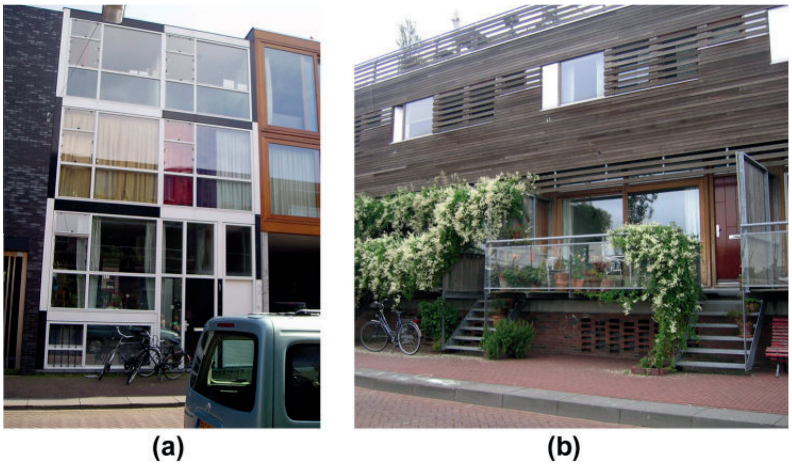


Figure 19. (a) and (b) view of the entrance from inside of the dwelling, and availability of outdoor private spaces. Private dwellings, Borneo, Amsterdam, The Netherlands, pictures: Author.

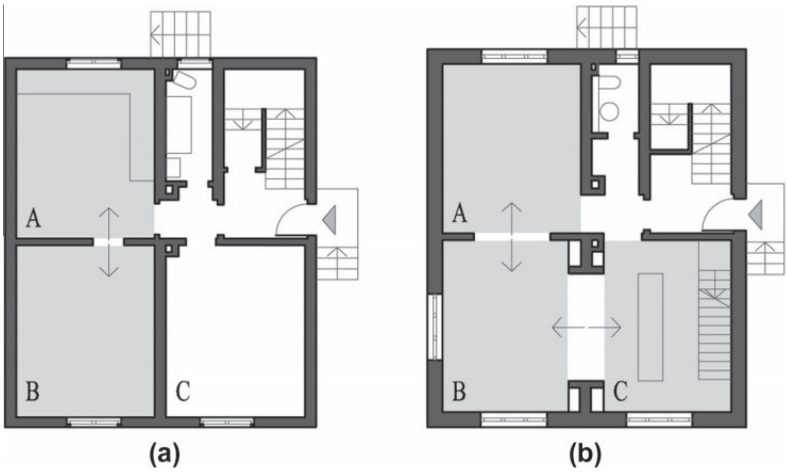


Figure 20. Plans of the ground floor before (a) and after (b) the dwelling renovation. Coordinated relationship of spaces. Private dwelling, Bochum, Germany.

in facade composition are likely to affect similarities in scale, proportion, facade decoration and materialisation, as well as rhythm of facade composition (ordered repetition to achieve an overall unified effect), and facade roughness (Figs. 23a–c). Similarity in facade composition means similar formats of architectural elements, similarities in scale, proportion and materialisation. Rhythm is the ordered repetition to achieve an overall unified effect. Facade roughness consists of the presence of projected bounces on the facade, such as balconies and bay windows (Serra, 1997).

Second, the measures of installation of a secondary glazed screen or shading (second skin) might bring the addition of outdoor private spaces such as a new balcony resulting from the space between the original house and the new second skin. This new outdoor space can become an effective staying area. Third, the new second skin and the reduction or increase of existing glazed area affect the clarity of the boundaries between public and private domains, for example due to excessive transparency of facades, which may blur the distinction between inside and outside domains.

One principle of the spatial quality determinant of (4) perceived, built and human densities is affected by the changes considered for the building component of windows (Tables 4 and 9). Namely, the principle of complexity for the overall facade composition that is considering the block's facade instead of only the building's facade. The

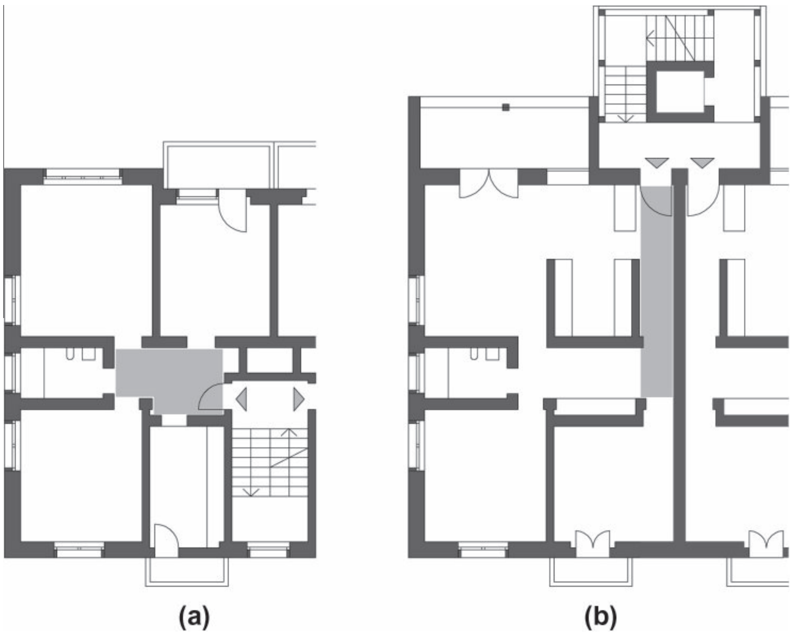
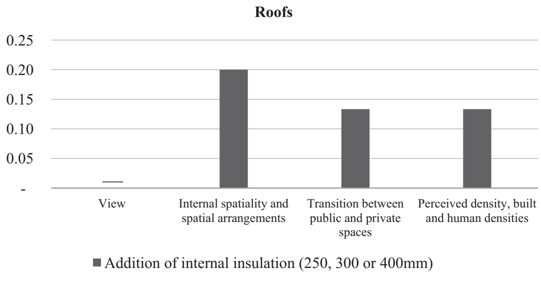


Figure 21. Plans of the first floor before (a) and after (b) the dwelling renovation. Space closure of the hall area. Residential building, Chur, Switzerland. © [Detail]. Reproduced by permission of detail.

complexity of the overall facade composition of the block is affected in terms of surface contrasts, which is the quality of continuity (continuance of edges or surfaces) and the harmony (similarity) of surface and form (building materials and use of common signs such as repetitive pattern of windows) (Lynch, 1960).

2.5.6. Building component of mechanical services and controls

Dwelling renovation in mechanical services and controls affects the four spatial quality determinants (Graph 6). However two measures considered by Burton (2012) are not relevant for spatial quality. The first measure is the improvement of the airtightness of the structure in order to reduce air leakage by repairing mortar joints, filling holes in the external walls, and applying sealant materials to fill gaps around windows, doors and frames. The second measure consists of improvements in the ventilation system such as with the installation of non-visible ducts (Burton, 2012).



Graph 4. The impact per technical measure of roofs' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

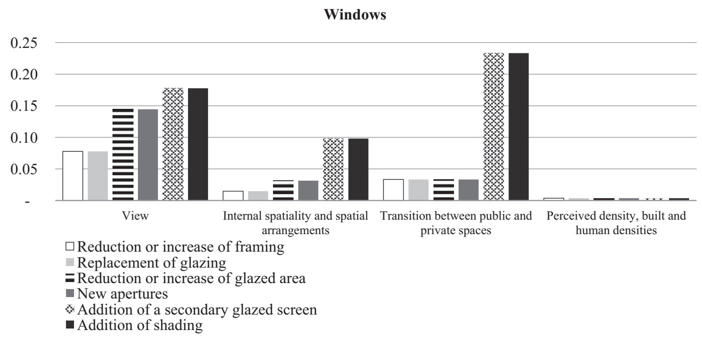
Three of the measures indicated by Burton (2012) are relevant for the spatial quality determinant of (1) view (Tables 1 and 10). The addition of extra south facing windows in order to increase solar gain affects the facade transparency and lighting because it increases the percentage of aperture areas. By contrast, measures to avoid overheating such as the implementation of shading also influence facade transparency and lighting because it decreases the percentage of aperture areas, as well as increasing the degree of sight protection (visual privacy). The addition of vegetation used as shading affects the depth of vision and view's quality (composition of the view).

The spatial quality principle of (2) internal spatiality and spatial arrangements is also affected by the changes considered by Burton (2012) for mechanical services and control. The changes affect two principles of this determinant, namely the spatial complexity and lighting. Spatial complexity is affected because of the space needed to accommodate technical equipment for heating such as solar water systems, gas and boilers, heat pumps and storage cylinders for the provision of domestic hot water (DHW). The space for technical equipment can be a room such as for gas and boilers, heat pumps and storage cylinders as well as height space required to accommodate a ventilation system. The effect on lighting is due to changes in the size of windows

Table 8
Impact of technical measures for dwelling renovation for roofs on the spatial quality determinants.

Roofs and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built and human densities
Roofs					
Roof insulation at ceiling or at rafter levels[a]		No impact is found	Measures can lead to changes on: B. Internal division of space and spatial density (B.3)	No impact is found	No impact is found
Insulation of flat roofs (possibility of adding a terraced private outdoor space)	External roof insulation: Insulation above the roof structure (inverted warm roof system)[a]		No impact is found	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1, C.3)
	Internal roof insulation: Insulation below the roof structure (cold roof system)[a]		B. Internal division of space and spatial density (B.3)	No impact is found	No impact is found
	Green roofs[b]		C. Spatial complexity (C.1, C.2)	C. Outdoor private spaces (C.1, C.2)	C. Built density (C.1, C.3)

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).



Graph 5. The impact per technical measure of windows' renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

(to increase solar gain and improve natural ventilation), the implementation of shading devices and vegetation (to avoid overheating) (Acre and Wyckmans, 2014).

The measures for mechanical services and control in dwelling renovations that affect the spatial quality principle of (3) transition between public and private spaces are the ones that imply changes in the facade composition (Tables 3 and 10). Changes in the size of windows and the implementation of shading devices affect the facade composition, therefore the principle of uniformity and coherence of boundaries (Figs. 18a and b). The relation between the parts and the whole is the focus of this principle. Changes to the principle of uniformity and coherence of boundaries consist of changes in similarity, rhythm and facade roughness. The addition of vegetation to avoid overheating may affect the principles of clarity on boundaries within private and public domains, and provision of outdoor private spaces. This is because the addition of vegetation may be accompanied by the creation of private outdoor staying areas, and these areas may result in buffer zones in the transition between private and public domains.

The principle of complexity for the overall facade composition is the only principle of the spatial quality determinant of (4) perceived, built and human densities affected by the dwelling renovation measures for mechanical services and control (Tables 4 and 10). The principle of complexity considers the overall facade composition of the block. Changes in the size of windows and the implementation of shading devices are particularly relevant for the principle of complexity. The principle of complexity refers to surface contrasts, which is the quality of continuity, and the harmony of surface and form. This principle focuses on building materials and use of common signs among the building of the same block, for example materialisation and repetitive pattern of windows (Acre and Wyckmans, 2014).

Table 9
Impact of technical measures for dwelling renovation for windows on the spatial quality determinants.

Windows and spatial quality determinants				
Building refurbishment dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition public and private spaces	Perceived, built, human densities
Windows				
Reduction or increase of framing to improve light and view conditions[a] Replacement of the glazing and the framing system[b]	Measures can lead to changes on: A. Facade transparency (A.2) B. Depth of vision (B.1) D. Lighting	E. Lighting (E.1c, E.2b, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)
Reduction or increase of existing glazed area[a] Changing the distribution of glazing by making new apertures to improve daylight distribution[b]	A. Facade transparency (A.1, A.3) B. Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	A. Centricity and concavity (A.2) E. Lighting (E.1c, E.2b, E.3b, E.3c)		
Installation of a secondary glazed screen[b] Use of shading[b] (This can result in extra outdoor spaces such as balconies) — Use of external shading; Use of internal shading; Use of integrated shading	A. Facade transparency (A.1, A.3) B. Depth of vision (B.1, B.2) C. Distance and degree of sight protection D. Lighting	A. Centricity and concavity (A.2a, A.2b, A.2c, A.3) C. Spatial complexity (C.2) E. Lighting (E.1c, E.2b, E.3b, E.3c)	B. Clear boundaries between private and public domains C. Outdoor private spaces D. Uniformity and coherence of boundaries	

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

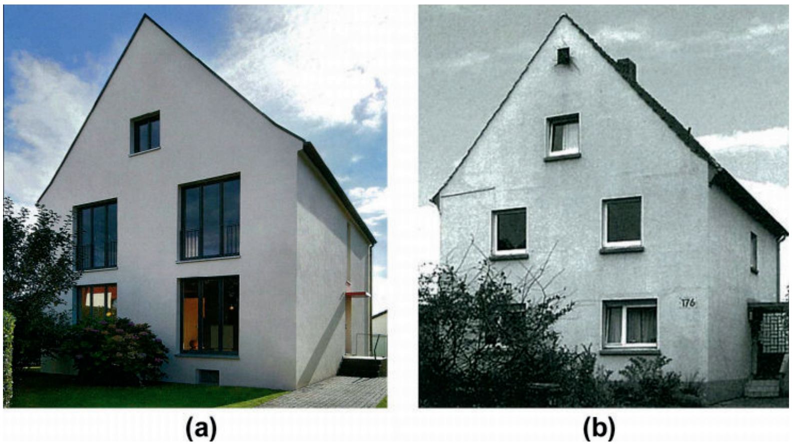
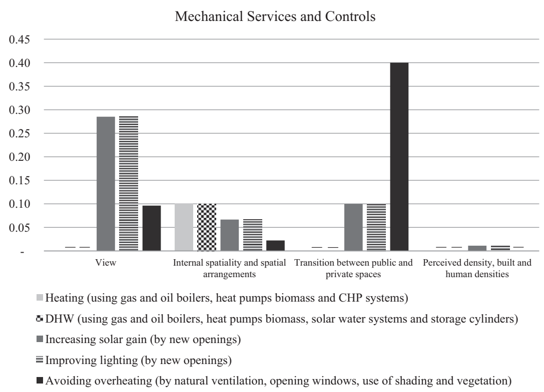


Figure 22. Changes in windows' size, after (a) and before (b) the dwelling renovation. Private dwelling, Bochum, Germany. © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.

