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The impact of dwelling renovation on spatial quality

The case of the Arlequin neighbourhood in Grenoble, France

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Abstract

Purpose – Non-technical dimensions such as spatial quality are just as relevant for energy efficiency as technical and economic dimensions in the renovation of dwellings. However, the significance of non-technical dimensions is often neglected in the energy renovation of dwellings. The purpose of this paper is to demonstrate how the renovation of dwellings for energy efficiency influences spatial quality in the MS-1 building in the neighbourhood of Arlequin, Grenoble, France. The Arlequin case study is part of the ZenN project, Nearly Zero Energy neighbourhoods, funded by the European 7th Framework Programme (Grant Agreement No. 314363).

Design/methodology/approach – The impact of the renovation on spatial quality is analysed by crossing technical measures, applied in the energy renovation of dwellings with the definition of spatial quality proposed by Acre and Wyckmans (2014). The spatial quality definition results from a literature review on quality of design and urban life, wherein works of Weber (1995) and Gehl (2010, 2011) are related to the residential use in the scales of the building and block. The impact of renovation on spatial quality is further evaluated by using the spatial quality assessment developed by Acre and Wyckmans (2015). The impact on spatial quality is observed by considering all the renovation measures, instead of only considering the measures primarily related to energy performance. This emphasises the need for a cross-disciplinary approach between technical and non-technical dimensions in the energy renovation of dwellings.

Findings – The results display both negative and positive impacts of the energy renovation on spatial quality in the dwellings and emphasise the potential of non-technical dimensions in promoting renovation. The impact on spatial quality is primarily negative when only measures adopted in order to improve energy efficiency are considered in the evaluation

Originality/value – This paper consists of a novel crossing of technical and non-technical dimensions in energy renovation of dwellings. The work aligns with the current European trend of nurturing energy-deep renovation to reach Europe's 2050 energy-efficiency targets (Buildings Performance Institute Europe (BPIE) 2011).

Keywords Energy efficiency, Residential buildings, Building renovation, Deep renovation strategy, Spatial quality assessment, Whole building approach

Paper type Case study

1. Introduction

The global issue of climate change motivates sustainable development and thereby the urge to improve energy efficiency in domestic buildings. Technical and economic efficiency requirements in building renovation often get priority over non-technical dimensions. This paper explores the impact of energy renovation on spatial quality in the residential neighbourhood of Arlequin in Grenoble, France. The study was made in 2014 and 2015 and was partially presented to the ZenN partners in October 2014. The research question is:

RQ1. Does the energy renovation of the MS-1 building affect spatial quality in the apartments?

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If yes, what is the nature of the impact of the renovation on spatial quality?

Non-technical dimensions refer to comprehensive features rather than only specific characteristics. Building renovation for energy efficiency usually refers to technical performance and economic feasibility. The present work explores the addition of a non-technical dimension, namely spatial quality in building renovation. According to ZenN (2012), non-technical dimensions are architectural values and cultural heritage, stakeholder awareness and behaviour, economic and ownership structures, legislation, governance and policy. Non-technical dimensions such as spatial quality, have the potential to increase stakeholders' understanding of and their openness towards building renovation, and thereby contribute to sustainable development.

This case study demonstrates how the renovation of dwellings for energy efficiency impacts spatial quality. The MS-1 building is chosen because of the advanced stage of the design phase and because it is a sample of the renovation strategy that is likely to be applied to the rest of the housing complex. Arlequin is part of the ZenN project, Nearly Zero Energy neighbourhoods, Work Package 4 Non-Technical Drivers. The goal of ZenN 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). The aim of WP4 is to support the success of energy-efficiency strategies in dwelling renovation by improving the interactions between technical and non-technical dimensions.

The spatial quality definition and assessment used in the analysis of Arlequin comprise a new approach. Spatial quality has normally been considered on the urban scale in the literature. However, spatial quality can also be defined and assessed at the scales of the residential unit, the building, and the block. The definition of spatial quality results from the literature on quality of design and urban life for residential use in building and block scales, specially Lynch (1960), Chermayeff and Alexander (1966), Rapoport (1970, 1971), Alexander *et al.* (1977/1978), Ashihara (1981), Russell and Snodgrass (1989), Weber (1995), Nasar (1992/2000), Owens (2008), Uytenhaak (2008), Gehl (2010, 2011) and Moulaert *et al.* (2011). Spatial quality can be assessed considering four determinants, which are discussed by the authors whose work inspired the spatial quality definition and assessment: views, internal spatiality and spatial arrangements, the transition between public and private spaces and perceived, built and human densities (Acre and Wyckmans, 2014).

This work aims at bridging the gap between theory on spatial quality and the practice of renovation of dwellings for energy efficiency. That is, using renovation to achieve more than improving technical performance only. The results reveal an impact of the renovation on spatial quality, and indicate the need to revise theoretical beliefs and methods in energy renovation and architecture. In terms of theory, the study of spatial quality in building renovation opens up an entire field involving the analysis of the relationships between technical and non-technical dimensions. In terms of practice, the work explores the potential of energy renovation of dwellings to improve non-technical dimensions such as spatial quality. It also emphasises the potential of the deep renovation strategy for improving spatial quality in domestic buildings. Currently, building renovations achieve around 20-30 per cent of energy savings, while deep renovation aims at achieving energy savings of at least 60 per cent (Buildings Performance Institute Europe (BPIE) 2013). Deep renovation strategy aims at reducing energy and fossil fuel demands by even higher levels of energy efficiency in building renovation (Bettgenhäuser *et al.*, 2014).

Spatial quality has the potential to contribute towards improving the synergy between users, architects and building owners. This is because the benefits of energy renovation for spatial quality can be used as arguments to convince users and building owners to undergo energy renovation. Users usually do not clearly see the benefits of energy renovation, as they remain abstract matters (Tweed, 2013). However, non-technical dimensions such as spatial quality are more familiar to human perception (Acre and Wyckmans, 2015).

The results of the spatial quality assessment did not influence the renovation of Arlequin. This is because the assessment was not completed by the time the renovation was taking place. However, the goal is to use the assessment simultaneously with the design phase of the renovation. Arlequin is the first case to be evaluated using the assessment. The case was a laboratory to develop the assessment rather than to explore how it can be integrated in design processes.

2. Method and material

2.1 Spatial quality definition and assessment

Spatial quality is defined as the interaction among four determinants: views; internal spatiality and spatial arrangements; the transition between public and private spaces; and perceived, built and human densities. Each determinant has three main topics, which are represented by five principles from A to E (see lists below). The four determinants are combined into a spatial quality assessment methodology (Acre and Wyckmans, 2015). The assessment is intended to be performed during the design phase of projects while design alternatives are being explored. The desired outcome of the assessment is an upgrading in spatial quality along with energy-efficiency improvements in renovation of dwellings.

Building performance assessment tools were the starting point for the development of the spatial quality assessment. The tools considered were the Sustainable Buildings Tool (SBTool) (2012), the Building Research Establishment Environmental Assessment Method (BREEAM) UK 2008 for Major Refurbishment and Multi-residential Use, the BREEAM Refurbishment Domestic Buildings (2012), the Leadership in Energy and Environmental Design (LEED®) 2009 for Existing Buildings, and the LEED® 2008 for Homes (2013). These tools were studied to check whether they include indicators that could assess spatial quality in renovation of dwellings. Daylight indicators found in the tools are among the indicators that can partially evaluate the impact of the renovation on spatial quality (Pacheco and Wyckmans, 2013; Acre and Wyckmans, 2014).

2.1.1 Spatial quality assessment for view. The three topics that drive the study of spatial quality determinant (1), view, are the view from the inside (private domain) to the outside (public domain) of dwellings, and from the outside to the inside (visual privacy); the distances between public and private domains; and the quality of the view. These topics are represented by five principles: (A) facade transparency; (B) depth of vision (Weber, 1995); (C) distance and degree of sight protection (Chermayeff and Alexander, 1966; Gehl, 2010, 2011); (D) lighting; and (E) enclosure and peripheral density (Weber, 1995). Principle (A), facade transparency, consists of the ratio between the external walls' areas and the openings' areas (windows and doors). The existence of openings that allow a view and the quality of this view are assessed in the principle of (B) depth of vision. Principle (C), distance and degree of sight protection, considers the visual privacy and the protection of the private domain. That is, how much control the user has to avoid or allow visual interaction with others. The configuration of the plan, which affects views from inside to outside and from outside to inside, is considered in principle (B), depth of vision. The focus of principle (D), lighting, is the access of daylight, and facade transparency and composition. The last principle, (E) enclosure and peripheral density, refers to the configuration of the block that affects views (see list below).

Spatial quality assessment – determinant 1: view (building and block scales) (Acre and Wyckmans, 2015)

(1) Facade transparency:
  - ratio between facade area and apertures (windows and doors) area;
  - ratio between apertures (windows and doors) area and glass surface areas; and
  - glazing properties of transmittance and absorptance.

(2) Depth of vision:
  - visibility:
    - percentage of the total number of spaces with a view;
    - visual openness index (Indraprastha, 2012); and
    - visual privacy index (Indraprastha, 2012).
  - quality of the view (composition of the view) (Matusiak, 2014; CEN, 2015)
    - distance of the view (depth) is >6 metres (yes or no question);
    - width of the view through window(s) is >28° (yes or no question); and
    - presence of layers of proximity (sky, landscape and ground) (yes or no question).
  - internal division of space (configuration of the plan that affects views from inside to outside, and from outside to inside):
    - window's length is equal to at least half of room depth (d), and $d \leqslant 5$ m, window area (wa) $= 1.25\,m^2$; $d > 5m$, $wa = 1.50\,m^2$ (yes or no question) (CEN, 2015)
    - visual distance (distance between the geometrical centre point *p* of an enclosed space to the midpoint of the openings – doors and windows) (Indraprastha, 2012);
    - viewing area (ratio between the room and the viewing areas from the geometrical centre point *p* of an enclosed space to the midpoint of the openings, with a maximum viewing area of 100º) (Indraprastha, 2012);

(3) Distance and degree of sight protection (visual privacy and protection of the private domain):
  - view of arriving visitors and entrance, and entry-lock (hall) area to dwelling:
    - possible to see arriving visitors (yes or no question);
    - possible to see arriving visitors without being seen (yes or no question); and
    - entry-lock (hall) area to dwelling (yes or no question).

- availability and configuration of private outdoor spaces:
  - availability of private outdoor spaces (yes or no question);
  - possibility of controlled visual contact with the neighbour's private outdoor spaces (yes or no question);
  - availability of private outdoor spaces on the ground floor level (yes or no question);
- placement of balconies:
  - ratio between the transparent (or translucent) and the opaque parts of the handrails;
  - balcony sticks out or is built into the facade of the building volume; and
  - balconies are on top of each other or staggered.

(4) Lighting (access of daylight) (Matusiak, 2014; CEN, 2015):
- daylight access (yes or no question);
- daylight factor (DF); and
- sky view factor (SVF).

(5) Enclosure and peripheral density (configuration of the block that affects views):
- southwest orientation of the main living areas (yes or no question);
- ratio between the height and the width of the enclosed courtyard space; and
- difference between the height of the building and the average height of surrounding buildings (difference in height than two-third of the average height of the surroundings) (yes or no question).

2.1.2 Spatial quality assessment for internal spatiality and spatial arrangements. The three topics of the spatial quality determinant (2), internal spatiality and spatial arrangements, are the articulation between space and its boundaries, and between adjacent spaces; privacy within the dwelling; and light (access of daylight, layout zoning; and sun orientation of openings). The five principles that represent these topics in the assessment are (A) centricity and concavity, (B) internal division of space and spatial density, (C) spatial complexity (Weber, 1995), (D) privacy within the dwelling (Chermayeff and Alexander, 1966) and (E) lighting. Principle (A), centricity and concavity, consists of the analysis of changes in the placement of space boundaries (walls) and their openings (the entrances). Internal division of space and spatial density (B) consists of the study of how a space is subdivided without the use of walls. Columns, stairs and differences in ceilings heights can subdivide a space. Spatial complexity (C) consists of the analysis of changes in spatial hierarchies. Spaces can be characterised by a coordinated or a subordinated spatial relationship. A coordinated spatial relationship is characterised by adjacent spaces with similar dominance, while 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). Privacy within the dwelling (D) is the study of the internal zoning of the dwelling considering different groups within the family. For example a distinction could be made between children's areas and adults' areas. Lighting (E) is analysed in terms of its behaviour in the space (see list below).