2.5.7. *Built area*

Dwelling renovation may bring changes in the built area of a block by the addition of new buildings and the demolition of existing ones (Giebeler et al., 2009). These changes affect all the four spatial quality determinants (Graph 7). Regarding the spatial quality determinant of (1) view, the changes to built area can affect the principles of depth of vision, distance and degree of sight protection, and enclosure and peripheral density (Tables 1 and 11). The principle of depth of vision implies changes on visibility (spaces with view) and view's quality (composition of the view). The addition or removal of buildings may change the distance and degree of sight protection, that is, visual privacy and protection of the private domain.

Figure 23. (a–c) Similarities in scale, proportion, materialisation, as well as rhythm and facade roughness. Student housing, Copenhagen, Denmark, pictures: Author.



Graph 6. The impact per technical measure of mechanical services and controls (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

Alterations in built mass may come with changes in the configuration of outdoor spaces, such as the inclusion or exclusion of private outdoor spaces, which affect the visual interaction between public, collective and private domains (Figs. 24a and b). The last principle of enclosure and peripheral density indicates the configuration of the block (proportion of the block, height to width ratio of the courtyard area) that affects the views from inside spaces to outside spaces, and from outside to inside.

Regarding the spatial quality determinant of (2) internal spatiality and spatial arrangements, the principle of lighting is the only one affected by changes in the built mass on the block scale (Tables 2 and 11). In particular, the access of daylight can be improved or worsened by the addition or removal of buildings in a block. The spatial quality determinant of (3) transition between public and private spaces can be affected by changes in the built mass when these changes affect the configuration of outdoor spaces, such as the inclusion or exclusion of private outdoor spaces (Tables 3 and 11).

The last spatial quality determinant of (4) perceived density, built and human densities is the determinant that is the most affected by changes in the configuration of the block (Tables 4 and 11). The principles of complexity, enclosure and peripheral density, built and human densities and functions undergo the impact of the addition and removal of buildings in a block. The principle of complexity refers to changes in surface contrasts, form simplicity and dominance. Surface contrasts bring up the quality of continuance of edges in facade composition, the nearness of parts (how buildings are clustered) and the harmony (similarity) of surface and form, for example by materialisation and the use of repetitive window patterns (Lynch, 1960, p. 106). The characteristic of form simplicity refers to building geometry, compactness, porosity and slenderness considering all buildings of a block as a whole. The characteristic of dominance refers to the impact of one part (for example a building) over others (the whole block) by means of size and proportion.

The principle of enclosure and peripheral density indicates the configuration of the block. The characteristics which are considered in this principle are height to width ratio of the enclosed space (relation between the dimensions of the courtyard and the heights of the peripheral buildings), articulation of space boundaries (contrast between the heights of the peripheral buildings), and continuity of space boundaries (if there are gaps in the perimeter of the block and how these gaps influence the block contour) (Figs. 11a–c) (Table 4). The addition or removal of buildings in a block clearly impacts both built density (square metre) and human density (people per built square metre). Functions can be added or removed from the block to fulfil new demands (Acre and Wyckmans, 2014). The issues of concern related to functions are the balance between compatible functions such as housing and retail, and the type of functions located on the ground and first floors. Functions located on the ground and first floors are determinants for social control and interaction (Gehl, 2010) (Figs. 25a and b).

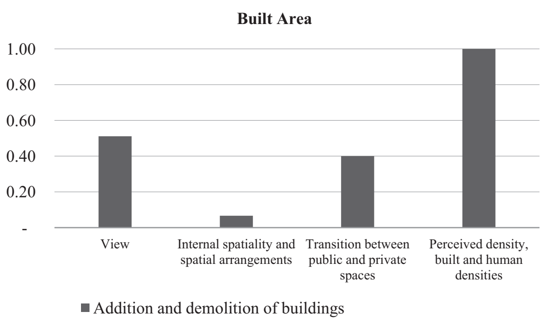
Table 10
Impact of technical measures for dwelling renovation for mechanical services and controls on the spatial quality determinants.

Mechanical services and spatial quality determinants					
Building refurbishment – dwellings Technical measures		View	Internal spatiality and spatial arrangements[c]	Transition between public and private spaces	Perceived density, built, human densities
Mechanical services and controls					
Heating[a]	Efficient space heating Gas and oil boilers, heat pumps, biomass systems and micro CHP systems	No impact is found	Measures can lead to changes on: C. Spatial complexity	No impact is found	No impact is found
Domestic hot water (DHW)[a]	Efficient provision of DHW Solar water systems Gas and boilers, heat pumps and storage cylinders				
Increasing solar gain[a]	New openings: sun entering a dwelling through east, south and west windows, as well as roof lights, assisted by thermal storage in floors and other thermal mass	A. Facade transparency . Depth of vision C. Distance and degree of sight protection (C.1) D. Lighting	E. Lighting (E.1, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)
Lighting installations[b]	New openings: maximise the use of daylight by architectural means in order to minimise artificial lighting energy				
Avoiding overheating[a]	Natural ventilation for cooling through opening windows The use of shading to avoid external heat gains				
	The use of planting and vegetation to avoid external heat gains	B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.1a, C.1b) D. Lighting	E. Lighting (E.2b, E.3b, E.3c)	B. Clear boundaries within private and public domains C. Outdoor private spaces as effective staying areas	No impact is found

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).
[c] Acre and Wyckmans (2014).

2.5.8. The use of renewable energy options

The implementation of renewable energy options is currently becoming a common practice in dwelling renovations (Burton, 2012). In particular the implementation of photovoltaic devices can affect all the spatial quality determinants (Graph 8 and Table 12). The technical measures that are relevant for the spatial quality determinants are the use of re-cladding panels and roof tiles, and the use of opaque PV as shading devices (Baker, 2009).



Graph 7. The impact of built area (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

Photovoltaic panels as cladding and shading devices influence the spatial quality determinants of (1) view because they might affect the facade transparency and the degree of sight protection (visual privacy) (Table 1). They may also impact the access of daylight in the spatial quality determinants of (1) view and (2) internal spatiality and spatial arrangements (Tables 1 and 2). The use of cladding and shading devices on facades influences the facade composition such as the features considered in the principle of uniformity and coherence of boundaries (Table 3). These features are similarity, rhythm of facade composition and figure and ground articulation. The changes in facade composition affect the principle of complexity of the spatial quality determinant of (4) perceived, built and human densities. This principle refers to surface contrasts and facade composition on the block scale.

3. Results and discussion

Energy renovation affects spatial quality in dwellings substantially that supports the hypothesis of this study. The hypothesis is confirmed by the analysis of the impact of current technical measures of energy renovation of dwellings on spatial quality. The results suggest the potential of energy renovation in increasing people's well-being

Table 11
Impact of technical measures for dwelling renovation for building area on the spatial quality determinants.

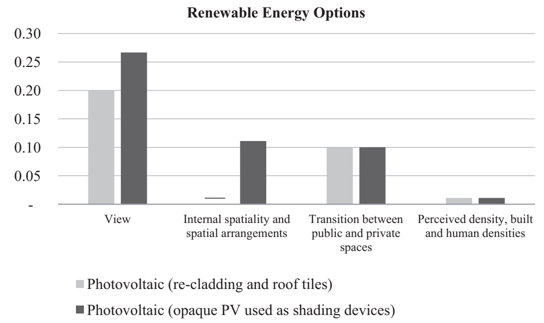
Built area and spatial quality determinants				
Building refurbishment dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition between public and private spaces	Perceived density, built and human densities
Built area				
Addition of new buildings and demolition of existing ones[a]	Changes on built area can lead to changes on: B. Depth of vision (B.2a, B.2c) C. Distance and degree of sight protection (C.2.) D. Lighting E. Enclosure and peripheral density (configuration of the block that affects views)	E. Lighting (E.3)	B. Clear boundaries between the private and public domains C. Outdoor private spaces	A. Principle of complexity B. Enclosure and peripheral density C. Built density D. Human density E. Functions

[a] Measures described in Giebeler et al. (2009).

Figure 24. (a) and (b) outdoor private spaces and gradual and physically clear transition between private and semi-public domains. Residential building, Oslo, Norway, pictures: Author.

Figure 25. (a) Storage spaces and parking located on the ground and first floors, functions with low human presence, residential building, Rotterdam, the Netherlands. (b) Retail and dwellings, functions with high human presence, Amsterdam, the Netherlands, pictures: Author.

and therefore user acceptation to renovation, through the consideration of the non-technical dimensions of view, privacy, lighting, spatiality, spatial arrangements, the transition between public and private spaces, and perceived, built, and human densities. The results of this work opens up for a whole underlying facet of building



Graph 8. The impact of renewable energy options (Baker, 2009; Burton, 2012; Giebeler et al., 2009) on spatial quality.

renovation that has not been clearly brought to the surface in the current literature and practice. This work considers particularly the whole building approach, which goes beyond punctual interventions in buildings and therefore aligns with the European deep renovation strategy.

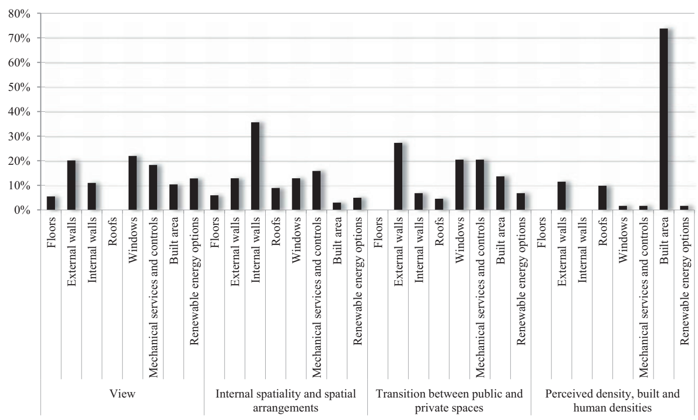
Many of the results were expected, such as the high impact of the renovation of external walls and windows on view and transition between public and private spaces (Graph 9). Also the renovation of internal walls was expected to highly influence the internal spatiality and spatial arrangements. Another expected result was the impact of the addition or demolition of buildings in an urban block on perceived density, built and human densities.

Surprisingly, renovation of mechanical services and control proved to affect the four spatial quality determinants (Graph 9). The reason for this impact indicates a rather positive development for the understanding of energy renovation. Technical equipment for heating, DHW and ventilation requires space to be accommodated. However, measures such as changes in the size of windows to increase solar gain and natural ventilation, the implementation of shading and use of vegetation to avoid overheating, are increasingly being considered as real alternatives in common energy renovation in dwellings both in the literature and in actual practice, instead of primarily the use of technical installations. Changes in the size of windows and the use of shading might be opportunities to

Table 12
Impact of technical measures for dwelling renovation for renewable energy options on the spatial quality determinants.

Renewable energy options and spatial quality determinants				
Building refurbishment – dwellings Technical measures	View	Internal spatiality and spatial arrangements	Transition between public and private spaces	Perceived density, built and human densities
Renewable energy options				
Photovoltaic re-cladding panels and roof tiles[a] Photovoltaic opaque PV used as shading devices[a]	Measures can lead to changes on: A. Facade transparency (A.1) B. Depth of vision (B.1, B.3a) C. Distance and degree of sight protection (C.1a, C.1b, C.2) D. Lighting	E. Lighting (E.1c, E.2b, E.2c, E.3b, E.3c)	D. Uniformity and coherence of boundaries	A. Principle of complexity (A.1c)

[a] Measures described in Baker (2009).



Graph 9. The impact of dwelling renovation (Baker, 2009; Burton, 2012; Giebeler et al., 2009) per building component on the four spatial quality determinants.

improve the facade composition. The use of shading devices and vegetation can offer the possibility to create outdoor staying areas and therefore improve social control and human interaction. This development opens up many possibilities towards sustainable practice in building renovation as well as towards the exploration of building renovation alternatives that focus primarily on the end user rather than on technical and economical concerns.

The spatial quality assessment (Tables 1–4) consists of the other main result of the paper. The assessment enables the comparability between the diverse technical measures related to spatial quality impact, and among the spatial quality determinants. After the analysis of the impact of energy renovation on spatial quality, the weighting initially adopted for each spatial quality determinant (25% per determinant of a total of 100%) remains unchanged. That is, the determinants have the same significance to the analysis of spatial quality; therefore the weighting of the four spatial quality determinants is expected to be the same. This is because the study indicates the real impact of energy renovation on spatial quality. The weighting of the sub-determinants and features (Tables 1–4) might vary according to the renovation case and context. The assessment provides an indication of how user-friendly in terms of spatial quality, the energy renovation can be for a dwelling. The assessment is intended to be used before the renovation, during the plan phase and after the renovation in order to evaluate the improvements and declines in the dwelling regarding spatial quality.

4. Conclusion and further work

The study explores the impact of energy renovation in domestic buildings with the aims of identifying the consequences of the renovation to spatial quality as well as of developing a spatial quality assessment. Energy renovation affects spatial quality in dwellings and its impacts should not be overlooked, mainly considering the actual incentives to the whole building approach of the deep renovation strategy. This study has three key messages to be considered for further work:

1. The study proposes a set of guiding principles that help design professionals and users to integrate spatial quality in energy renovation of dwellings.
2. The spatial quality assessment is context dependent at the same time as it leaves designers, developers, and building owners freedom for designing.
3. This work is carried on considering the actual tendency of energy renovation of dwellings towards non-technical concerns. This tendency is an opportunity that design professionals, building owners, end users and public and private developers should not overlook in the years to come.

The assessment is unlike to be a final product; rather, it is open for further development and improvements. Therefore the next step is to assess cases of dwelling renovation to improve the spatial quality definition and to further develop the assessment. These cases will be assessed preferably during the design phase of the renovation. This is because the design phase is the phase prior to the construction when there are more chances for interventions in the project in comparison to the construction phase. There is a higher potential to improve spatial quality in the dwellings when spatial quality is considered in the early stages of the renovation process.

The results of this study indicate that spatial quality concerns might have influence energy renovation in dwellings and encouraged building owners to undertake energy renovation. These two hypotheses are going to be explored in future work. The evidence of the spatial quality's influence of on energy renovation is that many of the measures taken in energy renovation, which affect spatial quality, are not necessarily related to energy concerns. Examples are the addition of a green roof, internal changes in the plan and the addition or demolition of buildings, though they could potentially be related to energy matters. Green roofs add thermal mass to the roof and therefore they contribute to cooling. Internal changes in the plan can result in a more efficient zoning regarding sun orientation and space use, decreasing the use of artificial lighting and heating. Also the demolition of poorly insulated buildings can lower the energy demands in an urban block. However, these measures that are not directly related to energy issues might have encouraged user's receptiveness towards energy renovation.

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Appendices

Appendix 1
Description of technical measures and their characteristics for floors.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Floors		
Solid concrete ground floors[a]	Insulation applied above existing concrete floors	Insulation on the top of the slab, timber battens at thresholds with metal nosing, vapour-control layer on the insulation, chipboard flooring and floor
	Insulation applied above new concrete floors	Damp-proof membrane, rigid insulation on the top of the slab, chipboard flooring and floor
	Insulation applied bellow new concrete floors	Sand bedding, damp-proof membrane, rigid insulation, concrete floor slab, floor and floor
Suspended timber ground floors[a]	Insulation applied to the upside of the floor boards	Flooring joints sealed, floor, insulation, netting to support insulation, timber joists
	Insulation applied to the underside of the floor boards	Floor, insulation, timber joists, plasterboard in the basement
	Insulation applied between the joists	Floor, insulation between timber joists, plasterboard in the basement
Intermediate floors[b]	Insulation is not relevant	Insulation is not relevant considering heat losses. However, acoustic insulation might be needed

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

Appendix 2
Description of technical measures and their characteristics for external walls.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
External walls		
External solid walls with external insulation[a]	Wet render system	Consists of insulant, fixings, base coat render with glass fibre plastic or metal mesh, and a top-coat render with or without a finish
	Dry cladding system	Consists of supporting framework or cladding fixing system fixed to the wall, ventilated cavity, breather membrane and cladding material. Useful where existing appearances (architectural features) need to be maintained
External solid walls with internal insulation[a]	Laminated insulation board fixed directly to the wall	Plasterboard laminated to insulation board, rigid closed cell insulation fixes with special fastening and adhesive
	Rigid insulation between battens fixed to the wall	Plasterboard, vapour check, rigid or semi-rigid insulation boards between the battens
	Frame with insulation leaving an 30 mm air gap between insulation and the wall	plasterboard, vapour control layer, insulation and 30 mm min air gap
	Cavity fill for existing brick and block cavity walls	insulation injected into the wall cavity
Addition, extension or removal of balconies risk of cold bridging[a]	Cantilevered balconies can result in serious cold bridges and are difficult to treat. Using insulated windows frames, applying some insulation to reveals, returning insulation along party walls, and insulating any mechanical fixings will overcome this problem	Where good insulation levels are applied in a house, uninsulated areas such as window frames and reveals and party walls can become cold bridges and attract condensation when internal humidity is high, which can lead to damp and mould growth

[a] Measures described in Burton (2012).

Appendix 3
Description of technical measures and their characteristics for roofs.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Roofs		
Roof insulation at ceiling level[a]		Plasterboard ceiling, insulation between joists, insulation above joists, cables lifted above insulation
Roof insulation at rafter level[a]		Plasterboard ceiling, vapour barrier, insulation between rafters, rigid insulation, 50 mm air gap
Insulation of flat roofs[a]	External roof insulation: Insulation above the roof structure (warm roof system)	Known as warm roof system, in order to avoid interstitial condensation. It consists of vapour check, rigid insulation, waterproof layer with reflective paint
	External roof insulation: Insulation above the roof structure (inverted warm roof system)	Known as inverted warm roof system, in order to avoid interstitial condensation. It consists of water proof layer, rigid insulation, vapour check and structural roofing (gravel or concrete tiles)
	Internal roof insulation: Insulation below the roof structure (cold roof system)	Known as cold roof system, where it is not possible to construct a warm roof system. It consists of insulation applied under the roof structure, vapour barrier and ceiling. External water proof membrane applied on the roof structure
Insulation of flat roofs[b]	Green roofs	Green roofs add thermal mass and evaporative cooling but considering that they are not a good thermal insulation, they should only be used as an option for the replacement of the original vegetation replaced by the refurbishment

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

Appendix 4
Description of technical measures and their characteristics for windows.

Building refurbishment – dwellings		
Technical measures		Technical characteristics
Windows		
Reduction or increase of framing[a]		Reduction or increase of framing to improve light and view conditions
Installation of a secondary glazed screen (second skin)[b]		It consists of high performance glazing screen and thermally insulated framing inside or outside (weathering layer). It affects the appearance either from inside or outside or in both sides
Replacement of the glazing and the framing system[b]		Existing elements replaced by high performance glazing and thermally insulated framing
Reduction or increase of existing aperture/ glazed area[a]		Changes of the aperture area to improve daylight conditions, as for example reduction of heat loss and unwanted solar gain, provision of more wall space for furnishings and equipment.[b] Changes of aperture area is applied as a last option. Before other causes for poor daylight performance should be eliminated first, e.g. low transmission of glass, obstruction due to framing or poorly designed fixed shading devices, low reflectance of interior surfaces or internal obstructions
Changing the distribution of glazing by making new apertures to improve daylight distribution[b]		
Implementation of shading[b]	Implementation of external shading	It can be fixed, adjustable or retractable, e.g. overhangs, louvres, vertical fins, blinds and perforated screens (superior thermal performance)
	Implementation of internal shading	It consists mostly of louvres (venetian blinds) and roller blinds (translucent or opaque)
	Implementation of integrated shading	It addresses daylight distribution function as well as selective shading

[a] Measures described in Burton (2012).
[b] Measures described in Baker (2009).

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Spatial Quality Determinants for Residential Building Renovation: A Methodological Approach to the Development of Spatial Quality Assessment

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Spatial Quality in Building Performance Assessment Tools, The case of Dwelling Renovation for Energy Efficiency

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Spatial Quality in Building Performance Assessment Tools

The case of Dwelling Renovation for Energy Efficiency

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Abstract: *The contribution of this paper is to analyse the availability of spatial quality assessment in two major building performance assessment tools that are used in Europe considering dwelling renovation: the Building Research Establishment Environmental Assessment Method UK 2008 (BREEAM UK 2008) and the Sustainable Buildings Tool (SBTool 2012). Spatial quality contributes to people's well-being and quality of life and therefore its inclusion in renovation processes gives arguments that may increase stakeholders' receptiveness to and investments in energy-efficiency renovation. This paper reveals part of the gap and the conflict between technical and non-technical dimensions in the tools, and suggests opportunities for improvement in terms of validity, reliability, sensitivity and specificity of the spatial quality assessment. Due to their relevance to (1) and wide-ranging cover of the building process, tools open up an opportunity to implement spatial quality assessment in dwelling renovation. Including more and better spatial quality indicators in the tools can contribute to raising awareness of the importance of this issue among design professionals and decision makers, and provide additional incentives for energy efficiency.*

Keywords: spatial quality, building performance assessment tools, BREEAM UK 2008, SBTool 2012, non-technical dimensions, energy renovation of residential buildings

1. Introduction

The two elements under consideration in the study are introduced in this section. The first element is spatial quality and the second element is the assessment of spatial quality available in actual building performance assessment tools used for dwelling renovation. In this section we first summarise the definition of spatial quality (2). Second, we introduce the analysis of building performance assessment tools for spatial quality assessment. We analyse two assessment tools for dwelling renovation: BREEAM (Building Research Establishment Environmental Assessment Methodology) UK 2008 for Major Refurbishment and Multi-residential Use, and SBTool (Sustainable Buildings Tool) (2012). The aim is to find out whether these tools include spatial quality and how effective they are in assessing spatial quality. BREEAM UK 2008 and SBTool (2012) have been selected for this study because of their relevance in the building industry in Europe.

The definition of the term spatial quality results from the literature review, which resulted in diverse approaches to spatial quality on the building scale being found (2). The result of the review of the literature on spatial quality is the setting up of and the definition of four determinants: (I) views, (II) internal spatiality and spatial arrangements, (III) the transition between public and private spaces and (IV) perceived, built and human densities (2).

The main topics of the spatial quality determinant of (I) view are: (a) the view from the inside to the outside of dwellings and from the outside to the inside (visual privacy), (b) distances between public and private domains and (c) view quality. The second determinant of (II) internal spatiality and spatial arrangements consists of the analysis of (a) the articulation between space and its boundaries, and between adjacent spaces, (b) the privacy within the dwelling and (c) light (access of daylight) (2). In (III) the transition between public and private spaces, the main topics for analysis are (a) physical barriers between public and private spaces, (b) outdoor private spaces and (c) the facade composition and permeability. The last spatial quality determinant of (IV) perceived, built and human densities considers (a) block physical boundaries, (b) the height-to-width ratio of internal block spaces and the sense of enclosure and (c) functions in the block, and built and human densities (2).

We found that spatial quality is already indirectly considered by BREEAM UK 2008 and SBTool (2012). Both tools have indicators whose issues of concern are directly related to the spatial quality definition (2), for example the fact that these tools consider the assessment of views and outdoor private spaces. This indicates the actual awareness of the relevance of non-technical dimensions such as spatial quality as well as of the potential for improvement of the tools in order to assess non-technical dimensions.

Assessment tools are designed to measure performance, and they are not necessarily the best options for guiding and promoting changes in design, despite their current influence in building processes (3). They concentrate on assessing diverse issues through metrics, checklists, scores and ratings. Most of the literature on building performance assessment tools concentrates on the technical character of the tools that indicate a ‘preference for clearly measurable outcomes’ (4, p. 131). Nevertheless, the inclusion of non-technical dimensions and the influence of the tools on stakeholders are as relevant as technical issues in the promotion of a sustainable building environment. Due to the widespread use of the tools, and the importance and diversity of the categories assessed, they constitute an opportunity to include and promote non-technical dimensions such as spatial quality.

2. Spatial Quality Assessment in Practice

We analysed two building performance assessment tools in the search for a spatial quality-related assessment. The sources considered for the analysis of the tools BREEAM UK 2008 for Major Refurbishment and Multi-residential Use, and SBTool (2012) are the official guidelines, the Excel® sheets and websites. For the purpose of this study BREEAM UK 2008 was calibrated to assess major refurbishment of multi-residential use. The generic version of the SBTool (2012) was calibrated to assess dwelling renovation. We considered the SBTool’s maximum scope, which is the full version with all criteria assessable in the tool.

The tools BREEAM 2008 and SBTool (2012) assess the environmental performance of buildings using sets of indicators organised into diverse categories. According to the World Health Organization (WHO) (5), an ideal indicator should have the scientific characteristics of (I) validity (it has to measure what it is possible to measure); (II) reliability (repeated measurements by different observers have to result in similar values for the same indicator); (III) sensitivity (the ability to capture changes); and (IV) specificity (only reflecting changes in a particular situation). Indicators are generic and are only intended for assessment; they consist of a description of data that have no positive or negative values associated with them (6). The context and the aim of the assessment lead to the definition of values for the assessment.

The term spatial quality is not mentioned in the tools BREEAM UK 2008 for Major Refurbishment and Multi-residential Use or SBTool (2012). However, the tools do in fact consider elements of spatial quality (Table 1) (2). The construction industry has been influenced by building performance assessment tools (4). This is because the tools function as guidelines for design teams regarding the dimensions that need to be considered in the construction process. This indicates the potential of the tools to include non-technical dimensions, such as spatial quality, in the construction and design process.

Table 1. Overview of the spatial quality related indicators in the tools BREEAM UK 2008 for Major Refurbishment and Multi-residential Use and SBTool (2012). The indicators are classified according to their relation to the four spatial quality determinants (2).

<table>
<tr><th>Assessment Tools →
Spatial Quality Determinants ↓</th><th colspan="2">BREEAM 2008 Major Refurbishment/ Multi-residential Use</th><th colspan="2">SBTool (2012)</th></tr>
<tr><td>Views</td><td>Hea[1] 2
View Out</td><td rowspan="2">Hea 1
Daylight</td><td>F1[4] Social Aspects
(Visual Privacy)
F3 Perceptual
(View Out)</td><td rowspan="2">F1 Social Aspects
(Sunlight)
D3[5] Daylight/ Illumination</td></tr>
<tr><td>Internal spatiality and spatial arragements</td><td>*</td><td>*</td></tr>
<tr><td>Transition between public and private spaces</td><td colspan="2">Hea 15 Outdoor Space
Ene[2] 18 Drying Space</td><td colspan="2">F1 Social Aspects (Private Open Space)</td></tr>
<tr><td>Perceived, built and humand densities</td><td colspan="2">LE[3] 1 Land Reuse</td><td colspan="2">A2[6] Urban Design (Efficiency of Land Use)</td></tr>
</table>

*Spatial quality feature not considered by the tool.

[1]Category Health and Well-being (Hea)

[2]Category Energy (Ene)

[3]Category Land Use and Ecology (LE)

[4]Category F Social, Cultural and Perceptual Aspects

[5]Category D Indoor Environmental Quality

[6]Category A Urban Design, Efficiency of Land Use

BREEAM UK 2008 for Major Refurbishment and Multi-residential Use
Views, daylight and outdoor private spaces are the spatial quality related topics considered by BREEAM UK 2008. The assessment associated with the spatial quality determinants of (I) views, (II) internal spatiality and spatial arrangements and (III) the transition between public and private spaces is included in the categories of Health and Well-being (Hea) and Energy (Ene). The issues related to views are Hea 2 View Out and Hea 1 Daylight. Daylight is the only issue related to the spatial quality determinant of internal spatiality and spatial arrangements in BREEAM UK 2008.