Spatial quality assessment – determinant 2: internal spatiality and spatial arrangements (building scale) (Acre and Wyckmans, 2015):

(1) Centricity and concavity:
   - geometric centre of the space:
     - the relevance of the geometrical centre is weakened (e.g. as a consequence of the addition of large openings and enclosing elements) (Von Meiss, 1997) (yes or no question);
     - room's shape has only one geometrical centre (figural character, regularity and symmetry) (yes or no question); and
     - secondary centres are symmetrically arranged (enforcement of the presence of the geometric centre of the room) (Weber, 1995) (yes or no question).
   - perceptual centres of the space (Indraprastha, 2012):
     - the space has more than one entrance (yes or no question);
     - areas of zones of influence of door(s) overlap (yes or no question); and
     - areas of zones of influence of window(s) overlap (yes or no question).
   - placement of entrances (concavity (Weber, 1995)):
     - entrance(s) located close to the axes of the room (yes or no question);
     - 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; and
     - entrance located on the longitudinal axis to increase privacy (yes or no question).

(2) Internal division of space and spatial density:
   - placement of columns and internal walls:
     - columns standing free in the space (yes or no question);
     - spaces defined (subdivided) by columns (yes or no question, if there are free-standing columns in the room); and
     - spaces redefined (subdivided) by internal walls (changes on dwelling's plan) (yes or no question);
   - placement of the stairs:
     - stairs are added or replaced (yes or no question);
     - free-standing stairs (detached from space boundaries) (yes or no question, if stairs are added or replaced); and
     - ratio between the stairs and room areas.
   - ceiling heights:
     - different heights in the same room (yes or no question);

- spaces defined (subdivided) by different heights (yes or no question, if there are differences in heights in the room); and
- minimum height of 2.4 metres (yes or no question).

(3) Spatial complexity (spatial hierarchies):

- coordinated spatial relationship (spaces with similar dominance):
  - areas (in square metres) of adjacent spaces are similar (area difference <30 per cent) (yes or no question);
  - direct connection between two or more coordinated spaces (yes or no question);
  - coordinated spaces have direct connection with the main circulation (yes or no question);
- subordinated spatial relationship (primary and secondary spaces):
  - areas (in square metres) of adjacent spaces are significantly dissimilar (area difference >30 per cent) (yes or no question);
  - direct connection between two or more subordinated spaces (yes or no question); and
  - function of the secondary space complements the primary space (yes or no question).
- degree of space closure (for spaces where people can spend the majority of their time):
  - ratio between the height and the width of the enclosed space;
  - room's width is at least the room's height (yes or no question); and
  - ratio between the width and the length of the enclosed space.

(4) Privacy within the dwelling (zoning according to the needs of different family group members):

- differentiation between social and private zones (yes or no question);
- children's domain is directly accessible from the circulation area (yes or no question); and
- buffer zone between the children's private domain and the parents' private domain (yes or no question).

(5) Lighting (Matusiak, 2006, 2014):

- access of daylight:
  - placement of windows/balcony doors adjacent to side walls (yes or no question);
  - placement of windows adjacent to horizontal surfaces (yes or no question); and
  - ratio between glazed area and indoor surfaces' area (walls, floor and ceiling); and relation between wall thickness and window area.

- light distribution in the space:
  - reflectance and absorptance of indoor surfaces' areas;
  - luminance distribution; and
  - ratio between the daylight (passive) and the non-daylight (non-passive) zones (Baker and Steemers, 1996, 2002).
- internal zoning of the diverse functions according to orientation:
  - internal zoning considers optimal sun orientation (yes or no question);
  - minimum of 80 per cent of the floor area of the room is lit by daylight (SBTool, 2012) (yes or no question); and
  - direct access of sunlight to living areas (SBTool, 2012) (yes or no question).

2.1.3 Spatial quality assessment for the transition between public and private spaces. The three drivers of spatial quality determinant (3), the transition between public and private spaces, are physical barriers between public and private spaces; outdoor private spaces; and facade composition and permeability. The five principles of this determinant are (A) the private entrance to the dwelling as a protected and sheltered standing space (Chermayeff and Alexander, 1966), (B) clear boundaries between the private and semi-public domains, and between private, semi-public and public domains (Chermayeff and Alexander, 1966; Gehl, 2010, 2011), (C) outdoor private spaces as effective staying areas, (D) uniformity and coherence of boundaries (Lynch, 1960; Weber, 1995) and (E) presence or absence of impact of the internal division of space on the facade composition. The configuration of the entrance is the focus of the first principle (A), while principle (B) consists of the analysis of the boundaries between the private, semi-public and public domains. The focus of principle (C) is the existence of outdoor private spaces as well as their location and how effective they are as areas which are actually used by the residents. Principle (D), uniformity and coherence of boundaries, consists of the study of the facade composition in terms of similarity, rhythm and roughness. The last principle, (E) internal division of space and spatial density, and the facade composition, considers the impact of changes to the inside space of dwellings on the facade composition of the building see list below.

Spatial quality assessment – determinant 3: transition between public and private spaces (building and block scales) (Acre and Wyckmans, 2015):

(1) Private entrance to dwelling is a protected and sheltered standing space (yes or no question);

(2) Clear boundaries between the private, semi-public and public domains:
- clear boundaries within the private and semi-public domains (neighbour to neighbour, tenant to management, interaction between dwelling and front garden) (yes or no question);
- clear boundaries between private, semi-public and public domains (relation between front yard and street) (yes or no question); and
- use of materials to indicate different domains (yes or no question).

(3) Outdoor private spaces:
   - presence of outdoor private spaces (yes or no question);
   - outdoor private spaces are actually used (yes or no question); and
   - outdoor private spaces on street level (yes or no question).

(4) Uniformity and coherence of boundaries (Weber, 1995) (single building)
   - similarity in facade composition:
     - similarity of architectural elements (similarities in scale and proportion) (yes or no question);
     - similarity of facade decoration and materials (yes or no question); and
     - symmetry and coherence of boundaries are achieved; however, lighting and ventilation demands are overlooked (yes or no question).
   - rhythm of facade composition:
     - ordered repetition of architectural elements to achieve an overall unified effect (yes or no question);
     - differences of formats and sizes of architectural elements (yes or no question); and
     - proportion considered in the figure (window) and ground (wall) articulation (yes or no question).
   - facade roughness (Serra, 1997):
     - presence of projected bounces on the facade (such as balconies and bay windows) (yes or no question);
     - ratio between the total area of projected bounces and the facade area (facade roughness); and
     - similarity of materials used on projected bounces and the facade (yes or no question).

(5) Internal division of space and spatial density and the facade composition (uniformity and coherence of boundaries) before and after intervention:
   - internal division of space impacts similarity of the facade composition (yes or no question);
   - internal division of space impacts the rhythm of the facade composition (yes or no question); and
   - internal division of space impacts the roughness of the facade composition (yes or no question).

2.1.4 Spatial quality assessment for perceived, built and human densities. The fourth spatial quality determinant (4) perceived, built and human densities, considers block physical boundaries; the height-to-width-ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure; and functions in the block, and built and human densities. The following five principles express these topics: (A) the principle of complexity (Lynch, 1960), (B) enclosure and peripheral density (Lynch, 1960; Weber, 1995), (C) built density, (D) human density and (E) functions. The principle of complexity (A) consists of the study of the facade composition in terms of surface contrast, form simplicity and dominance of parts. Surface contrast relates to the quality of continuity of edges or surfaces of the block, nearness of parts (such as a cluster of buildings); and similarity of surface and form among the buildings of the same block (building materials and use of common signs such as repetitive pattern of windows). Principle (B), enclosure and peripheral density of the block, consists of the study of the physical features of the block. The topics belonging to this principle are the height-to-width-ratio of the enclosed space (relation between the dimensions of the courtyard and the heights of the peripheral buildings), the articulation of space boundaries (contrast between the heights of the peripheral buildings) and continuity of space boundaries (perimeter of the block). Built density (C) is measured in square metres and human density (D) in the number of people per square metre of block area. Principle (E) consists of the study of changes in the use of space that occurs because of the dwelling renovation (see list below).

Spatial quality assessment – determinant 4: perceived density, built and human densities (block scale) (Acre and Wyckmans, 2015):

(1) Principle of complexity:

- surface contrasts (Lynch, 1960):
  - continuance of edges of the block (quality of continuity) (yes or no question);
  - similarity of surface and form of the block's boundaries (yes or no question); and
  - 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).
- form simplicity (Lynch, 1960; Serra, 1997):
  - geometry and compactness of the block shape (relation between the external block surface and its volume);
  - porosity of the block shape (presence of exterior spaces within the external perimeter of the block, such as courtyards) (yes or no question); and
  - ratio between the area of exterior spaces within the block's perimeter and the area of the block (porosity of the block shape).
- dominance (Weber, 1995) (impact of one part over others by means of size and proportion, and the interplay between vertical and horizontal):
  - slenderness of the block shape (relation between the vertical and the horizontal volumes of the block);
  - presence of strong vertical accents at the position of the main focus (yes or no question); and
  - presence of a vertical axis of symmetry at the position of the main focus (perceptual stability) (yes or no question).

(2) Enclosure and peripheral density (Weber, 1995):

- 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);
- 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); and
- presence of physical or perceived continuity of space boundaries (perimeter of the block) (yes or no question).

(3) Built density (Uytenhaak, 2008) (per square metre):

- floor space index (fsi) and average number of floors (l = fsi/gsi);
- ground space index (gsi); and
- open space ratio (osr).

(4) Human density (people per square metre of block area):

- percentage of residents of the total users population;
- percentage of non-residents of the total users population; and
- relation between square metres per person and the built area according to the functions' demands.

(5) Functions (use of the space):

- percentage of square metres per function;
- compatibility of functions within the block (yes or no question); and
- functions with low human presence located on the ground and first floors (such as parking and storage areas) (yes or no question).

2.2 Spatial quality assessment and weighting

The goal of the assessment is to predict the nature of the impact of the renovation on spatial quality before the construction. The assessment should be performed during the design phase of projects, i.e. when it is possible to make changes. Each of the four determinants is equally relevant in the study of spatial quality in dwellings (see lists). That is, of the total of 100 per cent, each determinant is given a weight of 25 per cent. While differences in weighting among determinants can be adjusted according to each project, all four determinants should be evaluated. The results of the assessment are first, inserted into Excel sheets, and subsequently transferred to an Excel database to generate the graphs that express the relationships between the renovation and spatial quality. The presence and nature of the impact on spatial quality are illustrated in graphs per building component and are summarised in the results section of this paper. The graphs represent the impact of the renovation only; the higher the bars are, the more significant the impact is, i.e. the bars and values in the graphs do not represent quantities or dimensions.