Transitions between public and private spaces appear in the issues Hea 15 Outdoor Space and Ene 18 Drying Space. The provision of outdoor amenity space both for private and collective use is recommended in the indicator Hea 15 and Ene 18. However, the provision of outdoor spaces in Ene 18 is only in order to provide space for drying clothes. The spatial quality determinant of (IV) perceived, built and human densities is taken into consideration in the category of Land Use and Ecology, issue LE 1 Land Reuse. However, the issues Hea 1 Daylight, 2 View Out, 15 Outdoor Space and LE 1 Land Reuse are not included in the list of minimum standards that must be attained in order to achieve a BREEAM rating (7). Furthermore, only the issue Hea 1 Daylight is included among the BREEAM credits required for a project to be considered as innovative (7).

SBTool (2012)
Views, visual privacy, daylight and outdoor private spaces are the spatial quality related topics considered by the SBTool (2012). The assessment associated with the spatial quality determinants of (I) views, (II) internal spatiality and spatial arrangements and (III) the transition between public and private spaces is included in two categories: (F) Social, Cultural and Perceptual Aspects and (D) Indoor Environmental Quality.

The criteria related to views are F1 Visual Privacy and Sunlight and F3 View Out. Measures to increase visual privacy are recommended in the sub-criterion SBTool F1.3 Visual Privacy. In this sub-criterion F1.3, the indicator consists of the analysis of visual privacy through the number of openings to exterior views and their placement on the facade. In the indicator of the sub-criterion SBTool F1.2 Sunlight, the access of direct sunlight is measured by the percentage of 'dwelling units whose principal daytime living areas have direct sunlight for at least 2 hours per day' (8, tool spreadsheet1). The indicator considers the most unfavourable time of the year, 12 noon at the winter solstice. The evaluation relies on the design documentation. The indicator of the sub-criterion SBTool F3.7 Access to Exterior Views from the Interior deals with the view quality, the presence of nature and distances between exterior artefacts and the viewer.

The criterion D3 Daylight and Illumination is both related to views and to internal spatiality and spatial arrangements. The indicator of the sub-criterion SBTool D3.1 Daylighting analyses the appropriate day lighting (daylight factor) in primary occupancy areas on the

[1] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12

ground floor of buildings. SBTool D3.1 is the only sub-criterion that is part of the minimum mandatory criteria. Transitions between public and private spaces are considered in the criterion F1 Private Open Space. The indicator of the sub-criterion SBTool F1.4 Private Open Space measures the private and collective outdoor spaces in square meters (m^2). It also considers the percentage of homes 'that have attractive and usable private outdoor areas' (8, tool spreadsheet[2]).

Determinant (IV), perceived, built and human densities, is taken into consideration in the category of (A) Site Regeneration and Development, Urban Design and Infrastructure, criterion A2 Urban Design, Efficiency of Land Use. The indicator of sub-criterion A2.1 Land Use measures the built density expressed as the ratio between the gross floor area achieved by the design and the maximum permitted gross floor area on the site (8, tool spreadsheet[3]). All the spatial quality related sub-criteria are active by default in the design and operational phases of the renovation project, except for sub-criterion A2.1 Land Use Efficiency, which is not active in the operational phase. However, none of the spatial quality related sub-criteria are automatically active in the pre-design phase.

3. SBTool (2012) and the Potential for Development of Spatial Quality Assessment

In this section, the sub-criterion SBTool F3.7 Access to Exterior Views from the Interior is presented as an example of the analysis made of the available indicators of SBTool for spatial quality assessment. The analysis also indicates the potential for development of spatial quality assessment in the SBTool.

Indicator evaluation

Name/description: Sub-criterion SBTool F3.7 Access to exterior views from interior

- Definition/description of sub-indicators/units. 'Visual quality of exterior artefacts or natural objects and their distances from the viewer'; this can be measured in meters (m).[4] Sub-criterion F3.7 is not a mandatory in the assessment.
- Principles of classification. 'To assess the quality of exterior views available to an observer located in an interior space of a main occupancy'.[5]
- Assessment. Comparability: The indicator fulfils the requirements of comparability because of the use of scores from -1 to 5. Assessment method: Analysis of the floor plans prepared by the design team only; Applicability: The indicator is applicable to two-dimensional assessment. The assessment is performed in the design phase only.

The indicator does not specify what is meant by quality of exterior views or visual privacy. It bases its assessments on subjective concepts that give space for individual interpretations, such as: 'views are unacceptably ugly', 'visually acceptable', 'features of considerable

[2] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12
[3] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12
[4] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12
[5] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12

interest' and 'natural features that are visually attractive'.[6] The indicator does not follow the scientific characteristics of an indicator of validity, reliability, sensibility and specificity (5) because the assessment is based on subjective concepts.

Furthermore, the sub-criterion to which the indicator belongs has a weight of only 0.24% out of 1.7% (criterion weight), the assessment is not considered mandatory, and the scale of the assessment is limited. The weight of 1.7% for the criterion F3 Perceptual is also low for its category, considering its impact on spatial quality. The building is the only object of the assessment, although the configuration of the block in which the building is located influences substantially the visual quality and distances between public and private domains. The status of the indicator indicates the potential for cooperation between SBTool and BREEAM in the development of indicators for assessing exterior views.

The score method offers reliable results for comparability, but the assessment method does not because the scores are given based on subjective assessment, such as views that are 'unacceptably ugly'.[7] The assessment uses only floor plans (two-dimensional), which, considering the complexity of visual quality and visual privacy, indicates the limitation of the assessment. The source of information for the assessment is also limited. The only material considered is that supplied by the design team; site visits done by external people are not mentioned.

4. Conclusion and Further Work

The results of the analysis of BREEAM UK 2008 for Major Refurbishment and Multi-residential Use and SBTool (2012) indicate the deficiency of these tools in assessing spatial quality. First, the study indicates that spatial quality is partially considered by BREEAM UK 2008 and SBTool 2012. Second, it indicates that the spatial quality related indicators available in these tools consist essentially of recommendations rather than sufficiently developed indicators. This is because these indicators do not fulfil the level of development necessary to be considered effective indicators according to the definitions of WHO (5) and ISO21929-1 (6). The most relevant limitation of both tools is the lack of definitions. For example, the indicators related to the access to exterior views in both tools consist of only recommendations about the need for an 'adequate view out' (BREEAM UK Hea 2) or the relevance of 'visual quality' (SBTool F3.7). Neither further direction nor clear assessments and definitions are given. However, SBTool (2012) does include visual privacy, while this is not mentioned in BREEAM UK 2008.

The analysis of BREEAM UK 2008 and SBTool (2012) indicates their large potential for the improvement of validity, specificity, sensitivity and reliability in assessing spatial quality. The results of this paper are the departure point for the development of new indicators and the improvement of existing ones to integrate spatial quality assessment into the renovation of dwellings. SBTool's spatial quality related indicators more often fulfil the requirements of the

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[6] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12
[7] SBTool Excel® spreadsheet SBT12_A_Generic_Max_3_Dsn_30Oct12

scientific characteristics of an ideal indicator than indicators of the same category in BREEAM UK 2008. For example, the sub-criteria SBTool F1.2, F1.3, F1.4 and F3.7 have indicators that measure percentages, metres and square metres (validity). That is, repeated measurements by different observers result in similar values of the same indicator (reliability). An indicator that has some kind of measurement can capture changes (sensitivity), because measurements can be taken repetitively, and changes in measurements are particular to a specific situation (specificity). BREEAM UK 2008 considers the spatial quality related assessment throughout the entire building process, whereas SBTool (2012) considers it only at the design and operational stages for dwelling renovation.

This research is connected to the ZenN project Nearly Zero Energy Neighbourhoods funded by the European 7th Framework Programme (grant agreement no: 314363), Work Package 4 Non-Technical Drivers. The ZenN project aims to 'demonstrate the advantages and affordability of energy efficiency renovation, and to create the right context to replicate this experience around Europe' (9). The goal of the WP4 is to support the success of energy-efficiency strategies in dwelling renovation by optimising the synergies between technical and non-technical dimensions, to which spatial quality belongs.

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Spatial Quality Assessments for Building Performance Tools in Energy Renovation

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Spatial Quality Assessments for Building Performance Tools in Energy Renovation

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ABSTRACT: This study explores existing technology that has the potential to assess defined spatial quality parameters. This paper focuses on the parameters of *views, isolation* and *contact*. The goal of this research is to develop indicators that best assess spatial quality. Suitable indicators enable the implementation of spatial quality assessment in building performance assessment tools. Examples of good indicators for *views, isolation* and *contact* consider visual openness and visual privacy to assess view quality. In future research, the spatial quality indicators developed here will be applied to case studies in the European context. Once they have been established, the indicators can be implemented in the building performance tool SBTool to improve spatial quality assessment in energy renovation. Improved spatial quality is one argument that provides stakeholders with justification for increasing investments in energy renovation because it contributes to individuals' well-being.

1 DEFINITION OF SPATIAL QUALITY

1.1 *Spatial Quality Parameters*

The existing literature shows that spatial quality is difficult to define because it embraces diverse features of various natures. The term is among the core concepts in urban planning and policy (Moulaert 2011). However, the definition of spatial quality needs to be reduced to the scale of the building because spatial interventions at the urban macro scale affect the micro scale of the building considerably. The work of Rapoport (1994a) set the departure point of the literature study. Several authors, including Alexander and Ishikawa (1978), Ashihara (1981), Gehl (2010, 2011), Lynch (1960), Moulaert (2011) and Weber (1995), also contributed to the definition of spatial quality. The boundaries of the study of spatial quality were defined through parameters, that define a system or sets the conditions of its operation (Oxford Dictionary). Thus, the range of definitions for spatial quality is bounded by the parameters defined according to the literature study.

In addition to the literature study on the definition of spatial quality, energy measures used in building renovation were also analysed. The goal was to define the spatial quality parameters that are most impacted by energy renovation. The following spatial quality parameters were defined according to the literature study: *views, isolation, contact, internal and external spatial arrangements, transition between public, semi-public, semi-private and private spaces, and perceived and built densities* (Pacheco 2013a). This paper concentrates on the *views, isolation* and *contact* parameters. These parameters are represented by visual openness and visual privacy and are affected by distance and the viewing angle (Gehl 2010, Indraprastha 2012). The possibility of encounters and visual interaction varies considerably according to the body distance and viewing angle.

2 SPATIAL QUALITY ASSESSMENT

2.1 *Spatial quality parameters, energy renovation and the building performance tool SBTool*

This paper focuses on the relation among the *views, isolation* and *contact* parameters for spatial quality and the energy renovation measures that consider the walls and windows of a building. The energy renovation measure of *changing the glazing distribution by new apertures* (Barker 2009) can exemplify the types of relations proposed. The aperture of the window and its placement in the façade are adjusted to improve the distribution of daylight (Barker 2009). The daylight distribution affects the *views, isolation* and *contact* parameters because it influences the visual openness and visual privacy of the building (Pacheco 2013a, b).

The SBTool Generic System (version 2012) building performance tool is considered for the analyses of the spatial quality indicators. The tool is "a generic framework for building performance assessment that may be used by third parties to develop rating systems that are relevant for a variety of local conditions and building types" (Larsson 2012). Despite its generality, "the SBTool is based on the philosophy that a rating system must be adapted to local conditions before its results can become meaningful" (Larsson 2012). We worked with the complete "developer version" of SBTool, which considers all of the criteria to be used by the core project team. The SBTool performs assessments through *focused variants*. The indicators considered related to spatial quality belong to the variant *Social and Perceptual Issues*.

2.2 *Definition of Indicators*

One of the main goals of this study is to develop spatial quality indicators at the building scale. The objective is to improve the assessment of spatial quality using the building performance tool SBTool. Thus, an indicator needs to be defined according to reliable literature.

The international standard ISO21929-1 (2011) states that an indicator has three main functions: quantify, simplify and communicate. Indicators can be used to define goals, monitor changes and illustrate a tendency. According to the World Health Organization (WHO), an indicator has the following scientific characteristics:

Validity: the indicator measures what it is possible to measure;

Reliability: the assessment provides similar results when repeated by different observers;

Sensitivity: the indicator is able to recognise changes; and

Specificity: the indicator reflects changes in specific circumstances.

The outcomes of the assessment given by indicators are not perfect; indicators provide an approximation of an actual situation. Thus, indicators are useful for assessments because no positive or negative values are associated with the outcomes. The aggregation of value results from the interpretation and analysis of these outcomes.

2.3 *Spatial Quality Indicators in the Building Performance SBTool*

The SBTool has two indicators for assessing the spatial quality parameters of *views, isolation* and *contact.* Both indicators belong to the Social, Cultural and Perceptual Aspects category (F):

SBTool F1.3 – "Visual privacy in principal areas of dwelling units. Indicator: The percentage of dwelling units whose bedroom and living areas are open to horizontal or downward views from a point within 20 m of the exterior windows" (Larsson 2012); and

SBTool F3.7 – "Access to exterior views from interior. Indicator: Visual quality of exterior artefacts or natural objects and their distance from the viewer" (Larsson 2012).

SBTool F1.3 belongs to the Social Aspects criterion (F1), and SBTool F3.7 belongs to the Perceptual Aspects criterion (F3).

The energy renovation measure of *changing the glazing distribution by new apertures* (Barker 2009) exemplifies the potential for using these indicators (SBTool F3.7 and F1.3) to assess spatial quality. This renovation measure affects the *views, isolation* and *contact* parameters because it influences the visual openness (or visual contact) and thus the level of privacy (Rapoport 1994b, Gehl 2010). Visual openness in terms of visual contact and privacy is the main focus of these SBTool spatial quality indicators. Thus, these indicators have the potential to evaluate the effect of *changing the glazing distribution by new apertures* on the *views, isolation and contact* parameters (Pacheco 2013b).