Throughout the assessment, "patterns of relationships" are identified between two variables, namely the energy renovation of dwellings and spatial quality (Groat and

Wang, 2013, p. 206). The assessment is divided into two parts (A1 and A2) and the aim is to answer two questions for each feature of the spatial quality determinant: Does the measure influence the spatial quality feature (Figure 1(a), Window A1)? And what is the nature of the impact (positive, irrelevant or negative) (Figure 1(b), Window A2)? The existing building as it was prior to the renovation is not assessed – only the impact of the changes on the building is considered. Each renovation measure in the project passes through the two parts of the assessment. For example, ceiling heights with the addition of fire-resistant insulation (150 millimetres) below the existing slab and the principle of "internal division of space and spatial density" (item B) in determinant (2), internal spatiality and spatial arrangements, are considered. In part 1 of the assessment, the question asked is: does the measure influence the ceiling height? The answer is yes, because the addition of fire-resistant insulation (150 millimetres) below the existing slab will lower the ceiling height. In the example of the MS-1 building, the ceiling height before the renovation is 2.50 metres and after the renovation it will be 2.35 metres. In part 2 of the assessment, the question asked is, what is the nature of the impact (positive, irrelevant or negative)? Considering that the height should not be less than 2.40 metres (TEK10 Byggteknisk Forskrift, The Norwegian Agency for Building Quality), the impact in the example is considered to be negative because after the renovation the ceiling height will be reduced from 2.50 to 2.35 metres. If the answer to the question "does the measure influence the ceiling height?" in part 1 of the assessment is "no", the assessment stops because there would be no impact on spatial quality and so no need for evaluation.

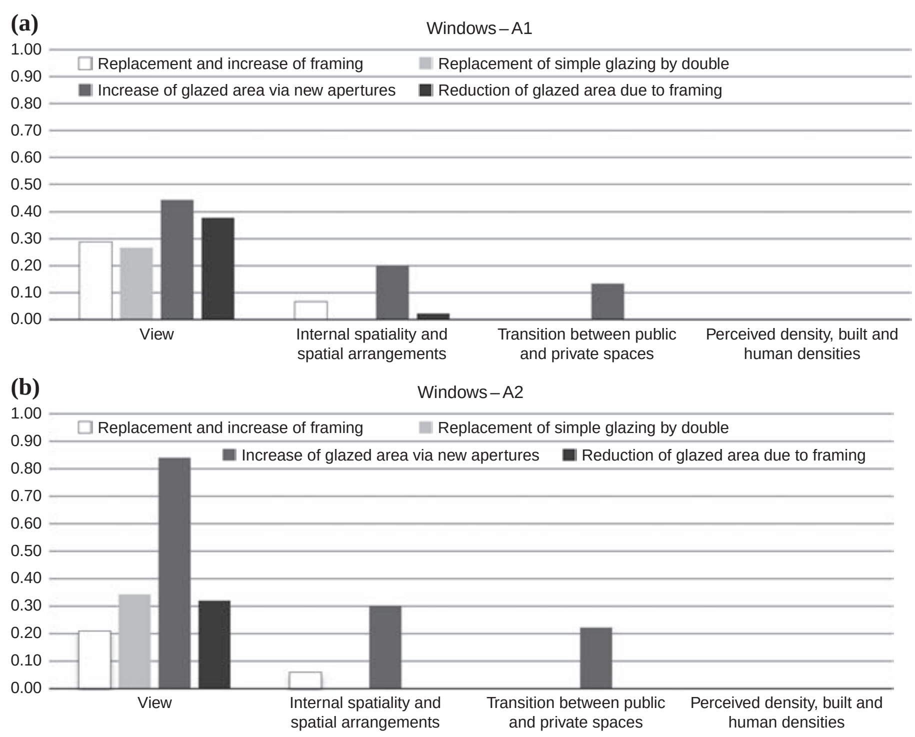

Figure 1.
(a) Assessment 1, the existence of the impact of the renovation of windows on spatial quality, MS-1 building, Arlequin
(b) Assessment 2, the nature of the impact of the renovation of windows on spatial quality, MS-1 building

3. Neighbourhood of Arlequin, Grenoble, France

3.1 Architectural values and cultural heritage

Arlequin was built at the end of Second World War and follows the principles of polemic modernism in architectural and urban design (Figure 2). High-rise apartment blocks surrounded by vast green areas were built in the outskirts of cities in Europe and around the globe. It was believed that architecture and urban design could play a role in improving social conditions and reorganising the city. Collective thinking, community life and living in a healthy environment with proper ventilation and enough daylight were the prevailing paradigms of modern architecture and urban design.

The neighbourhood of Arlequin was planned to accommodate 2,200 homes and to have a wide range of facilities such as schools and a market. Unfortunately, many of the facilities were not built, which deepened the mono-functional residential character of the area. Nowadays, several of such residential neighbourhoods are characterised by degradation and crime; local authorities have been urged to intervene. The renovation of Arlequin represents a trend in the redevelopment of cities and a need for the city to regain these areas.

3.2 Energy renovation of the MS-1 building

The renovation of the Arlequin Neighbourhood had an ambitious target for energy consumption that had to be adjusted because of budget constraints. The initial target was 30 kWh PE/m^2/year for heating, domestic hot water, ventilation and lighting. The current target is 69 kWh PE/m^2/year, though this value does not yet consider the energy production from photovoltaics and biomass. The goals are expected to be achieved by improving the U-values (heat transfer coefficient) and air tightness of the building envelopes. The technical measures that are expected to be implemented in the MS-1 building (Plates 1 and 2, Figure 3) are described in Appendix for the building components of windows, external and internal walls, mechanical services and controls, floors and the built area.

The renovation will bring significant changes in the MS-1 building. Currently, the lifts stop on each successive third floor and the stairs inside the apartments lead to

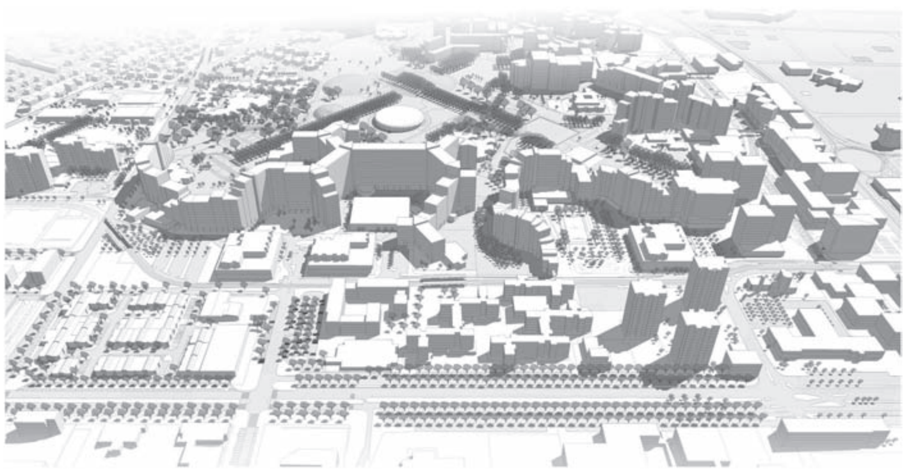

Figure 2.
The Arlequin Neighbourhood and surroundings before the renovation, Grenoble, France

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Source: © (Aktis Architecture & Urbanisme); reproduced by permission of Aktis Architecture & Urbanisme

Plate 1.
MS-1 building before the renovation

Source: © (Aktis Architecture & Urbanisme); reproduced by permission of Aktis Architecture & Urbanisme

Plate 2.
MS-1 building after the renovation

the floors that do not have access to the lifts. The existing lift and staircase tower will be demolished and a new tower will be constructed, which will result in changes to the floor plans (Figure 4(a)-(c)). After the renovation, the lifts will reach half of the apartments up to the 13th floor. The floor plans are identical and therefore they are

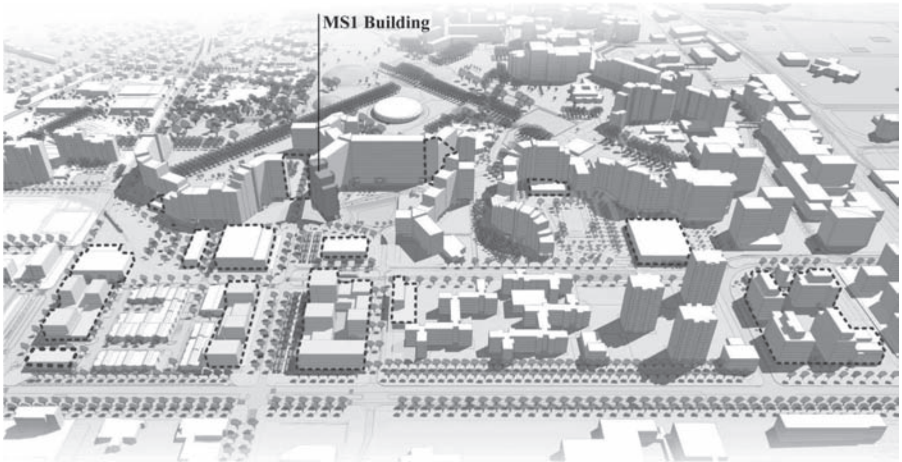

Figure 3.
The MS-1 Building is indicated in the figure. Additions and demolitions of buildings are indicated with dotted lines. Arlequin Neighbourhood after the renovation, Grenoble, France

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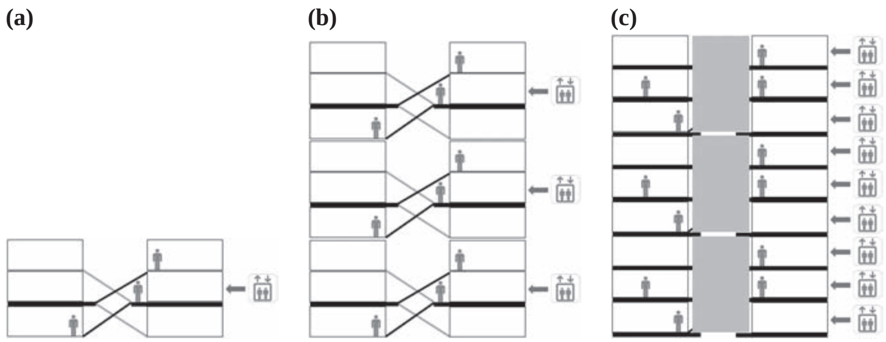


Figure 4.
Schematic drawing of the module with three floors

Notes: The elevator stops on the 2nd floor of the module (4a). Schema of the building; the module is repeated until the 13th floor (4b). Schema of the building after the renovation; the lifts stop on every floor until the 13th floor (4c)

Source: Pictures: Author

grouped according to the changes on the plan: Group A (1st, 3rd and 4th floors), Group B (7th, 9th, 10th, 12th and 13th floors), Group C (2nd and 5th floors) and Group D (13th, 14th and 15th floors). The 6th, 8th and 11th floors are not going to be mentioned in this paper though they were considered for the assessment. Group B is partially mentioned since it is similar to Group A. Groups A and D are presented as examples of the issues evaluated by the spatial quality assessment to simplify the content of this paper.

3.2.1 Windows. Windows will be replaced and openings will be made for new windows in the facades (Appendix). The renovation of the windows will have an overall positive effect on spatial quality. The existing wooden windows with single-glazing in the living rooms will be replaced by new windows with uPVC framing and double glazing. The total glazed area of the facades will be reduced by around 8 per cent due to the new framing in comparison with the existing windows. The glazed area in the living rooms will be reduced by 26 per cent because of the new balcony doors. However, openings will be made for new windows because of the construction of the new tower.

The measures affect three of the spatial quality determinants (Figure 1(a)). The impact of the renovation is particularly relevant for view and internal spatiality and spatial arrangements because of changes to the glazed area. The reduction of the glazed area caused by the new windows' framing reduces facade transparency and the access of daylight into the apartments. However, the addition of new openings for windows partly compensates for the negative impact of the new, more robust framing.

The openings for the new windows in the facade comprise the only measure that impacts (3), the transition between public and private spaces. The overall effect of the new windows on the similarity and rhythm of the facade composition is considered positive. Similarity and rhythm will be emphasised by using shades of yellow between windows, and by the addition of the new windows after the demolition of the tower on the northwest facade (Figure 5). Despite the lack of similarity between the existing windows in the facade, and the new windows that will be installed where the tower faced the building, the new windows together form a block with its own character, regularity and symmetry (Figures 5). However, the size of the new windows scores negatively in the assessment because the windows' length is not at least half of the room's depth, which compromises lighting in the rooms (European Committee for

Notes: Before (5a) and after (5b) the renovation (Figure A1)

Source: Pictures: Author

Figure 5.
North-west facade

Standardization, CEN, 2015). That is, symmetry and coherence of the facade composition are achieved at the cost of failing to meet lighting demands.

3.2.2 External walls. The renovation of external walls consists of the addition of 120 millimetres of external insulation with coloured coating and the renovation of balconies (Appendix). The measures affect the four spatial quality determinants (see lists) (Figure 6(a)). The addition of external insulation affects the determinants (1) and (2) because it results in thicker external walls, which negatively affects daylight access. The balconies on the southwest facade will be more transparent after the renovation, and will have a lower possibility of controlled visual contact with neighbours' private outdoor space. However, balconies that are more transparent allow significant improvements for daylight access.

The changes to the facade have a considerable impact on determinants (3) and (4) (see lists). Metal covering will be applied on the northwest facade to the new lift and staircase tower to improve ventilation. After the renovation, facades and balconies will have changed, but the facades will keep the existing similarity in composition in terms of materialisation, scale and proportion, emphasising the different parts. The colours will be white and grey. The balconies will be more transparent after the renovation following the removal of the existing planters and railings and from using perforated metal applied up to the slab edge on the southwest facade (Figure 7). Since the existing tower disturbs the symmetry and rhythm of the composition as a whole, the impact of the removal of the tower is considered positive in terms of the

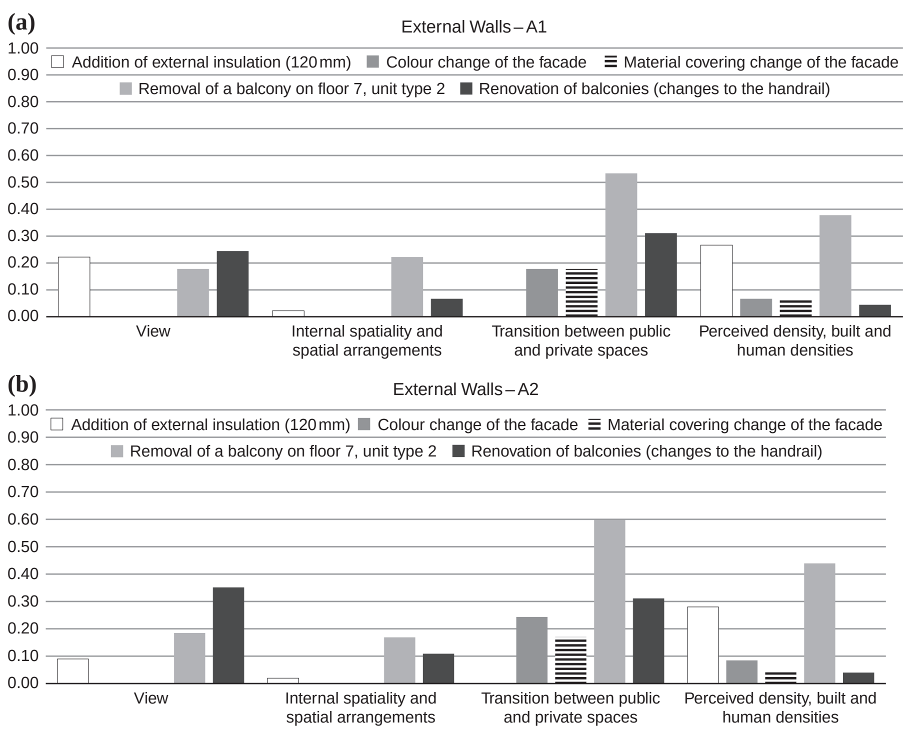
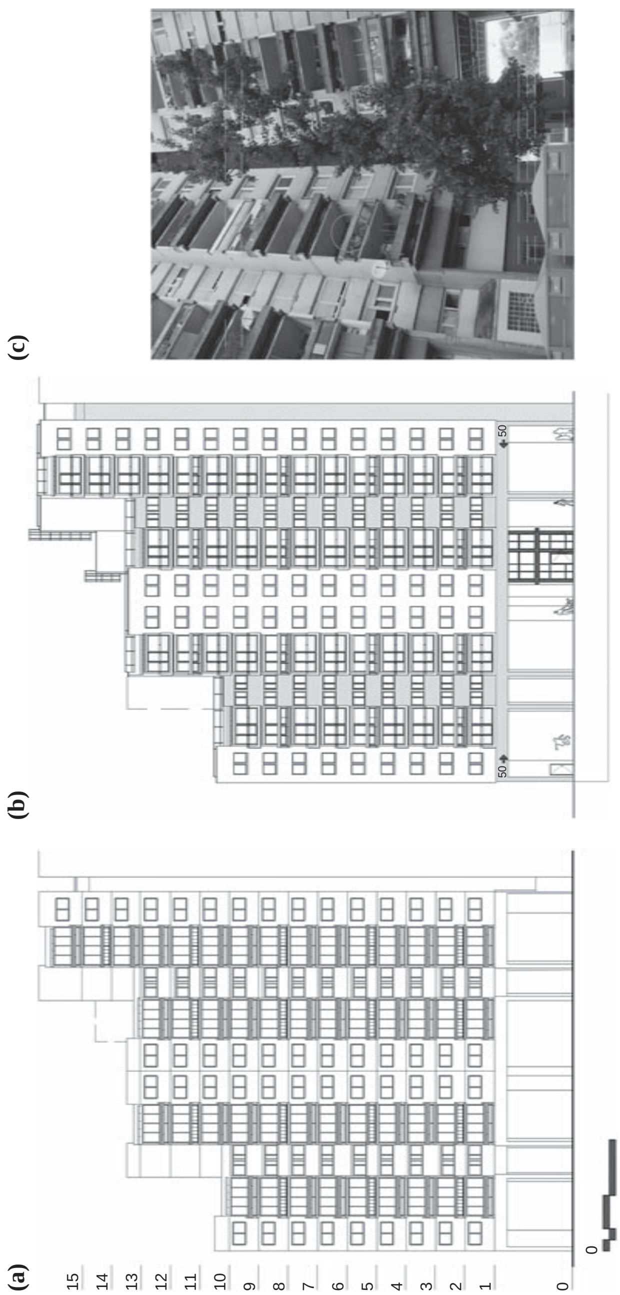


Figure 6.
(a) Assessment 1, the existence of the impact of the renovation of external walls on spatial quality, MS-1 building, Arlequin (b) Assessment 2, the nature of the impact of the renovation of external walls on spatial quality, MS-1 building



Notes: Before (7a) and after (7b) the renovation (Figure A2); Balconies before (7c) the renovation
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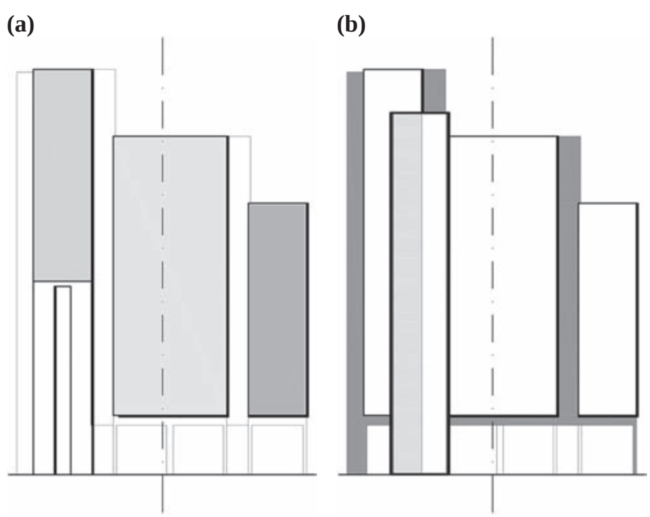
Figure 7.
Southwest facade

uniformity and coherence of the facade (Figures 5 and 8). The metal covering the new tower will be considerably different in appearance from the materials used in the immediate surroundings (determinant 4). The new tower will also create a strong vertical accent near the main focus (midpoint) of the facade, which contrasts with the neighbouring buildings and their predominant horizontal accent (Figures 3 and 8).

3.2.3 Mechanical services and controls. The renovation of mechanical services in the MS-1 building is characterised by passive strategies, such as increasing solar gain, lighting and avoiding overheating by having new openings on the facade (Appendix). Therefore, the assessment for mechanical services is equal to the assessment for windows (Section 3.2.1). The overall effect is positive as indicated in Figure 9(a) and (b).

3.2.4 Internal walls. The changes to internal walls will mainly impact the spatial quality determinants (1) and (2) (see lists) (Appendix). Some of the apartments in the building will have their entrance on their floor level, which eliminates the need to go either up or down the stairs that are currently inside the apartments. The construction of the new tower will lead to significant changes in the area of the units. Apartments in Groups A will decrease by 20 square metres (Figure 10) while apartments in Group C will increase by 50 square metres (Figure 11). Group D willhave one loft apartment, a result of the merging of two units. Also in Group D, a unit type 2 will be created



Notes: Scheme before (8a) and after (8b) the renovation. Before the renovation, the front layer was painted in shades of yellow and orange, and the setback layer between the three parts was in light yellow (indicated in white in Figure 8a). There will still be a difference in colours between the front and the back layers after the renovation, but they will be white and grey. The strong vertical accents that will be present after the renovation (8b) were previously non-existent (8a)

Source: Pictures: Author

Figure 8.
Northwest facade

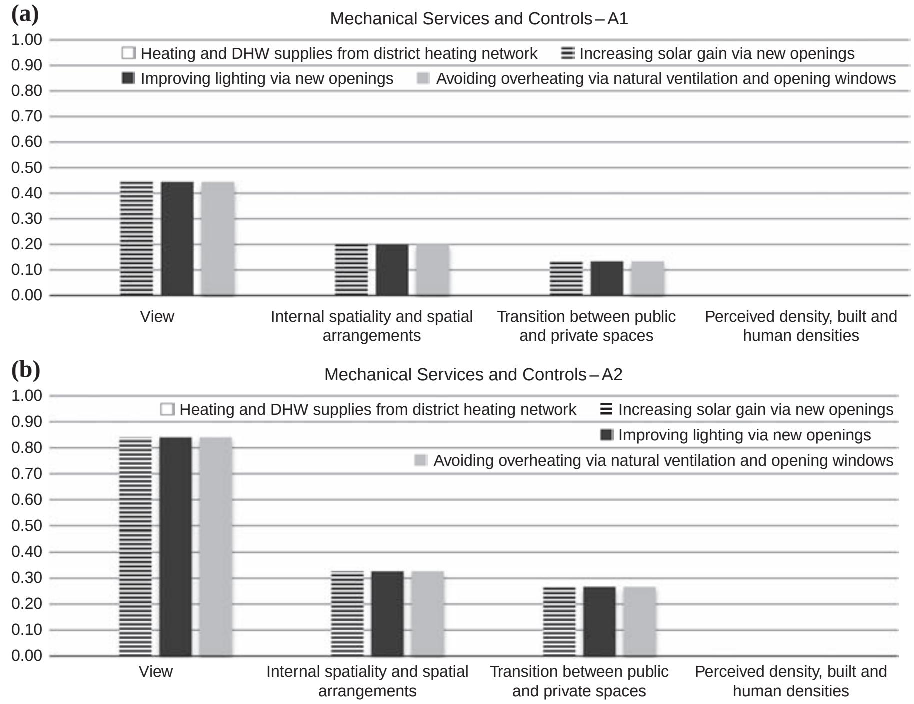


Figure 9.
(a) Assessment 1, the existence of the impact of the changes on mechanical services on spatial quality, MS-1 building, Arlequin (b) Assessment 2, the nature of the impact of the changes on mechanical services on spatial quality, MS-1 building

from the merging of the apartment with the former circulation area on the 14th floor (Figures 12 and 13).