The indicators analysed here primarily offer recommendations rather than a reliable assessment of spatial quality. Definitions are lacking, and the assessment relies on individual interpretations. These SBTool indicators do not follow the scientific characteristics required to be considered real indicators (section 2.2). However, the analysis illustrates the potential for using the SBTool to assess spatial quality.

This paper explores the existing spatial quality assessments for improving SBTool indicators F1.3 and F3.7. This exploration is presented in section 3. Visual openness and visual privacy are the main focus of both indicators. Therefore, further research on ways to assess these issues is required. Furthermore, the indicators do not define the terms "visual quality of external views" and "privacy levels", which constitute the backbone of the assessment proposed by these indicators.

3 EXPLORATION OF SPATIAL QUALITY ASSESSMENTS ON VISUAL OPENNESS AND VISUAL PRIVACY

3.1 *Potential of spatial mapping and 3D modelling*

The spatial quality indicator to be developed focuses on assessing the spatial quality parameters of *views, isolation* and *contact* (section 1.1). The issues of concern are visual openness and visual privacy, both of which are assessed in two approaches, following the mapping model proposed by Indraprastha (2012). The first approach considers the visual distance (in meters), and the second approach considers the viewing angle. Indraprastha's (2012) mapping model evaluates visual openness and visual quality through a mathematical approach (see the appendix). The model starts by defining the geometrical centre point of a room. A Cartesian grid is proposed, with its origin at this centre point. Then, the edges of the apertures of doors and windows are projected perpendicular to both the vertical (y) and horizontal (x) axial lines. The space is subdivided in enclosed spaces according to the projections on the x and y axial lines. The geometrical centre point of each enclosed space is determined and numbered (figure 1).

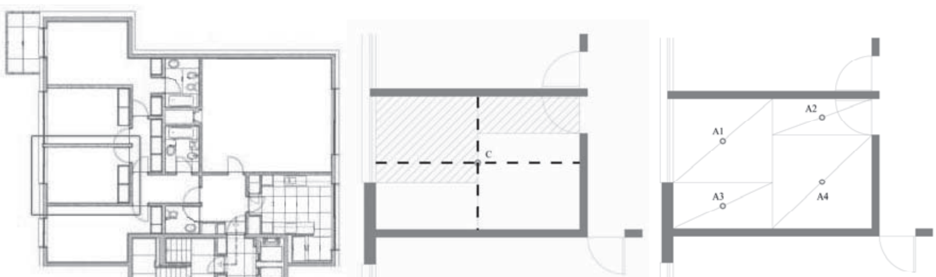

Figure 1. Boa Vista House, architect: Alvaro Siza, Porto, Portugal. Subdivision of a sleeping room in enclosed spaces and placement of the geometrical centre point *A* of each enclosed space considering the projection of the openings (door and window) on the vertical axial line *y*

Centricity is among the *principles of figural segregation* defined by Weber (1995). Considering the relevance of the concept of centricity in Indraprastha's model (2012), centricity is the only figural segregation principle considered here. According to Weber (1995), space is perceived "both as the corporeality of physical objects and the shape of the void these objects create". The architectural space is "the void between walls and buildings" that "can assume the quality of a perceptual figure" (Weber 1995). Weber defines and exemplifies the shape of the void in the *principles of figural segregation* considering three-dimensionality. The author refers to these principles as only applicable to "*clearly defined spaces*", which possess the figural character of an enclosed shape with subordinate boundaries. According to Weber (1995), *centricity* is not necessarily the geometrical centre of a shape, but it is the perceptual centre. The perceptual centre considers the dynamics of the interaction between the subordinate boundaries of a shape (walls) and the openings (windows and doors).

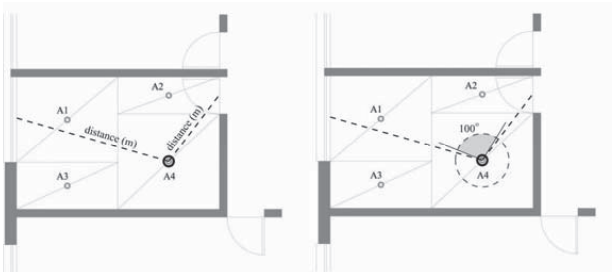

Figure 2. Boa Vista House, architect: Alvaro Siza, Porto, Portugal. Distance (m) and maximum viewing angle of 100° between the geometrical centre point *A4* of the enclosed space to the midpoint of the openings.

The assessment of the spatial quality issues of visual openness and visual privacy follows Indraprastha's mathematical approach (2012), which is presented in the appendix of this paper.

Visual openness. Three variables are defined to calculate visual openness (see the appendix):

- Visual distance: the distance between the geometrical centre point *p* of an enclosed space and the midpoint of the openings (doors and windows).
- Transparency ratio: the ratio between the area of the openings and the area of the wall where the opening is placed.
- Viewing area: the ratio of the viewing area from the geometrical centre point *p* of an enclosed space, considering a maximum viewing area of 100°.

Visual privacy. The calculation of visual privacy considers two distinct methods: the average value of privacy both by distance and by viewing area. In the method of calculating privacy by distance, the distance from a point *p* to the opening determines the level of privacy. The method of calculating privacy by viewing area considers how many windows and doors are covered by the viewing angle, where the privacy is lower if more openings are covered (a geometrical centre point *p* is more visible from outside when the viewing angle covers many openings) (see figures 1 and 2 and the appendix).

In the Indraprastha model (2012), the results of the analysis are interpreted as follows:

- Visual openness index: the visual openness index decreases with an increasing average distance from a geometrical centre point *p* to the windows and increases with an increasing viewing angle at *p* covering all of the windows.
- Visual privacy index: the visual privacy index increases with an increasing average distance from a geometrical centre point *p* to the windows and doors and decreases with an increasing viewing angle at *p* covering all of the windows and doors.

The visual openness and visual privacy indexes are calculated for each enclosed space: "the term visual openness index refers to the level of visual influence at a center point *p* of a subdivided enclosed space", and visual privacy refers to the presence of a point *p* in bounded area as "a result of being viewed from external spaces" (Indraprastha 2012).

In the proposed method, the results of both approaches (the visual distance and viewing angle) are combined to obtain an average weight of visual openness and visual privacy. The average is found for the geometrical centre point *p* of each enclosed space (figures 1 and 2). The result can be used to both explore design alternatives and analyse the impact of design changes.

4 RESULTS

This section presents a short summary of the potential technology and literature on spatial quality reviewed in this research. Some of the current technologies for assessing the spatial quality parameters of *views, isolation, and contact* are presented below.

The Indraprastha (2012) model is integrated as part of the spatial quality assessment. The assessment consists of spatial quality indicators, which are developed and integrated into the building performance tool SBTool. The model is expected to contribute to the assessment of the impact of energy renovation on spatial quality parameters (section 1.1). The Indraprastha (2012)

CAD-based mapping model analyses the interior spaces with accurate computer simulation. However, the model has limitations. According to Indraprastha (2012) the model does not consider the height of the ceiling. In addition, the restriction of analysing visual openness and visual privacy considering only the interior spaces is a potential topic for future research (section 5).

Indraprastha (2012) considers the openings (windows and doors) to be highly influential on the visual openness and privacy assessments: “spatial quality evaluation depends on the layout configuration of the openings that made up the spatial mapping as we developed”. The main contribution of the Indraprastha (2012) model to spatial quality assessments is the distribution of the openings’ influence to each enclosed space considering their location in the room. Furthermore, the method is efficient in defining the geometrical centres of the enclosed spaces, thus allowing the analysis to obtain reliable results more quickly than when implementing, for example, a raster method.

The concept of centricity presented by Indraprastha (1995) corresponds with Weber’s (1995) *principles of the figural segregation of centricity*. Centricity is related to the centre of a shape (Weber 1995). Nevertheless, the centre is not necessarily the geometrical centre of a shape but rather the perceptual centre. Such a centre is defined by the convergence of forces resulting from the entire organisation of the shape and the articulation with its boundaries. A shape may have many sub-centres, but the shape is clearer if it has fewer sub-centres (Weber 1995). Indraprastha's model (2012) considers the forces resulting from the entire organisation of the shape and its boundaries by defining the geometrical centres of each enclosed space and by distributing the openings’ influence to these enclosed (sub-)spaces both geometrically and mathematically (figure 1).

Assessments of spatial quality assessment at the building scale extend beyond the building scale self (Weber 1995). Weber (1995) emphasises the impact of larger-scale elements on the perception of the space of single entities. His considerations are an inspiring departure point for developing spatial quality assessments. Indraprastha's (2012) CAD-based mapping model analyses only the interior spaces. Thus, any influence of the immediate exterior space in the interior space is not considered in the analyses of visual openness or visual privacy.

5 CONCLUSIONS AND FUTURE WORK

A spatial quality assessment is being developed in the research to which this paper belongs. Visual openness and visual privacy are among the topics considered using the proposed spatial quality parameters (section 1.1). Spatial quality indicators for both visual openness and visual privacy will be developed. These indicators can be used with the building performance tool SBTool to assess the impact of the energy renovation measures on spatial quality, such as the impact of the energy renovation measure of *reduction of aperture area* on the spatial quality parameters of *views, isolation* and *contact* (section 2.1). This impact will be analysed considering the impacts of energy renovations. The indicator can also be used to explore refurbishment alternatives considering their impact on spatial quality.

Weber's *principles of figural segregation* (1995) will contribute to the analysis of the results of the spatial quality assessment to be developed by future research.

A review of the literature on the definition of spatial quality shaped our needs and priorities in developing a spatial quality assessment. From this review, we identified both the potential and need to complement the Indraprastha model (2012). Following Weber’s (1995) consideration that spatial quality assessment at the building scale extends beyond the building scale self, the Indraprastha model (2012) needs to be extended to include the immediate exterior space adjacent to the external boundaries. The inclusion of the exterior space enables a complete assessment in terms of the analysis of visual openness and visual privacy. Ways of providing visual and systematic spatial quality analysis that are able to connect with and complement the Indraprastha model (2012) will be explored, and spatial quality indicators will be proposed.

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APPENDIX

The procedures for measuring the visual openness and visual privacy indexes for each geometrical centre point *p* are explained below in seven steps (Indraprastha 2012).

- VO: Visual openness

  1. Calculate the average distance (D) between point *p* and the windows:

$$\bar{D}_p^{vo} = \frac{\sum_{i=1}^{n} dW_{ip}^{vo}}{n} \tag{1}$$

  2. Calculate the visual openness strength of influence at point *p* using the distance method:

$$\overline{VO}_p = Exp \frac{-\bar{D}_p^{vo2}}{\bar{D}_p^{vo}} \tag{2}$$

  3. Calculate the visual openness level using the distance method considering the transparency index of the window:

$$VO\bar{D}p = VO\bar{D}p(tr) \tag{3}$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{vo} = \frac{\theta_p}{100\circ} \tag{4}$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$VO_{\omega_p} = Exp\frac{\omega_p^{vo2}}{\omega_p^{vo}} \tag{5}$$

6. Normalise the VO level (3) and strength of influence values (5).

7. Combine the VO level (3) and strength of influence values (5) to obtain the arithmetic average:

$$VO_p = \frac{1}{2}(VO\bar{D}p + VO_{\omega_p}) \tag{6}$$

– PR: Visual privacy
1. Calculate the average distance (D) between point *p* and the windows and doors:

$$D_p^{-pr} = \frac{\sum_{i=1}^{k} dD_{ip}^{pr}}{k} \oplus \frac{\sum_{i=1}^{n} dW_{ip}^{pr}}{n} \tag{7}$$

2. Calculate the visual privacy strength of influence at point *p* using the distance method:

$$PR_p = Exp\frac{D_p^{-pr2}}{D_p^{-pr}} \tag{8}$$

3. Calculate the visual privacy level using the distance method, considering the transparency index of the window:

$$PR\bar{D}p = PR\bar{D}p(\bar{tr}) \tag{9}$$

4. Calculate the ratio of the covered angle:

$$\omega_p^{pr} = \frac{\theta_p}{100\circ} \tag{4}$$

5. Calculate the visual privacy strength of influence at point *p* using the viewing angle method:

$$PR_{\omega_p} = Exp\frac{-\omega_p^{pr2}}{\omega_p^{pr}} \tag{10}$$

6. Normalise the PR level (3) and strength of influence values (5).

7. Combine the PR level (3) and strength of influence values (5) to obtain the arithmetic average:

$$PR_p = \frac{1}{2}(PR_{\bar{D}p} + PR_{\omega_p}) \tag{11}$$

where
dW_p = distance from the geometrical centre point *p* to the midpoint of the window;
dD_p = distance from the geometrical centre point *p* to the midpoint of the door;
aW_i = area of window i; aW_{Li} = area of the wall where window i is placed;
aD_i = area of door i; aW_{Di} = area of the wall where door i is placed;
n = number of windows; k = number of doors;
$tr_{wi} = (aW_i / aW_{Li})$ = transparency index of window i;
$tr_{di} = (aD_i / aW_{Di})$ = transparency index of door i;
θ^{vo} = visual angle at the geometrical centre point *p* having all windows covered;
ω^{vo} = visual openness ratio of the covered angle;
θ^{pr} = visual angle at the geometrical centre point *p* having all windows and doors covered;
ω^{pr} = privacy ratio of the covered angle;

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Summary

This paper consists of the conclusion of the first part of the on-going PhD research: the crossing between spatial quality definition on building scale, energy renovation measures and building performance assessments. The current paper presents the results of a *search for* and an *evaluation of* available indicators that best represent perceived spatial quality, with particular weight on energy renovation. The results of the analysis of the available spatial quality indicators show a significant potential for improvement of the indicator's basic scientific characteristics (validity, specificity, sensitivity and reliability) in assessing spatial quality. That is the indicators on spatial quality are entirely to be developed. Improved spatial quality gives decision-makers, politicians and building owners solid argumentation for increased investments in energy efficiency, making a highly visible contribution to the attractiveness and public image of a building block, as well as people's every-day life, well-being and health. This is, however, only possible if objective, measurable spatial quality indicators, assessment and design methods are available for decision-making. By stressing the architectural and user value of energy efficient renovation, this research thus aims to contribute to widespread implementation of energy efficiency goals in building performance assessments. This paper forms part of PhD research project *"Definition, Assessment and Implementation of Spatial Quality Parameters in Energy Renovation of Residential Buildings",* aiming to contribute to decision-support for the design of energy-efficient built environments with high spatial quality. The main aim of the PhD is to propose a clear definition of spatial quality to be considered in energy renovation; and to develop practical indicators to assess spatial quality parameters on building scale.
Keywords: spatial quality indicators, energy efficiency, building renovation, residential buildings, building performance assessments.