View (determinant 1) is the second determinant in terms of the relevance of the impact of the changes to internal walls on spatial quality (Figure 14). After the renovation, there will be a larger number of dwelling spaces with views on the northwest facade. Daylighting and views from the apartments, which face the circulation tower, will benefit considerably from the removal of the tower. Visual privacy and protection of the private domain improve with the new entrances and larger halls in these apartments. The facade loses a total of 20 windows. Moreover, the window framing will increase, reducing the surface area of the glass. On the other hand, there will be an additional 12 windows on the facade after the renovation (Figures 5, 7, 10 and 11). However, the new windows will be insufficient in terms of daylighting. According to CEN (2015), if the room depth (d) is $d \leqslant 5$ m, the window area (wa) should be least 1.25 m^2 and if $d > 5$ m, $wa = 1.50$ m^2.

The units will improve significantly following the renovation in terms of determinant (2), despite the decrease in the apartments' area and the lower ceiling height, which cast a shadow on the benefits of the renovation. In Group A, the apartments will lose bedrooms, in Group C, apartment type 1 will lose part of the living room, and apartment type 2 will get extra bedrooms because of the construction of the new tower. Privacy within the dwelling will improve with the addition of the extra bedrooms (Figures 10 and 11).

In Group B apartments, the non-structural wall and the sliding door between the two bedrooms will be removed (Figure 15). This represents a considerable improvement

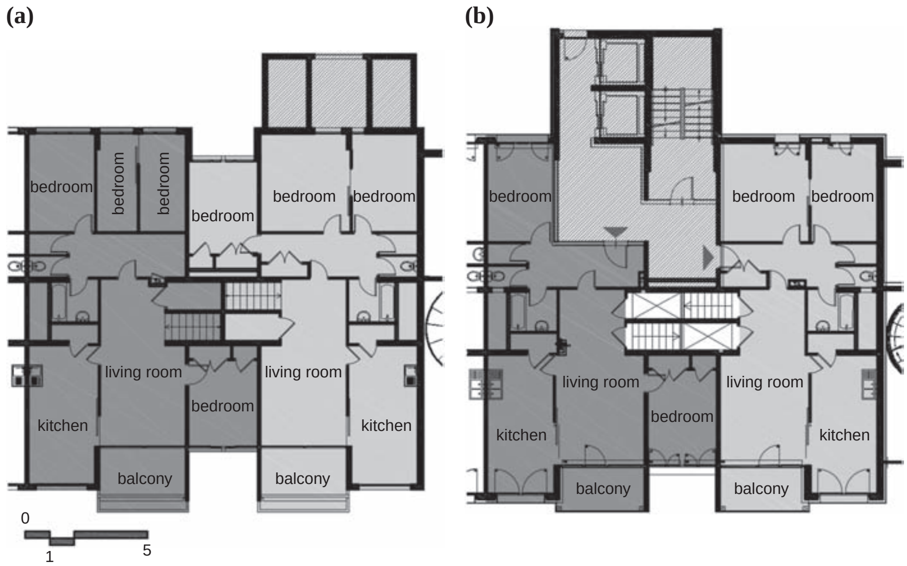


Figure 10.
Group A – Fragment of the 1st, 3rd and 4th floors before (9a) and after (9b) the renovation

Notes: The images indicate apartment types 1 (left on the images) and 2 (right on the images) that will decrease by 20 m^2 (indicated in shades of grey in the black and white print, or orange and yellow in the colour print) (Appendix 4)

Source: Pictures: Author

because, first, once the sliding door is open, the geometrical centres of the spaces are weakened. Second, the proportions of the bedrooms before the removal of the non-structural wall are not adequate in terms of the degree of space closure (ratios between the height and width, and width and length of the space).

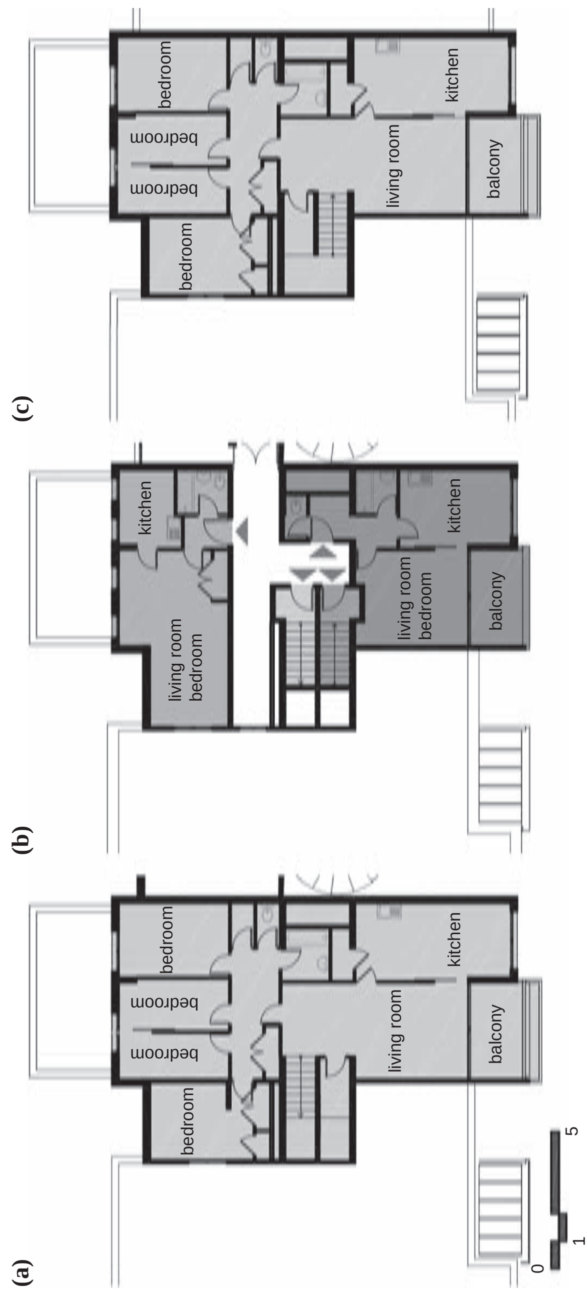
A change that affects determinant (2) in the unit type 2 in Group D, is the addition of the former corridor to the area of the apartment (Figures 12 and 13). This addition creates a subordinated spatial relationship between the main room of the apartment (primary space) and the former corridor (secondary space). However, after its addition to the unit, the former corridor does not clearly complement the main room in terms of function. The impact of the space generated by the former corridor is considered negative in terms of the degree of space closure. This is because the ratios between height and width, and width and length indicate that the proportions of the room are not adequate for a space where residents can spend the majority of their time. The new space generated by the former corridor consists of a circulation area that is used to access the new bathroom (Figures 12 and 13).

3.2.5 Floors. The renovation of floors consists of the addition of fire-resistant insulation of 150 millimetres below the existing concrete slab (Appendix). The measure affects the spatial quality determinants (1) and (2) (see lists) (Figure 16). The ceiling height of 2.50 metres will be reduced to 2.35 metres after the renovation. This measure is considered negative because the minimum ceiling height accepted in the spatial quality assessment is 2.40 metres (TEK10). The ratio between the height and the width of the space will be lower and the daylight (passive) zone will be reduced (Baker and Steemers, 1996, 2002). The daylight factor (DF) and the luminance distribution (Matusiak, 2006, 2014, 2015; CEN, 2015) are also affected by the change to ceiling heights.

Notes: At the top left corner of the images is apartment type 1 that will decrease by 15 m^2. At the bottom right corner is apartment type 2 that will increase by 50 m^2 (indicated in shades of grey in the black and white print, or green and blue in the colour print) (Figure A4)

Source: Pictures: Author

Figure 11.
Group C – Fragment of the 2nd and 5th floors before (11a) and after (11b) the renovation



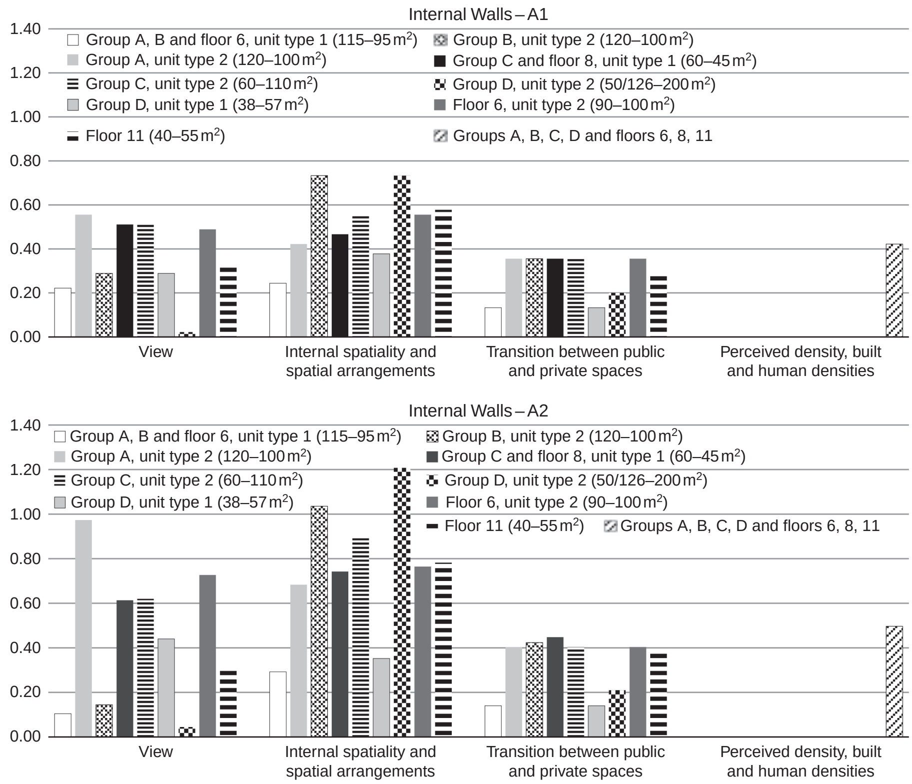
Source: Pictures: Author

Figure 12.
Group D – Fragments of the 13th, 14th and 15th floors before the renovation (Appendixes A5, A6 and A7)

Notes: The apartment type 1 on the 13th floor will decrease by 20 m^2 (13a) and its entrance will be moved to the 13th floor. The apartment types 2 and 3 (13a to 13c) will also have their entrance moved to the 13th floor. The type 2 apartment will increase by 19 m^2 (shown at the top of Figure 13b) and the type 3 apartment (13a to 13c) will result from the merging of 2 units into a new unit of 200 m^2 (indicated in shades of grey in the black and white print, or yellow, green and blue in the colour print) (Appendixes A5, A6 and A7)

Source: Pictures: Author

Figure 13.
Group D – Fragments of the 13th, 14th and 15th floors after the renovation



Notes: The measure of addition of a new tower is the same for the four determinants, therefore they are grouped in the item "Groups A, B, C, D and floors 6, 7, 11" only for the assessment of (4) perceived, built and human densities

Figure 14.
(a) Assessment 1, the existence of the impact of the renovation of internal walls on spatial quality, MS-1 building, Arlequin (Table A1): (b) Assessment 2, the nature of the impact of the renovation of internal walls on spatial quality, MS-1 building, Arlequin (Table A1)

3.2.6 Built area. The impact of the renovation on the built area (FSI – floor space index) consists of the demolition of the existing lift and staircase tower and the construction of the new tower (Appendix). The changes to the built volume affect the four spatial quality determinants (see lists) (Figure 17). The measure affects spatial quality determinants (1) and (2) in terms of lighting and the quality of the view. The impact of the renovation on determinant (3) consists of the effect on the similarity in scale and proportion among the different volumes of the building (Figure 8).

Determinant (4), perceived, built and human densities, is the most influenced by the changes to the building volume (Figure 17). The main impact of the renovation on determinant (4) is on the principle of complexity. After the renovation, the building will have a vertical accent, and the symmetry among the three parts that existed before the renovation will be disturbed (Figure 8).

4. Results and discussion

The results indicate that the energy renovation of the MS-1 building affects spatial quality in several of the apartments, and that the overall impact of the renovation on spatial quality is expected to be positive. This impact varies considerably per determinant and

Source: Pictures: Author

Figure 15. Group B – Drawings of bedrooms of the apartment type 2 before (13a) and after (13b) the renovation

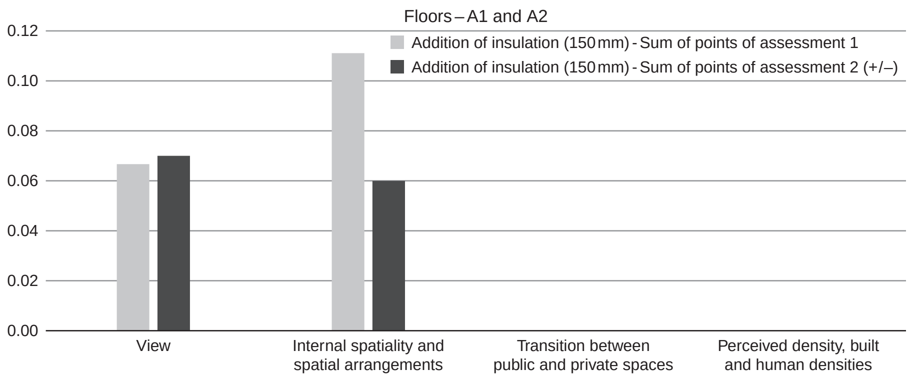


Figure 16. Assessment 1 (light grey bars), the existence of the impact of the renovation of floors on spatial quality, MS-1 building, Arlequin. Assessment 2 (dark grey bars), the nature of the impact of the renovation of floors on spatial quality, MS-1 building

building component (Figure 18). Determinants (1), views, and (2), internal spatiality and spatial arrangements, are the most affected by the renovation of the MS-1 building.

Lower grey bars rather than black ones, are warning signs of the assessment because they indicate the negative effect of the renovation on spatial quality (Figure 18). Regarding determinants (1) and (2) the spatial quality will be worse due to measures applied in the renovation of floors and external walls. However, changes to internal walls, windows, mechanical services and the built area will have a positive impact on spatial quality for the same determinants. In relation to determinants (3) and (4) the overall impact on spatial quality is expected to be positive.

The negative impact of the renovation of floors on (1), views, and (2), internal spatiality and spatial arrangements, is because of the lower ceiling height after the renovation (2.35 metres). The negative impact is observed in the daylight factor and the luminance distribution. The internal division of space and spatial density, and the ratio between the daylight (passive) and the non-daylight (non-passive) zones are the features that are negatively affected by the lower ceiling height in determinant (2).

The renovation of external walls of the MS-1 building has a negative impact on the spatial quality determinants (1) and (2) (Figure 18). The addition of external insulation of 120 mm scores negatively in relation to the access of daylight. The significantly higher transparency of the handrails after the renovation is beneficial for the access of daylight, but it affects the control of the visual contact with the neighbours' private outdoor spaces. The new tower and the change to the material covering of the facade will negatively affect the similarities of surface, form and facade composition because the facade will look considerably different from the existing surrounding buildings after the renovation.

The renovation of internal walls has an overall positive impact on spatial quality (Figure 18). However, the changes on the floor plans will decrease the area of several units and therefore the number of windows. Fewer windows decrease the facade transparency, which scores negatively in the assessment of determinant (1). In addition, the new windows after the renovation will not fulfil the CEN's (2015) requirement, in which the window's length should be equal to at least half of the room depth, and therefore this leads to a negative effect on the assessment. The changes to internal walls have, somehow, a negative impact on determinant (2). Examples of this negative impact are in the differentiation between social and private zones, and in the buffer zone between the children's and the parents' private domains, which are weakened by the decrease in area in several units. The addition of 19 square metres of the former circulation space of the corridor to the unit type 2 in Group D also has a negative impact on determinant (2) (Figures 12 and 13).

The negative effect of the renovation of windows is observed on determinants (1) and (2) and a positive effect is observed on determinant (3) (Figure 18). The windows will be changed for new windows with a more robust framing. The increase in the framing area and consequently the decrease in the glazed area of the windows scores negatively related to determinants (1) and (2). The decrease in the glazed area has a

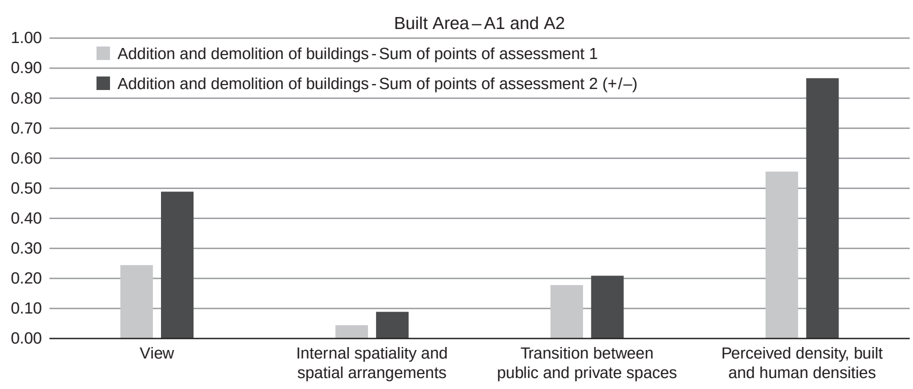
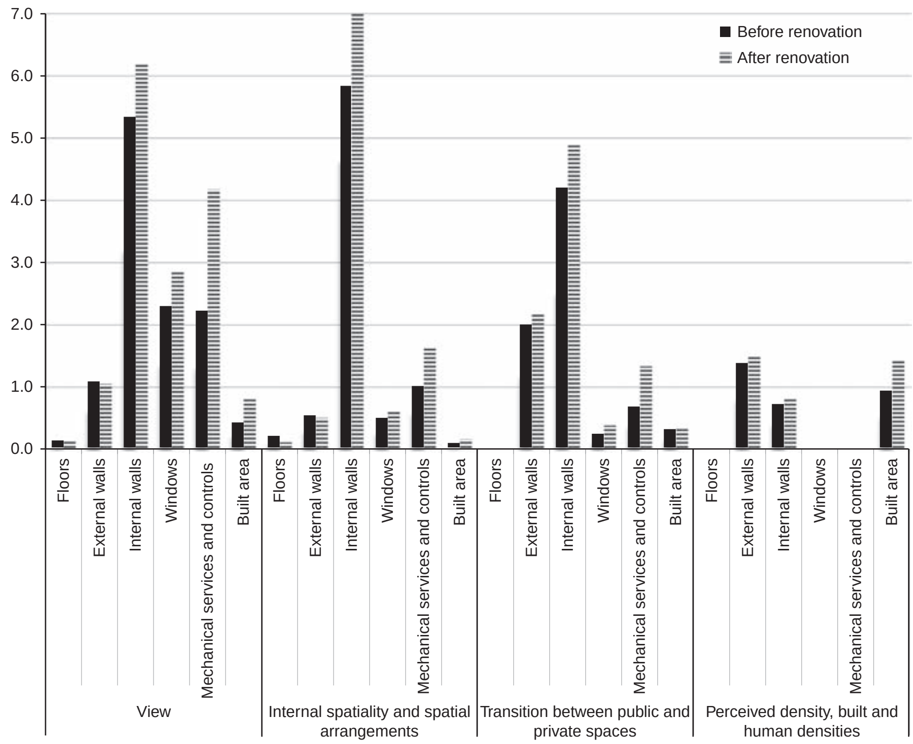


Figure 17. Assessment 1 (light grey bars), the existence of the impact of the changes on the built area on spatial quality, MS-1 building, Arlequin. Assessment 2 (dark grey bars), the nature of the impact of the changes on the built area on spatial quality, MS-1 building



Notes: The impact of the dwelling renovation (Table A1) on spatial quality is indicated per building component. The dark bars represent the existence of the impact of the renovation on spatial quality while the light grey bars represent the nature of the impact on spatial quality if the renovation is carried out as planned

Figure 18. Spatial quality assessment of the MS-1 building before and after renovation

negative impact on the access to and distribution of daylight wherein the ratio between the glazed area and the indoor surfaces' area decreases. The symmetry and coherence of the facade composition (3) are achieved to the detriment of lighting and ventilation demands. That is, the new openings remain small but follow the existing pattern of windows. However, the similarity and rhythm of the facade composition after the renovation scores positively in the assessment. This is because the similarity of the new windows in terms of materialisation, scale and proportion, and their ordered repetition achieves an overall unified effect in the facade composition. In addition, windows in diverse formats and sizes are used to create rhythm.

The changes to the built area have an overall positive effect on spatial quality (Figure 18). The demolition of the existing tower will increase daylight and view conditions in several units. Despite the lack of rhythm between the new tower and the existing building volumes, the addition of the tower scores positively in relation to the built area and functions in determinant (4). This is because of the efficient use of the space in the new tower, which will house two lifts bigger than the existing ones, a staircase and a hall. The new tower will increase the total plot area of the building by a mere 2.11 per cent or 11 square metres.

5. Conclusion and further work

This paper indicates how the renovation of dwellings for energy efficiency is expected to impact spatial quality in the MS-1 building in Arlequin. From analysis of drawings before and after the renovation, it is clear that the overall impact of the renovation is positive (Figure 18). However, despite the numerous improvements made by the renovation to the spatial quality in the dwellings, the assessment leads to the conclusion that some key points of the renovation should be re-evaluated.

Alternatives for the renovation that do not solely consider energy efficiency should be explored in order to achieve a balance between existing negative conditions and how the renovation can help to improve them. The impact on daylight, for example, needs to be further evaluated. The increase in the framing area and consequently the decrease in the glazed area of the windows affect daylight and view conditions. The lower ceilings also affect daylight and luminance distribution; however, the lower ceilings do not necessarily affect luminance distribution in a negative manner, for example if the glazed area remains unchanged. The challenging issue in the renovation of the MS-1 building is the combination of negative existing features such as small windows and deep rooms with renovation measures that worsen these features. Such measures are the increase in the framing area and smaller openings, the decrease in the glazed area, the lower ceiling height, thicker external walls and deep and narrow rooms.

Alternatives should be explored for reducing the negative impact of the renovation on spatial quality. The main renovation measures that should be reviewed are:

(1) Addition of fire-resistant insulation of 150 millimetres below the existing reinforced concrete slab of 120 millimetres. The current ceiling height is 2.50 metres, and after renovation it will be 2.35 metres (TEK10).

(2) Addition of external insulation of 120 millimetres.

(3) Renovation of balconies and changes to the handrails. The handrails after the renovation will be significantly more transparent, which affects the control of the visual contact with the neighbours' private outdoor spaces.

(4) Change of the material covering the facade. Metal covering will be applied on the new lifts' and stairs' tower. The facade will considerably different from the existing surrounding buildings after the renovation.

(5) New windows and new openings. The new openings will remain small following the existing pattern of windows.

(6) Replacement and increased area of framing. The existing framing will be removed in all levels and more robust uPVC framing will be installed.

(7) The addition of 19 square metres of the former corridor to the unit type 2 in Group D (Figures 12(b) and 13(b)). The space of the corridor will be added to the area of the apartment, but the proportion (ratios between height and width, and width and length) of the corridor limits its use.

Some opportunities for improvements that were overlooked by the renovation plan were identified during the spatial quality assessment. The possibilities for improvements did not influence the assessment's results. The entire building will be renovated but the floor plans will only be partially improved. After the renovation, only the units on the right-hand side of the building will gain direct access to the new lift and staircase tower on their level. The apartments on half of several floors will still have stairs inside the units as the main entrances and will not gain access to elevators on their level. This is considered to be a lost opportunity in the renovation. In addition, the large ground floor will remain characterised by as being used for activities with low human presence.

This work indicates both the potential and the limitations of the spatial quality assessment, and it encourages the whole building approach in dwelling renovation, which gives directions for further work. A comparison between the situation before and after the renovation is proved to be an efficient way to trace challenges for spatial quality in the renovation strategy. However, one limitation of the assessment is that it does not cover all aspects of spatial quality. The analysis of the MS-1 building indicates that the spatial quality assessment is sensitive to negative effects, but this sensibility should be higher considering the number of renovation measures that should be reviewed in the MS-1. That is, all the negative impact does not clearly appear in the results because of the equal weighting given to all measures in the assessment.