1 Spatial Quality Definition

One of the goals of this paper is to present the definition of spatial quality parameters for energy renovation of residential buildings, and their in- and outdoor environments. The concept of spatial quality is usually handled on the macro scale of the city. But deeper study on both literatures on architecture and environmental aesthetics showed that there are spatial quality parameters, which clearly address the micro scale of the building. Rapoport (1969, 1994), Alexander (1977, 1979) and Gehl (2010, 2011) are the main authors considered for the study. The following parameters are the result of the literature study on the definition of spatial quality:

1. Views, isolation and contact (access to external views and visual privacy);
2. Internal and external spatial arrangements (daylight conditions);
3. Transition between public, semi-public, semi-private and private domains (availability of semi-public/ semi-private spaces and private outdoor space);
4. Perceived density (high degree of enclosure and intricacy of spaces).

The next step is to relate these four perceptual parameters to physical measures for energy renovation of residential buildings, for buildings components as floors, walls, roofs, windows, double skins and mechanical services (see tab. 2). In order to start this work, first a review has been made of how the parameters are represented in three building performance assessments (see tab. 1 for the SBTool assessment).

2 Tools for building performance assessment

After defining the spatial quality parameters on building scale through literature study (column Literature Study on Spatial Quality Definition of table 2), the next step was to analyse the energy renovation measures for residential buildings (column Energy Efficient Measures for Sustainable Refurbishment of table 2). The goal was to identify the measures that directly affect the spatial quality parameters. Subsequently the availability was checked of assessment systems those consider and/ or evaluate the impact of such measures on the spatial quality parameters (column Building Performance Assessments of table 2). Thus the result of the initial literature study on spatial quality guided the later selection of the building assessments indicators to be further considered in the research.

The table 2 partially presents the results of the first part of the research. The table shows an example of the sort of relations identified between literature on spatial quality, energy renovation measures and building performance assessments. The example shows the relation between the energy renovation measure of *reduction of aperture* on the building component *windows*, the spatial quality parameters of *views, contact and isolation*, and the indicators belonging to the building performance assessments SBTool (indicator F1.3/ F3.7), BREEAM (indicator Hea 2.) and LEED (indicator IEQ Credit 2.4). These indicators are considered to fulfil the assessments on visual contact and consequently the level of privacy, field of vision, overview and light access (Rapoport 1969, Gehl 2010).

The study was made for all the building components of floors, walls, roofs, windows, double skins and mechanical services. The indicators of the SBTool assessment related to the parameters of spatial quality are partially described in table 1.

The first and main assessment tool analysed in this study is the SBTool Generic system (version of 2012), which is "a generic framework for building performance assessment that may be used by third parties to develop rating systems that are relevant for a variety of local conditions and building types" (Larsson 2012). The secord tool considered is the BREEAM for Major Refurbishment (2008), which consists of an assessment method for sustainable refurbishment projects (BREEAM website). The last tool analysed is the LEED (2009), which is an assessment program for "third-party verification of green buildings" (LEED website) (see tab. 1)

3 Conclusions

The available spatial quality indicators belonging to the three building performance assessments SBTool 2012, BREEAM 2008, and LEED 2009 analysed in this study do not offer an effective assessment of the spatial quality parameters considered (see section 1). However there is clearly a considerable potential for improvement of the indicator's basic scientific characteristic of validity, specificity, sensitivity and reliability in the existing indicators in order to assess spatial quality. The danger of underdeveloped indicators is that spatial quality will essentially depend on the judgment and awareness of the architect and stakeholders involved in the renovation of the building. This may lead to fragmented measures that do not recognise the relevance of spatial quality neither promote its inclusion in building renovation. This inclusion is, however, only possible if objective, measurable spatial quality indicators, assessment and design methods are available for inclusion in decision-making tools for energy efficiency renovation.

The deficiencies of the available indicators on spatial quality were identified in this first part of the PhD research. In the second part the goal is to develop and propose spatial quality indicators to be included in the building performance assessment SBTool. The third part of the PhD research will consist of the evaluation of the indicators proposed in the second part. The goal is to clearly integrate spatial quality assessment in the energy renovation. Methods that can be used to assess the spatial quality parameters will be analysed, and their potential will be explored for further use in the development of indicators.

Tab. 1 *Relation between spatial quality parameters and the building assessment SBTool (2012).*

Building performance assessments	**(Perceived) Parameters - Building/Building Block Scales (micro scale)**		
	Views Isolation/ Contact	**Internal/ External Spatial Arrangements**	**Transition Public/ Private Domains**
SBTool (2012) Indicative: Indoor Environmental Quality	SBTool F1.3 Visual privacy in principal areas of dwelling units. Indicator: The percentage of dwelling units with exterior views. SBTool F3.7 Access to views. Indicator: Visual quality	SBTool F1.2 Access to direct sunlight from living areas of dwelling units Indicator: The percentage of dwelling units whose principal daytime living areas have direct sunlight for at least 2 hours per day	SBTool F1.4 Access to private open space from dwelling units Indicator: Minimum area and dimensions, in m

4 Future application in case studies: FP7 project ZenN Nearly Zero Energy Neighbourhoods (2013 – 2016)

This research is connected to ZenN project “Nearly Zero Energy Neighbourhoods” funded by the European 7th Framework Programme. The ZenN project aims to promote energy efficiency renovation both at district and building level and to replicate this experience around Europe. ZenN will support demonstration cases in Norway, Sweden, France and Spain. The PhD research is planned to link to Work Package 4 “Non-Technical Drivers”, which concerns to main non-technical issues related to architectural and cultural values, social and financial barriers. In addition the WP4 promotes the engagement of users to ensure the success of strategies for energy efficiency, and the optimization of synergies between energy efficient strategies considering the quality of the urban environment. The PhD research will concentrate mainly on ZenN cases in the Nordic context, i.e., Oslo and Malmö, with a possible transferability to other European cases.

Tab. 2 *This table express the crossing between Efficiency Measures for Sustainable Refurbishment, Literature Study and Building Performance Assessments. Example of Building Component: Windows, and Spatial Quality Parameter: Views Isolation/ Contact.*

<table>
<tr><th colspan="4">Spatial Quality - Literature Study - Energy Renovation - Building Performance Assessments</th></tr>
<tr><th colspan="2" rowspan="2">Energy Efficient Measures for Sustainable Refurbishment</th><th colspan="2">Spatial Quality Parameter: Views, Isolation/ Contact</th></tr>
<tr><th>Literature Study on Spatial Quality Definition</th><th>Building Performance Assessments: SBTool (2012)/ BREEAM (2008)/ LEED (2009)</th></tr>
<tr><td rowspan="9">Windows</td><td>Reduction of aperture area (reduction of heat loss and unwanted solar gain, provision of more wall space for furnishings and equipment)</td><td rowspan="3">Reduction or increase of aperture area, or changing the distribution of glazing by making new apertures are related to psychological effects of unwanted sensory interaction with other people, equivalent to loss of privacy (privacy levels) (Rapoport, A.) Field of vision, overview and light/ hindered line of vision/ visual contact on street level/ protection of the private domain (privacy levels) (Gehl, J.)</td><td rowspan="3">SBTool F1.3
SBTool F3.7
BREEAM Hea 2.
LEED IEQ Credit 2.4</td></tr>
<tr><td>Increase of aperture/glazed area to improve daylight conditions as a last option</td></tr>
<tr><td>Changing the distribution of glazing by making new apertures to improve daylight distribution</td></tr>
<tr><td>Implementation of shading to reduce the quantity of radiation and to redistribute daylight</td><td rowspan="5">Implementation of shading related to psychological effects of unwanted sensory interaction with other people, equivalent to loss of privacy (privacy levels) (Rapoport, A.) Field of vision, overview and light/ hindered line of vision/ visual contact on street level/ protection of the private domain (privacy levels) (Gehl, J.)</td><td rowspan="5">SBTool F1.3
SBTool F3.7
BREEAM Hea 2.
LEED IEQ Credit 2.4</td></tr>
<tr><td>Implementation of external shading which can be fixed, adjustable or retractable</td></tr>
<tr><td>Implementation of internal shading</td></tr>
<tr><td>Implementation of interpane shading</td></tr>
<tr><td>Implementation of integrated shading (address daylight distribution function as well as selective shading)</td></tr>
</table>

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Density and Spatial Quality, High density and spatial quality

IV CIB Smart and Sustainable Built Environments, SASBE2012 Emerging

Economies Sao Paulo–SP, Brazil (ISBN 978-85-65823-05-0)

Author: Acre, F.

Peer reviewed conference paper, presentation and poster

June, 2012

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Improving People's Well-being – The Key to Renovation Acceptance

European Project ZenN, Nearly Zero Energy Neighbourhoods

(7th Framework Programme, Grant Agreement number 314363)

Newsletter 2

Authors: Acre, F. & Wyckmans, A.

April, 2014

[redacted]

The Arlequin demonstration site in Grenoble, France, before and after renovation.
Photograph: Fernanda Acre, Illustration: David Corgier

Improving people's well-being – the key to renovation acceptance

Disregarding non-technical effects on occupants is a potentially critical mistake in energy renovation projects. In order to secure acceptance and support by end users, the project must consider improvements in people's well-being along with technical advances. As part of the ZenN project, we aim to illustrate that energy improvements can also have a positive impact on non-technical dimensions.

By: Fernanda Acre and Annemie Wyckmans, NTNU

Fernanda Acre and
Annemie Wyckmans, NTNU

The contribution of our research to the ZenN project is to explore the potential of dwelling renovation as a promoter of occupants' well-being and quality of life. Improvements brought by energy renovation in dwellings can not only improve energy performance, but can also improve non-technical dimensions such as spatial quality. The perceived non-technical benefits experienced by occupants are important factors to be taken into account when planning renovation efforts.

One way in which people experience the impact of technology on their physical space is demonstrated in the example of a dwelling renovation completed in 2010 in Newport, South Wales (Tweed 2013). The renovation affected the buildings form and space, facade, appliances and mechanical systems. Changes in form and space consisted of the addition of a sun space with roof light that functions as a buffer space for the living room, as well as a light tube installed above the stairs to introduce natural light.

After interviews with the occupants, Tweed (2013) noted that the dwelling renovation was primarily valued for the extra space, i.e. the sun space added to the living room, rather than any thermal benefit. This illustrates a contradiction between two aspects of the dwelling renovation: the rarely discussed role of energy efficiency, which was "not a major concern for the occupants", contrasted with the impact of the additional sun space, which "tended to dominate the conversations with the family".

This illustrates how non-technical aspects affected by energy renovation in dwellings, such as spatial quality, impact occupants' receptiveness to the renovation. For a successful renovation project, occupants need to consider energy renovation as a process that will contribute to their well-being, rather than an intrusive procedure with little personal gain. Therefore, as part of the ZenN project, we are in our research developing a spatial quality assessment for dwellings in order to promote a link between the benefits of energy renovation and improvements in people's well-being.

The assessment will compare the ZenN case studies both before and after the renovation work. Views, spatial arrangements, public-private spaces and density are examples of non-technical dimensions that are clearer to human perception than many technical advantages of renovation. The improvement of these factors may therefore help occupants to understand and support energy renovation. Based on a wide reference base originating in the 1960s, we define spatial quality as the interface between four determinants considering residential use, building and block scales, and indoor and outdoor environments (Acre & Wyckmans, 2014):

1. View (visual privacy and quality of the view);
2. Internal spatiality and spatial arrangements (articulation between indoor spaces and their boundaries, and articulation among adjacent internal spaces);
3. Transition between public and private spaces (physical barriers between public and private domains);
4. Perceived, built and human densities (proportion and boundaries of the block, and both built and human densities).

In our research, we draw attention to the relevance of non-technical dimensions, such as spatial quality, as essential elements in increasing stakeholders' interest in and acceptance of energy renovation of dwellings. Focus lies on case studies from the ZenN project, which consists of buildings and neighbourhoods located in Oslo (NO), Malmö (SE), Grenoble (FR) and Eibar (ES) that are undergoing energy renovation. The research is connected to Work Package 4 "Non-Technical Drivers", whose goal is to support the success of energy efficiency strategies by optimising synergies with non-technical issues such as spatial quality and social, economic and policy perspectives.

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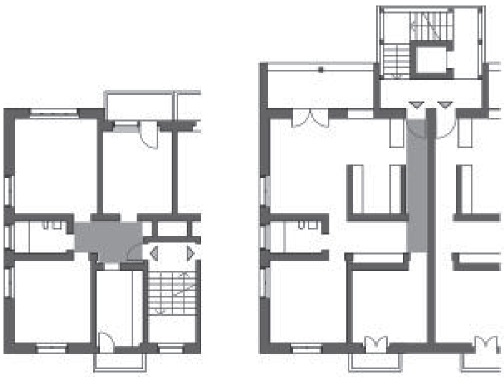

Plans of the first floor before (first image) and after (second image) the renovation of a residential building, scale 1:400. Proportion of the internal space of the hall.

Q

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Examining the influence of renovation options on architectural values and cultural heritage

European Project ZenN, Nearly Zero Energy Neighbourhoods

(7th Framework Programme, Grant Agreement number 314363)

Newsletter 3

Authors: Lindkvist, C., Acre, F. & Wyckmans, A.