The main strength of the assessment is that it illustrates the weaknesses of renovation strategies that focus on energy efficiency and overlook non-technical concerns. However, further work is necessary to increase the sensitivity of the assessment to measure negative effects. Assessing spatial quality in building renovation promotes more than only improvements on energy performance. It also makes building renovation more attractive by increasing perceived spatial values to building owners and users. The next step of this work is to develop the assessment and to explore the potential of spatial quality as an incentive for energy renovation. This can be achieved by creating guidelines to promote synergies and avoid conflicts between non-technical dimensions such as spatial quality, and energy renovation.

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References

Acre, F. and Wyckmans, A. (2014), "Spatial quality determinants for building renovation: a methodological approach to the development of spatial quality assessment", *International Journal of Sustainable Technology & Urban Development, SUSB*, Vol. 4 No. 3, pp. 183-204. doi: 10.1080/2093761X.2014.923793.

Acre, F. and Wyckmans, A. (2015), "Dwelling renovation and spatial quality: the impact of the dwelling renovation on spatial quality determinants", *International Journal of Sustainable Built Environment, IJSBE*, Vol. 4 No. 1, pp. 12-41. doi: 10.1016/j.ijsbe.2015.02.001.

Alexander, C., Ishikawa, S. and Silverstein, M. (1977/1978), *A Pattern Language: Towns, Buildings, Construction*, Oxford University Press, New York, NY.

Ashihara, Y. (1981), *Exterior Design in Architecture*, Van Nostrand Reinhold, New York, NY.

Baker, N. and Steemers, K. (1996), "LT Method 3.0: a strategic energy-design tool for Southern Europe", *Energy and Buildings*, Vol. 23 No. 3, pp. 251-256. doi: 10378-7788(95)00950-3.

Baker, N. and Steemers, K. (2002), *Daylight Design of Buildings*, James & James, London.

Bettgenhäuser, K., de Vos, R., Grözinger, J. and Boermans, T. (2014), "Deep renovation of buildings: an effective way to decrease Europe's energy import dependency", Project No. BUIDE14901, Ecofys Germany GmbH by order of Eurima, Köln, available at: www.ecofys.com (accessed July 2014).

Building Research Establishment Environmental Assessment Method (BREEAM) UK (2008), UK 2008 for Major Refurbishment, available at: www.breeam.org/ (accessed August 2014).

Building Research Establishment Environmental Assessment Method (BREEAM) (2008), Multi-residential use, available at: www.breeam.org/ (accessed August 2014).

Building Research Establishment Environmental Assessment Method (BREEAM) (2012), Refurbishment Domestic Buildings, available at: www.breeam.org/ (accessed August 2014).

Buildings Performance Institute Europe (BPIE) (2011), *Europe's Buildings Under the Microscope: A Country-by-Country Review of the Energy Performance of Buildings*, BPIE, Brussel, available at: www.bpie.eu/eu_buildings_under_microscope.html (accessed June 2014).

Buildings Performance Institute Europe (BPIE) (2013), *A Guide to Developing Strategies for Building Energy Renovation – Delivering Article 4 of the Energy Efficiency Directive*, BPIE, Brussel, available at: www.bpie.eu/documents/BPIE/Developing_Building_Renovation_Strategies.pdf (accessed June 2014)

Chermayeff, S. and Alexander, C. (1963/1966), *Community and Privacy: Toward a New Architecture of Humanism*, Pelican Books, Aylesbury and Bucks, PA.

European Committee for Standardization (CEN) (2015), "CEN/TC 169/WG 11 N50 – Daylight of Buildings", Working Document No. prEN xxxx: 2013.7, European Standard, CEN, 2015, Brussels.

Gehl, J. (2010), *Cities for People*, Island Press, Washington, DC.

Gehl, J. (2011), *Life Between Buildings: Using Public Space*, Island Press, Washington, DC.

Groat, L. and Wang, D. (2013), *Architectural Research Methods*, John Wiley & Sons, New York, NY.

Indraprastha, A. and Shinozaki, M. (2012), "Computation model for measuring spatial quality of interior design in virtual environment", *Building and Environment*, Vol. 49 No. 1, pp. 67-85. doi: 10.1016/j.buildenv.2011.09.017.

Leadership in Energy and Environmental Design, LEED® 2009 for Existing Buildings (2009), available at: www.usgbc.org/LEED (accessed August 2014).

Leadership in Energy and Environmental Design, LEED® 2008 for Homes (2013), available at: www.usgbc.org/LEED (accessed August 2014).

Lynch, K. (1960), *The Image of the City*, MIT Press, Cambridge, MA.

Matusiak, B. (2006), "The impact of window wall design on the size impression of the room. Full-scale studies", *Architectural Science Review*, Vol. 49 No. 1, pp. 43-51.

Matusiak, B. (2014), "Discussions on daylight definition and assessment", Personal communication, Trondheim, 17 March and 9 May.

Matusiak, B. (2015), "Discussions on definitions of daylight factor and luminance distribution", Personal communication, Trondheim, 8 April.

Moulaert, F., Schreurs, J. and Van Dyck, B. (2011), "Reading space to address spatial quality", *paper presented at the SPINDUS Conference, Spatial Innovation Planning Design and User Involvement, January, Leuven*, available at: http://e-scapes.be/spindus/download/Addressing%20spatial%20quality.pdf (accessed January 2014).

Nasar, J.L. (1992/2000), "The evaluative image of places in person environment psychology: new directions and perspectives", in Walsh, W.B., Craik, K.H. and Price, R.H. (Eds), *Person-Environment Psychology: New Directions and Perspectives*, Lawrence Erlbaum Associates Publishers, Mahwah, NJ, pp. 117-169.

Nearly Zero Energy neighbourhoods, ZenN (2012), "Seventh Framework Programme Part B", collaborative project with predominant demonstration component, report, project description, available at: http://zenn-fp7.eu/ (accessed May 2015).

Owens, P.M. (2008), *Beyond Density: Measuring Neighborhood Form. Deriving Urban Form Measures for Neighborhoods, Blocks, and Streets in New England Towns*, VDM Verlag, Berkeley, CA.

Pacheco, F. and Wyckmans, A. (2013), "Spatial quality assessments for building performance tools in energy renovation", *Conference of Sustainable Buildings SB13 Contribution of Sustainable Buildings to Meet EU 20-20-20 Targets*, *October*, *Guimaraes*, ISBN 9789899654372: 473-480.

Rapoport, A. (1970), "The study of spatial quality", *Journal of Aesthetic Education*, Vol. 4 No. 4, pp. 43-58, in Rapoport, A. (Ed.) (1994), *Thirty Three Papers in Environment-behaviour Research: Includes a Complete Bibliography of the Author's Work*, Urban International Press, Newcastle-upon-Tyne.

Rapoport, A. (1971), "Human and psychological reactions", paper presented in the Symposium on the Environmental Aspects of the Design of Tall Buildings, December, Sydney, Australia, available in *Architecture Science Review*, Vol. 14 No. 2, pp. 125-135, in Rapoport, A. (1994) (Ed.), *Thirty Three Papers in Environment-behaviour Research: Includes a Complete Bibliography of the Author's Work*, Urban International Press, Newcastle-upon-Tyne.

Russell, J.A. and Snodgrass, J. (1989), "Emotion and environment", in Stokols, D. and Altman, I. (Eds), *Handbook of Environmental Psychology*, John Wiley, New York, NY, pp. 245-280.

Serra, R. and Koch, H. (1997), *L'Energia nel Progetto di Architettura [Energy in the Project of Architecture],* Citta Studi, Torino.

Sustainable Buildings Tool, SBTool (2012), iiSBE, available at: www.iisbe.org/ (accessed August 2014).

Tweed, C. (2013), "Socio-technical issues in dwelling renovation", *Building Research & Information*, Vol. 41 No. 5, pp. 551-562.

Uytenhaak, R. (2008), *Cities Full of Space: Qualities of Density*, 010 Publishers, Rotterdam.

Von Meiss, P., Frampton, K. and Oswald, F. (2011), *Elements of Architecture: from Form to Place*, Routledge, London.

Weber, R. (1995), *On the Aesthetics of Architecture: A Psychological Approach to the Structure and the Order of Perceived Architectural Space*, Avebury, Aldershot.

Further reading

TEK10 Byggteknisk Forskrift (The Norwegian Agency for Building Quality), "§ 12-7. Krav til rom og annet oppholdsareal", available at: http://dibk.no/no/BYGGEREGLER/Gjeldende-byggeregler/Veiledning-om-tekniske-krav-til-byggverk/ (accessed January 2015).

Appendix

Windows
1. Replacement and increase of framing, the existing woodwork in the living rooms will be removed in all levels and PVC framing will be installed.
2. Replacement of simple glazing in the living rooms by double glazing ($U = 1.4 W/m^2.K$)
3. Increase of glazed area, new openings: lifts' doors will be closed and widows will be installed on the upper part of the opening, the lower part will be closed with a brick wall.
4. Reduction of the glazed area: due to the framing the new windows can have up to 8% less glazing area than the existing windows.

External Walls
1. External walls with external insulation: Addition of external insulation 120 mm.
2. Colour change of the facade: The current shades of yellow will be changed with grey, white or red brown colour coating.
3. Material covering change of the facade: Metal covering will be applied on the new lifts' and stairs' tower.
4. Renovation of balconies (changes on the handrail): Removal of the existing planters and railings in all levels where they are found
   Perforated metal applied until the slab edge with thermostatic grey painting.
5. Removal of a balcony on floor 7, unit type 2: Removal of the existing balcony of the apartment number 304 on the 7th floor

Mechanical Services and Controls
1. Heating supply from district heating network.
2. Domestic hot water (DHW) supply from district heating network.
3. Increasing solar gain by new openings.
4. Lighting installations improved by new openings to maximise the use of daylight by architectural means in order to minimise artificial lighting energy.
5. Avoiding overheating by natural ventilation for cooling through opening windows and new windows with "2 ways" valve regulation.

Internal Walls
1. Group A and 6th floor, unit type 1: Change in the plan (area decrease), floors 1, 3, 4 and 6. Unit before the renovation: 115 m^2; after the renovation: 95 m^2. Changes in the apartments' entrance; changes on the lifts' and staircase's tower; decrease in the number of bedrooms.
2. Group A, unit type 2: Change in the plan (area decrease), floors 1, 3 and 4. Unit before the renovation: 120 m^2; after the renovation: 100 m^2. Changes in the apartments' entrance; changes on the lifts' and staircase's tower; decrease in the number of bedrooms.
3. Group B, unit type 1: Change in the plan (area decrease), floors 7, 9, 10, 12 and 13. Unit before the renovation: 115 m^2; after the renovation: 95 m^2. Changes in the apartments' entrance; changes on the lifts' and staircase's tower; decrease in the number of bedrooms.
4. Group B, unit type 2: Change in the plan (area decrease), floors 7, 9, 10, 12 and 13. Unit before the renovation: 120 m^2; after the renovation: 100 m^2. Changes in the apartments' entrance; changes on the lifts' and staircase's tower; decrease in the number of bedrooms.
5. Group C and 8th floor, unit type 1: Change in the plan (area decrease), floors 2, 5 and 8. Unit before the renovation: 60 m^2; after the renovation: 45 m^2. Changes on the lifts' and staircase's tower; part of the living room is lost with the new tower.
6. Group C, unit type 2: Change in the plan (area increase), floors 2 and 5. Unit before the renovation: 60 m^2; after the renovation: 110 m^2. Changes on the lifts' and staircase's tower; addition of two bedrooms.