November, 2014

[redacted]

Examining the influence of renovation options on architectural values and cultural heritage

The first results from ZenNs WP4 on non-technical drivers present a taxonomy, i.e. groupings of near-zero energy renovation options that impact the technical and the non-technical drivers. Furthermore, their influence on architectural and cultural heritage was studied, focusing on the effects on spatial quality in the Grenoble demonstration case. Findings indicate that spatial quality is mainly positively affected by the dwelling renovation.

The taxonomy of near zero renovation options develops groupings that impact the technical and non-technical drivers. These groupings account for overlapping issues which can be both technical and non-technical which impact the drivers. The rational for examining the drivers in this way comes from work done on ZenN Deliverable 1.1, "Common barriers and challenges in current nZEB practice in Europe", which found that there are overlapping technical and non-technical drivers which impact on the progress of a ZEB renovation rather than viewing these drivers as singular entities. The characteristics relevant to the taxonomy of near zero energy renovation options start to emerge in ZenN 1.1. The deliverable 1.2 contributed with a common technical definition for nZEB renovation, which was integrated into 4.1 in order to ensure consistency regarding the term technical between the two reports.
The non-technical is one branch of the grouping and is broken down to stakeholder awareness and behavior, economic and ownership structures, legislation, policy and governance, architectural value and cultural heritage. There are further groupings drawn from the individual non-technical drivers in the following way:

Stakeholder awareness and behaviour
o Culture of energy awareness
o User centric development been initiated
Economic and ownership structures
o Business models and incentives
o Socio-economic benefits for various stakeholders
Legislation, policy and governance
o Political goals with local climate and resource
o Leadership and decision-making structures
Architectural values and cultural heritage
o Impact of architecture and cultural values
o Restrictions which limit choice of market solutions
o Regulations for historic buildings

	Taxonomy influence: architectural value and cultural heritage	
Integration	Impact of architecture and cultural values	Well-being and attractiveness
		Accessibility
		Functionality and service life
		Revitalisations of local urban neighbourhoods
Upgrading	Restrictions which limit choice of market solutions	Economic and business model factors
	Regulations related to historic buildings	Integrity, authenticity and compatibity with local building traditions

Figure 1 Conceptual model with taxonomy of near-zero energy renovation on architectural value and cultural heritage

The driver architectural value and cultural heritage is emphasised in this report as the other non-technical drivers will be examined in the upcoming deliverables of work package 4. The taxonomy of near-zero energy renovation influence on architectural values and cultural heritage is developed into a conceptual model, visualising the key concepts which make up the groupings for the taxonomy of near-zero renovation influence on architectural values and cultural heritage. It can be used in examining taxonomy of near-zero energy renovation influence on architectural value and cultural heritage.

The Grenoble case study illustrates architectural value and cultural heritage as an integral part of its design characteristics inherited from its original construction and continued in its renovation. In addition, spatial quality assessment is used to understand the positive and negative effects of renovation. Spatial quality is defined here as the excellence of the space in terms of views, privacy, lighting, spatiality, transition between public and private domains, and perceived, built, and human densities.
The Grenoble case was chosen as a test case for the spatial quality evaluation methodology, as this demonstrator represents the most substantial physical changes in building mass among the ZenN demonstrators. The dwelling renovation significantly changed a large range of building characteristics such as external and internal walls, facade composition, built area and plans. A detailed assessment of the physical changes in spatial quality as a result of the dwelling renovation was carried out.

The results of the spatial quality assessment (Acre & Wyckmans, Forthcoming) of the MS-1 building in Grenoble indicate that spatial quality is mainly positively affected by the dwelling renovation. Particularly views from the dwellings to the outside as well as internal spatiality are expected to be improved after the renovation. However, there are some points of alert in the results. The renovation of the building component of floors scores low in the assessment indicating a negative effect of the renovation on spatial quality related to some aspects of internal spatiality. This is because the ceiling height of 2.50 m will be lowered to 2.35 m after the renovation.

In the next steps, the potential for adaptation to climate change will be integrated into the taxonomy for both technical and non-technical drivers and be presented in the later deliverable presenting an holistic design kit for nZEB renovation.

For more information, contact **Carmel Lindkvist**, NTNU, carmel.lindkvist@ntnu.no or **Fernanda Acre**, NRNU, fernanda.acre@ntnu.no

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Helsefremmende boligmiljø i et ressursperspektiv

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Forsiden: Fuktproblemer innendørs (foto: Kai Gustavsen, NAAF)

lys og mulighet for utsyn til omgivelsene – det bidrar til bedret helse og trivsel.

Fukt
Fukt-problematikk er viktig i inneklima-sammenheng. Det bygningstekniske regelverket har stor fokus på dette for å sikre at fukt og følgeskader av fukt ikke forårsaker helseproblemer og skader.

Vår adferd har endret seg vesentlig på relativt få år. Å rette oppmerksomheten på endrede bovaner, byggeskikk og ikke minst forståelsen av sammenhengen mellom disse to, blir mer og mer viktig. Derfor bør vi forsøke å legge til rette for økt "bo-kompetanse" gjennom de ulike statlige virkemidlene, der regelverket må suppleres med informasjonsarbeid og andre egnede virkemidler. I Norge vil klimaendringene innebære betydelig økning av nedbørsmengde og -intensitet , og vi må være beredt til å møte mulige økte negative helsemessige utfordringer som følge av vann og fukt.

Bo bedre – flerkulturelt samarbeid for helsevennlig inneklima

Med midler fra ExtraStiftelsen Helse og Rehabilitering har Norges Astma- og Allergiforbund (NAAF) Region Oslo og Akershus startet et samarbeid med den frivillig flerkulturell organisasjonen Likestilling, Inkludering og Nettverk (LIN) for å lære flerkulturelle i Oslo om astma, allergi og inneklima.

Første stadiet av prosjektet – en pilot – ble holdt 28. november i år av sykepleier Rose Lyngra, seniorrådgiver inneklima Kai Gustavsen og regionssekretær Eva Høili for rundt 30 kvinner med innvandrerbakgrunn i LINs lokaler på Furuset. Det var en nysgjerrig og aktiv gjeng som stilte spørsmål og også åpnet opp om egne helseplager. Seminaret baserte seg på Power Point presentasjoner med mye bilder for å illustrere sykdomsmekanismer og praktisk inneklimaarbeid.

Rådgiver fra LIN Adeela Amjad har dette å si om piloten: «Det var lærerik og nyttig informasjon. Dere brukte lett språk, noe som var kjempe bra. Vi har også fått tilbakemeldinger fra noen av deltakerne at dette var bra.»

Bakgrunnen for prosjektet er NAAFs ønske om å jobbe forebyggende med alle samfunnsgrupper i forhold til den stadig økende forekomsten av astma- og allergisykdommer. Forhold ved inneklima er viktig for helse, trivsel og prestasjoner. For eksempel er fukt den enkeltfaktoren, utenom røyking, som bidrar mest til dårlig inneklima. Mennesker som oppholder seg i bygninger med fuktskader har økt risiko for alvorlige helseplager, som flere og verre luftveisinfeksjoner, astma, allergiske luftveislidelser og andre luftveisplager.

Utfordringen vi står overfor er at vi tilbringer så mye tid innendørs, og at standarden på mange boliger i dag faktisk er langt lavere enn det vi kunne ønske oss. Dette er tilfellet for flere kommunale boliger og boliger på det private leiemarkedet. Innvandrere er en gruppe som ofte ikke har økonomiske midler til å velge bort dårligere boliger. Mange bor trangt og mye av inntekten deres går til å bo. Igjen blir det lite midler til drift av boligen. Når mange dessuten ikke har erfaring med å bo i hus og leiligheter i norsk klima, kan summen av dårlig inneklimapraksis over tid være utslagsgivende for at det utvikler seg et helseskadelig inneklima i boligen. Tilbakemeldinger til NAAFs rådgivningstjeneste om personer som teiper igjen ventiler og vinduer i leiligheten for å spare strøm, eller ikke benytter ventilator i kjøkkenet ved matlaging av redsel for å få kulde inn i boligen, fungerte som ekstra pådriver til å få prosjektet i gang.

Målet for prosjektet er å vise flerkulturelle hvordan man med enkle grep i eget hjem kan tilrettelegge for et helsevennlig inneklima og med de ressurser familien har til rådighet. Vi tror at dette kan bidra til at færre får astma og flere får bedre allergihelse for seg selv og familien. For flere av kvinnene i piloten var noen av de praktiske tiltakene som ble diskutert ting de allerede hadde tenkt på. Dette viste seg i utsagn som «Ja, mennene må begynne å røyke ute» og «Astmaen min er blitt bedre etter at jeg har begynt å gå tur og jeg trenger heller ikke bruke så mye medisiner». Mens andre tiltak som å holde lukteprodukter til et minimum var ting de ikke var vant med: «Men jeg må bruke duftlys for å få bort krydderlukten» eller «Jeg sprayer med parfyme for å få god lukt i huset».

NAAF har gjennom mange år bygget opp kompetanse på inneklima. NAAF Region Oslo og Akershus ønsker å bidra til at denne kompetansen når ut til samfunnsgrupper som ikke så lett får tilgang til slik informasjon, eller som har forutsetning til å forstå inneklimarelaterte problemer som kommer med det å bo i et kaldt og delvis fuktig klima. Mange problemene med inneklima skyldes ofte feil bruk, eller at skader og mangler ikke blir rettet opp i tide.

Gjennom dette prosjektet skal NAAF:
1. utvikle et lettfattelig undervisningsopplegg tilpasset mål gruppen
2. utvikle brosjyremateriell tilpasset målgruppen
3. danne grunnlag for videre samarbeid med flerkulturelle organisasjoner og befolkningsgrupper i Oslo-området og landet for øvrig
4. jobbe for å gjøre verktøyet tilgjengelig i kommunenes opp læringsprogram innen praktisk bo-kompetanse for innvandrere.

På nyåret holdes ytterligere to seminarer for flerkulturelle i Osloregionen. Hovedsakelig beboere i bydelene Gamle Oslo, Alna, Grorud og Søndre Nordstrand. Alle interesserte kan henvende seg eva.hoili@naaf.no eller mobiltelefon 995 07 940 for mer informasjon og påmelding.

Helsefremmende boligmiljø i et ressursperspektiv

Forfattere: Annemie Wyckmans, Karin Tømmerås, Geir Arild Espnes, Gøril Thommassen, Stig Larssæther, Solvår Wågø, Barbara Matusiak, Fernanda Pacheco, Karin Høyland, Steinar Krokstad og Bendik Manum

Endringer i befolkning og ressursbruk utøver stor innflytelse på utformingen av det bygde miljø, og godt samsvar mellom klima, sted og bygget form spiller en stadig viktigere rolle. NTNU har flere viktige satsinger som sammen kan bidra til å belyse problemstillingen: helse, velferd og teknologi; energi; bærekraftig samfunnsutvikling; og smarte byer.

Helse, velferd og teknologi (HEVET)
Ifølge verdens helseorganisasjon defineres helse som en tilstand av fullstendig fysisk, psykisk og sosialt velvære og ikke bare fravær av sykdom eller lidelse. En slik utfordring kan bare løses av sektorovergripende arbeid med stor vekt på helsefremming og forebygging, i tett samarbeid med tverrfaglige forskergrupper. Slikt samarbeid former et viktig ledd i NTNUs nye satsing «HEVET» - Helse, Velferd og Teknologi. Satsingen skal blant annet bidra til å forstå prosesser og faktorer på individ- og samfunnsnivå som fremmer helse og forebygger sykdom, både gjennom teknologi og

utforming av bygde omgivelser. Også SINTEF har samfunnsvitere, arkitekter og humanister som arbeider med disse problemstillingene. Moderne og helsefremmende bomiljø, god kommunikasjon og sikker og trygg teknologi i menneskenes tjeneste.

I løpet av få år vil samfunnet bestå av en langt større andel eldre mennesker enn i dag. En stadig større del av befolkningen vil være friske velfungerende pensjonister, eller leve med kroniske sykdommer de ikke skal dø av, men leve med. At menneskene skal leve lange, aktive og gode liv har alltid vært et mål, men det gir store utfordringer både til enkeltmenneskene og til de systemene og strukturene menneskene skal leve i for framtiden. Det er fastslått at vår tenkning om helse og helseutfordringer må gjennomgå store endringer i løpet av få år. At befolkningens helse først og fremst skal ivaretas av helsevesenet er en umulighet for framtiden både hva gjelder økonomi og personalbehov. Oppgavene må løses på nye måter der både sosial- og teknologisk innovasjon blir viktige innsatsfaktorer. De fysiske rammene rundt dette, bomiljø og lokalsamfunn vil bli viktigere for helseområdet enn har vært definert tidligere.

De fysiske omgivelsene påvirker rammen rundt vårt hverdagsliv på ulike måter. De kan i ulik grad innby til fysiske aktiviteter, de kan gi oss vakre opplevelser eller gjøre det mulig å komme ut å rekreere, eller møte andre mennesker. Dette er alle faktorer man anser som viktige for menneskets helse enten man er ung eller gammel. Når vi snakker om omgivelsenes betydning for helse og velvære handler det ikke bare om den har helbredende virkning. Det dreie seg derfor om hvordan omgivelser kan bidra til innhold og livskvalitet til det livet man har og ikke nødvendigvis måles opp i mot om det har helbredende virkning.

Når vi skal definere hva som er helsefremmende løsninger er det viktig å drøfte dette ut i fra ulike brukerperspektiver. Er man dårlig til beins kan et boligområde i landlige omgivelser bety isolasjon og innaktivitet, mens det for skiløperen legger godt til rette for fysisk aktivitet. Urbane byområder kan gi voksne gode muligheter for å sykle eller gå, er de imidlertid dårlig tilrettelagt for at barn kan bevege seg trygt ute kan de medføre lite bevegelsesfrihet for de minste barna. På denne måten kan den samme fysiske løsningene påvirke menneskers hverdagsliv på ulike måter. En måte å få innsikt i dette samspillet på er å studere ulike løsninger og hvordan de invirker på ulike menneskers helse og hverdagsliv.

Det er et mål at også mennesker som har omsorgsbehov også skal oppleve verdighet og trygghet, at de får bruke de ressuser de har og at de får bo og bevege seg i omgivelser der de har en følelse av mestring og god livskvalitet. For å få dette til trengs det forsking og utvikling av boligløsninger og nærmiljø som er bygd opp rundt en tanke om at beboerne skal oppleve både utfordringer og mestring, samt oppleve hverdagen som trygg og med mening. Trygghet for at de får hjelp når det trengs, men også trygghet for at omgivelsene er ivaretagende også i det daglige hverdagslivet. For å få dette til må det tenkes nytt og inkluderende i i utforming av bomiljø, i tenkning knyttet til bruk av i hus. Vi må ha mer kunnskap om hvordan vi sikrer gode og fungerende sosiale arenaer, hvordan vi arkitektonisk utformer bomiljø, hvordan sosiale medier kan være bidrag, hvordan enkel teknologi utvikling kan bidra. Slike tanker er nedfelt i flere offentlige meldinger, og det påligger det offentlige (stat, fylkeskommuner og kommuner) å legge til rette, men hvordan det skal løses praktisk er det forskningsinstitusjonene og næringsliv.

Her ser vi også en spennende kobling til utviklingen av såkalte «smarte byer» som prosjekterer og forvalter byform, arkitektur og infrastruktur på en integrert måte (energi, vann, avfall, arealbruk, mobilitet, kommunikasjon, helse osv) og som bruker smart teknologi for å forbedre disse prosessene. I en helsefremmende «Smart City»-arkitektur vil sosiale arenaer, miljø, teknologisk instrumentering av hus (og mennesker), moderne tjenester fra helsetjenester og transport / kommunikasjon tillate folk å leve i sitt hjemmemiljø mye lengre med mer kontroll over sine liv og bedre helse.

Å skape et hjem i klimaendringens tid – hvordan boligkvalitet påvirkes av ulike lavenergikonsepter

Bygningers påvirkning på miljøet og energibehovet i bygninger har medført økt fokus på energieffektivitet. Energieffektive designprinsipper som medfører en velisolert, tett og kompakt bygningskropp, føringer på orientering og bruk av glass, medfører arkitektoniske muligheter og begrensninger. Nye tekniske løsninger som har til hensikt å senke energiforbruket, kan legge føringer for beboerpraksis, innflytelse og opplevelse av velvære og hjemfølelse.

Et prosjekt som undersøker hvordan energieffektivitet håndteres og hvordan det påvirker boligkvalitet, velvære og beboerpraksis er nesten ferdigstilt. Det er utført i en norsk kontekst, basert på vår kulturs forhold til natur og klima. Prosjektet undersøker hvordan fokuset på energieffektivitet har påvirket det norske regelverket (Teknisk forskrift) og hvordan arkitekter håndterer energireglene og ivaretakelse av boligkvaliteter som dagslys, utsikt og frisk luft. Det visuelle og sensoriske forholdet mellom inne og ute gjennom utsikt, dagslys og frisk luft, var sentrale aspekter ved boligkvalitet gjennom modernismen, og er det fortsatt blant arkitekter.

Om beboere som bor i energieffektive boliger opplever at disse kvalitetene er viktige, om de er ivaretatt der de bor, og om de opplever at boligens løsninger påvirker deres måte å bo på, hjemfølelse og opplevelse av velvære, har vært sentralt i min undersøkelse. Om de faktisk forbruker mindre energi er også undersøkt. Dybdeintervjuer med arkitekter som er opptatt av energieffektivitet og boligkvalitet, og beboere i 4 energieffektive boligprosjekter, samt tegninger og data for målt energibruk over 4 år i ett av boligprosjektene, utgjør det empiriske materialet.

Dagslys, helse og velvære

Koblinger mellom dagslys, helse og velvære er blitt fremhevet i flere rapporter produsert i regi av den Internasjonale Belysningskommisjonen (CIE) i 2004, 2009 og sist i 2012 med tittel: «The Physiological and Psychological Effects of Windows, Daylight, and View at Home: Review and Research Agenda". De viktigste prinsippene for helsebringende belysning, etter CIE, kan bli oppsummert slik:

- Menneskelig velvære er avhengig av daglig dose av sterkt lyseksponering, men i Vesten mottar folk antageligvis for lite lys på daglig basis.
- I tillegg til lysstyrke er spektralsammensetning på lyset meget viktig; størst følsomhet for lys som innvirker positivt på helse ligger i den blågrønne delen av spekteret (dagslys er meget rik på blått lys)
- Tidspunktet for belysningen er også viktig, et sterkt lys tidlig på dagen fremskynder vår circadiansk system mens en tilsvarende eksponering sent på dagen saktner det med en konsekvens i form av sent oppvåkning og tretthet dagen etter.
- Det er lyseksponering på øye som er bestemmende for helse, derfor både lyset fra en lyskilde og lyset reflektert fra omgivelsene har innvirkning. Lyset reflektert innendørs er spesielt viktig siden vi befinner oss innendørs opp til 90% av tiden.
- Behovet for mørke om natten er like viktig som behovet for lys på dagtid.

Hva er konsekvensene av undereksponering for lys?

En liten gruppe, ca. 5% av befolkning, utvikler klinisk vinter-depresjon (eng. SAD, Seasonal Affective Disorder) som en konsekvens av langvarig undereksponering på lys, e.g. i løpet av vinteren; de får medisinsk hjelp, ofte i form av regelmessig eksponering mot sterkt lys. En enda større gruppe (opp til 20%) opplever en mildere form av nedsatt livskvalitet, med følgende symptomer: redusert interesse for ulike aktiviteter, økt irritasjon, humørsvingninger, forstyrrelse i søvnmønster og forstyrrelse i spisemønster.

Utsikt mot utemiljø er også viktig for velvære, spesielt hvis utsikten er mot naturladskap eller attraktiv bymiljø, hvorfor? La oss sitere William Lam:

"We pay more attention - conscious and unconscious - to biologically important factors, than we do to other sensory data that are less relevant to our physical, intellectual, and emotional well-being."

Det biologiske behovet for informasjon er, etter W. Lam, knyttet til: sted, tid, været, mulighet for beskyttelse, tilstedeværelse av andre levende organismer, eget territorium, mulighet for avslapning og mulighet for utflukt. Uten disse informasjonene er det meget vanskelig å fokusere på gjøremål. Behov for informasjon om sted, tid og været er vanskelig å tilfredsstille uten vindu og utsikt. Utsikt mot naturlandskap eller –elementer kan i tillegg forbedre eller fornye konsentrasjonsevne.

Hva er konklusjonene for prosjektering av de bygde omgivelser?

Alle rom for varig opphold bør ha rikelig tilgang på dagslys. Dette vil selvfølgelig skape utfordringer for prosjektering av tette by-områder og krever nøye planlegging. Man bør sørge for utsikt mot grønne arealer eller i det minste grønne elementer, fra alle oppholdsrom. Dette innebærer at et parkområde eller -sti bør være uunngåelig del av planer på alle nivåer.

Byform, daglige reiser og helse

Det er også interessant å undersøke hvordan folks tilgjengelighet til daglige reisemål påvirker ikke-motorisert mobilitet, fysisk aktivitet og dermed folkehelsen. Basert på offentlige helsedata fra HUNT (Helseundersøkelsene i Nord-Trøndelag) og nylig utviklet GIS-programvare kan man nemlig undersøke forholdet mellom folkehelse og folks tilgjengelighet til daglige reisemål.

I Norge er det nå en uoverensstemmelse mellom store investeringer i bilbasert utvikling av byer og bygder og medisinske råd om helseproblemer knyttet til redusert fysisk aktivitet. Disse to spørsmålene har en sannsynlig årsakssammenheng men denne har ennå ikke blitt nøye undersøkt. Samspill mellom resultater og metoder fra NTNU og HUNT finnes det et betydelig potensial for å utvikle et tverrfaglig forskningsfelt av stor betydning for samfunnet.

Slike undersøkelser kan for eksempel vise hvordan gatenettverk, tetthet og lokalisering av boliger og menneskers daglige reisemål kan ha en positiv påvirkning på daglig fysisk aktivitet og folkehelse (ved å øke sannsynligheten for folk å velge å gå eller sykle til sine daglige reisemål) .

Tilpasningsdyktighet, robusthet, motstandskraft (eng «resilience»)

I møte med endringer i klima og befolkningsstruktur spiller utforming av arkitektur og infrastruktur en stadig større rolle for å balansere god livskvalitet og omgivelseskvalitet, i en skala som rangerer fra detaljering av materialer til tilgjengelighet av grønne og offentlig rom. Riktig og fleksibel arkitektonisk utforming kan forbedre tilgjengelighet, brukervennlighet og funksjonalitet av bygd miljø på en nesten umerkbar måte; mens feil utforming raskt oppfattes og kan danne et betydelig hinder for innbyggernes hverdag, velvære og helse.

Sårbarhetsrisiko og tilsvarende kostnader kan reduseres betraktelig ved utforming av bygde miljø med iboende fleksibilitet for tilpasning til konsekvenser av klimaendringer og ekstremvær som flom og hetebølger. Tilgang til sol og skygge, beskyttelse fra vind og regn, og integrerte grønne og blåe områder kan gi viktig lindring i tilfeller av ekstremvær. Diversifierte løsninger gir større tilgjengelighet av varer og tjenester hvis noen tilføringsveier bryter ned. Investeringskostnader for slike tiltak kan reduseres betraktelig dersom tiltakene knyttes til generell oppgradering av eksisterende og utforming av nye og spenstige områder, integrert i langsiktig planlegging for byer og bygder. Eksempler på utforming, kostnader og indikatorer for utforming av klimarobuste områder finnes blant annet på http://www.ramses-cities.eu.

Eksempel: Utvikling av Brøsetområdet i Trondheim

I helhetlig områdeplanlegging er det å stimulere til fysisk aktivitet og utvikle helsefremmende omgivelser et mål i seg selv, og adresseres ofte gjennom utforming av spesifikke program som retter seg mot ulike målgrupper, eks barn, unge, eldre og personer med funksjonshemming. Mye av dette ivaretas gjennom eksempelvis lovverk om minste tillatte uteromsareal for boliger skole og barnehager, forskriftskrav om universell utforming og andre forhold som må ivaretas i planprosessen som obligatoriske krav. Det gjenstår imidlertid et stort handlingsrom der en av ulike årsaker ønsker å gå lenger enn forskriftene for å oppnå mer ambisiøse målsetninger.

I planleggingen av Brøset har koblingen mellom en mer lokalisert livsstil og fysisk aktivitet kommet i fokus som et resultat av svært høye mål for reduksjon av klimagass-utslipp, fra 8-11 tonn CO_2 per år per person som er dagens gjennomsnitt, til under 3 tonn. En slik dramatisk endring skjer ikke uten vesentlig omlegging av livsstilen til beboerne, der både transportaktivitet og generelt forbruksmønster må dreies bort fra utslippsintensive områder og over til praksiser som gir vesentlig lavere utslipp. I og med at relativt få at de potensielle beboerne på Brøset vil være primært drevet av idealistiske hensyn, skaper dette en stor utfordring i forhold til å ramme inn nye måter å gjøre ting på slik at det ikke oppleves som et offer, men som noe attraktivt eller en ekstra kvalitet ved det å bosette seg på et slikt område.

I områdeplanen for Brøset er det satt av ca 100 dekar til offentlige friområder, utformet som et gjennomgående grøntdrag med blant annet turstier, bekkedrag og dyrkingsfelt, og parkområder med ulike program for ulike brukergrupper. En ønsket effekt er at varierte uteområder av høy kvalitet skal stimulere beboerne til å tilbringe mer av tiden sin i nærområdet og få dekket noen av de behovene som genererer transport (eks til hytta i helgene) gjennom lokale tilbud. Mens det legges opp til redusert bruk av privatbil gjennom lav parkeringsdekning og bilfrie soner sentralt i området, har gang- og sykkelveier fått en framtredende rolle i transportnettet slik at det skal framstå som attraktivt å forflytte seg ved hjelp av ikke-motorisert transport. Det gis også muligheter for noe lokal dyrking gjennom at 10 prosent av de gjennomgående grøntdragene og 25 prosent av parken foran hovedbygningen settes av til private parseller. I tillegg er det lagt inn et krav om at 25 prosent av den offentlige beplantningen skal være nyttevekster:

- Alle beboere skal ha tilgang på uteområder av høy kvalitet, med variert utforming.
- Prioritet av gange og sykkel i transporthierarkiet
- Gjennomgående tursti
- Private dyrkingsområder
- 25 % av all offentlig beplantning skal være nyttevekster (for eksempel urban dyrking)
- Ulike typer program for å aktivisere beboerne

Felles for disse tiltakene er at de kan bidra til bedre livskvalitet og helse for beboerne, samtidig som de gir et lavere klimafotavtrykk. Det er imidlertid vanskelig å si på forhånd hvordan oppslutningen blir blant de som faktisk flytter inn på området, og om de positive effektene blir realisert i praksis. Mye avhenger av hvordan området blir utviklet og markedsført, og hvordan beboerne blir involvert eller selv involverer seg i den mer detaljerte utformingen av boliger og offentlige fri-områder. Det en kan si med sikkerhet er at sannsynligheten for at beboerne vil endre sin praksis i klima- og helsevennlig retning er større når slike hensyn er tatt med i planleggingen enn hvis det kun blir opp til den enkelte å legge om sin atferd.

Erfaringene fra Brøset vil gi verdifull kunnskap om hvilke effekter som kan forventes gjennom de virkemidlene som i dag er tilgjengelig i planleggingen eller om det blir nødvendig å utvikle andre framgangsmåter eller tiltak som reduserer gapet mellom forventede målsetninger og faktisk atferd. Mer informasjon om prosjektet finnes på
http://www.trondheim.kommune.no/gronnbybroset.