(*continued*)

Table AI.
Renovation measures and description. [a]Building components of windows, external walls, mechanical services, internal walls, floors and built area

7. Group D, unit type 1: Change in the plan (area increase), floor 14. Unit before the renovation: 38 m^2; after the renovation: 57 m^2. Changes on the lifts' and staircase's tower; unit's entrance moved from the 14th to the 13th floor; addition of stairs inside of the unit; former collective circulation area is added to the unit.
8. Group D, unit type 2: Change in the plan (area increase), floors 14 and 15. Units before the renovation: 50 m^2 and 126 m^2; merge of 2 units into a single unit: 200 m^2. Changes on the lifts' and staircase's tower; merge of two units to one; unit's entrance moved from the 15th to the 13th floor; stairs inside of the unit connects three floors.
9. 6th floor, unit type 2: Change in the plan (area increase), floor 6. Unit before the renovation: 90 m^2; after the renovation: 100 m^2. Changes in the apartments' entrance; changes on the lifts' and staircase's tower; increase in the number of bedrooms.
10. 11th floor: Change in the plan (area increase). Units before the renovation: 40 m^2 and 30 m^2; single unit after the renovation: 55 m^2. The apartment unit of 30 m^2 will be removed; addition of one bedroom to the new unit.

Floors

1. Solid concrete floors: addition of fire-resistant insulation 150mm below the existing reinforced concrete slab 120 mm (ceiling height of 2,50 m before the renovation, after renovation it will be 2,35 m).

Built Area

1. Demolition of the existing tower of the lifts and staircase and addition of the new tower to the building volume.

Note: [a]Source of project's drawings and technical specifications: MANASLU Ing.

Table AI.

Figure A1.
Facade Northwest, before and after renovation

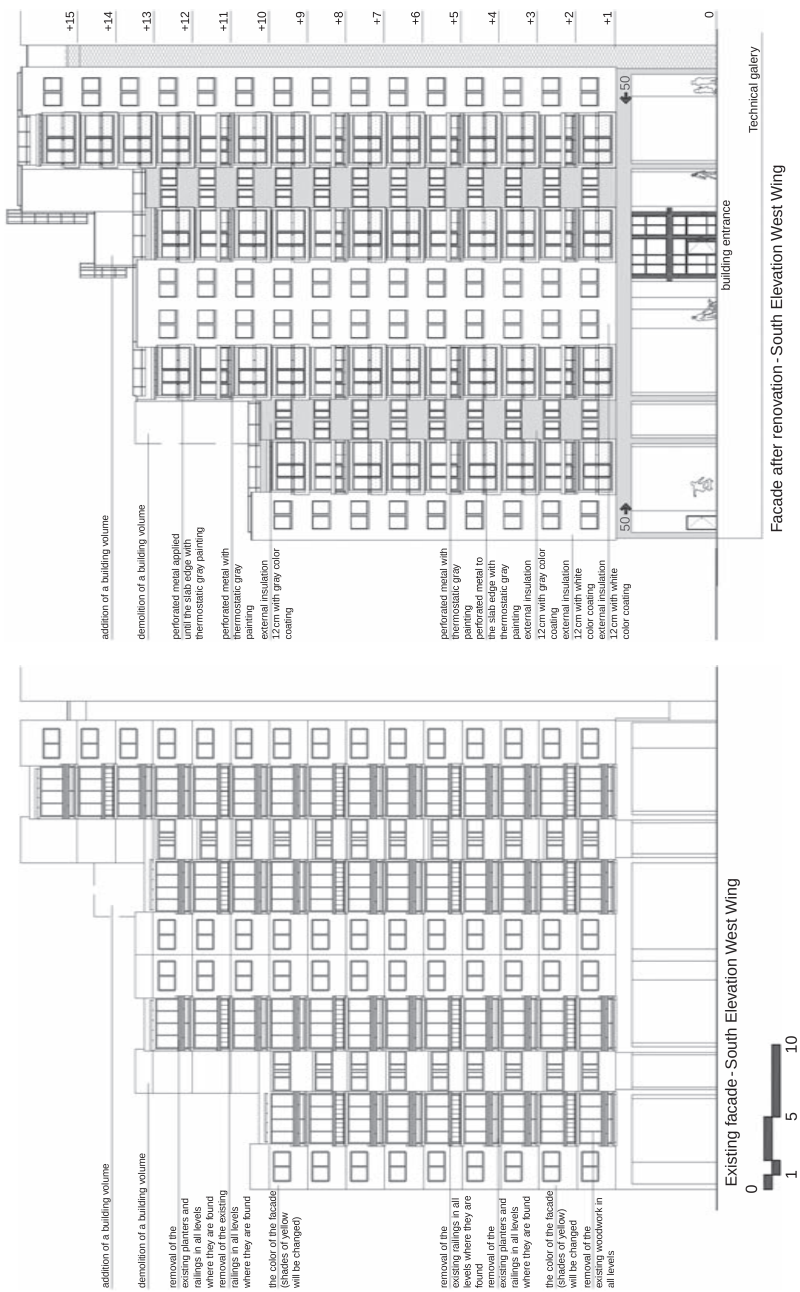

Figure A2.
Facade Southwest, before and after renovation

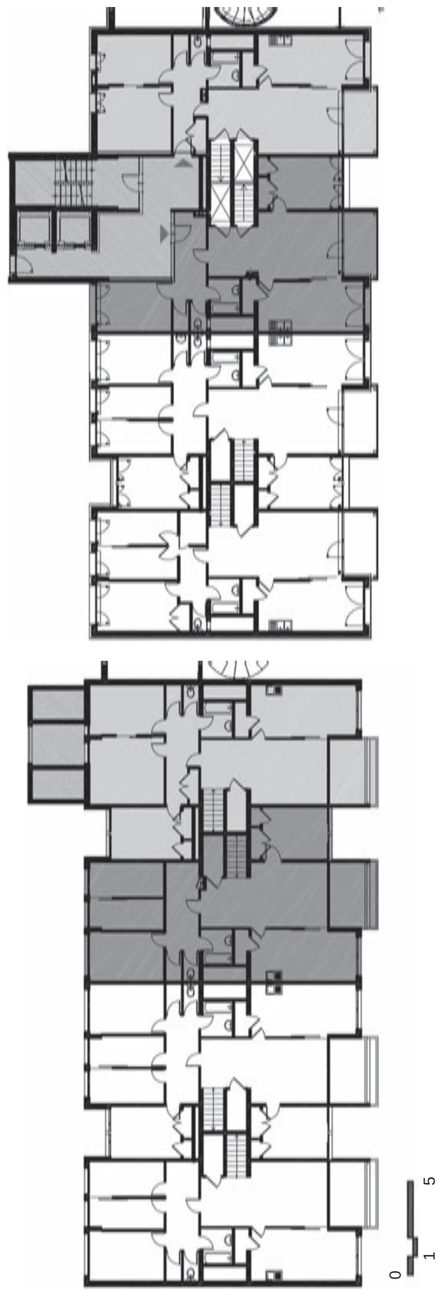

Figure A3.
Plans Group A, before and after renovation

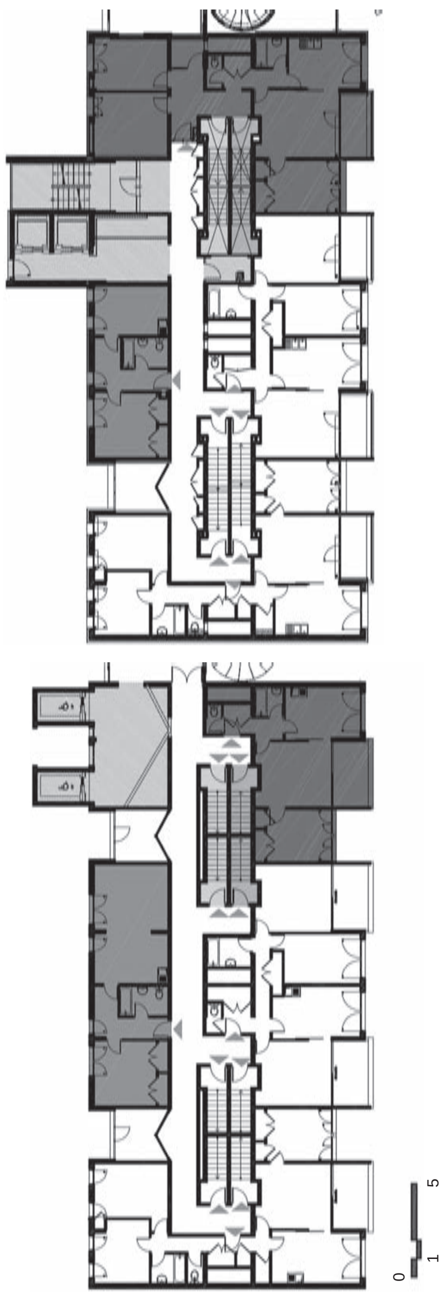

Figure A4.
Plans Group C,
before and after
renovation

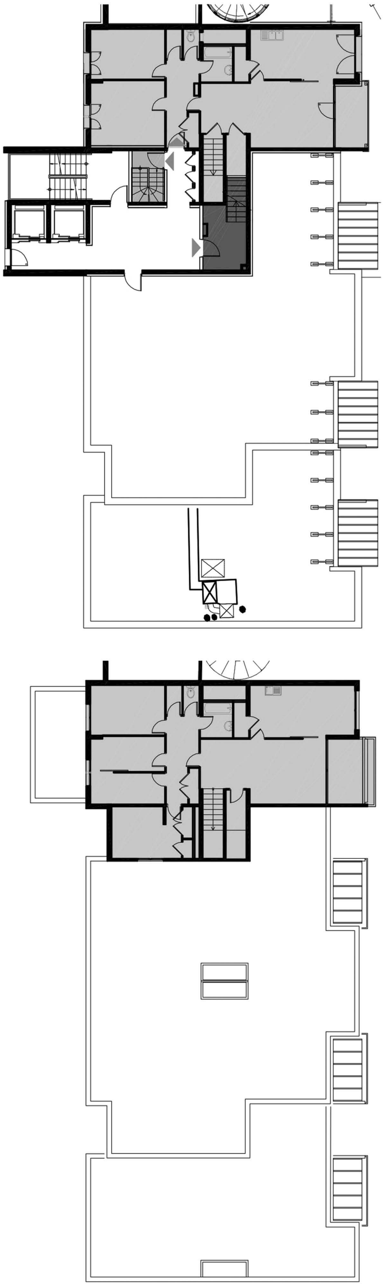

Figure A5.
Plans Group D,
before and after
renovation

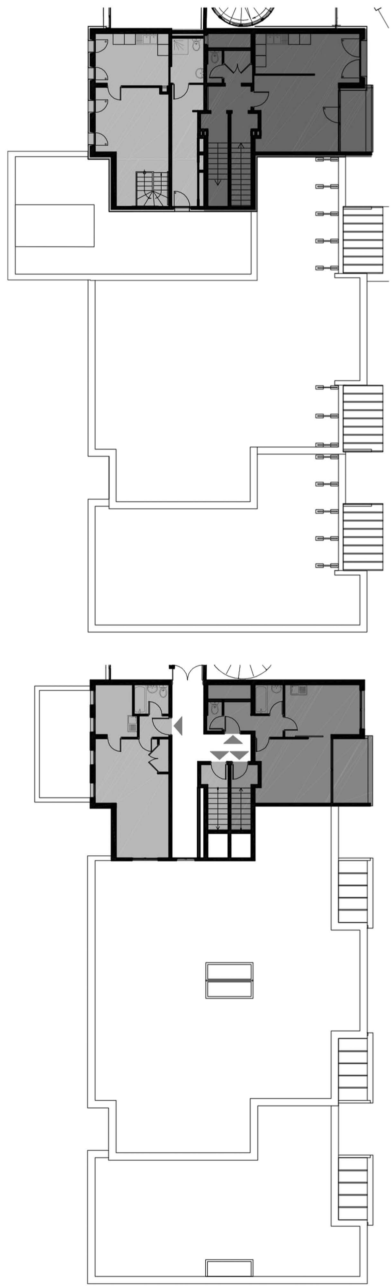

Figure A6.
Plans Group D,
before and after
renovation

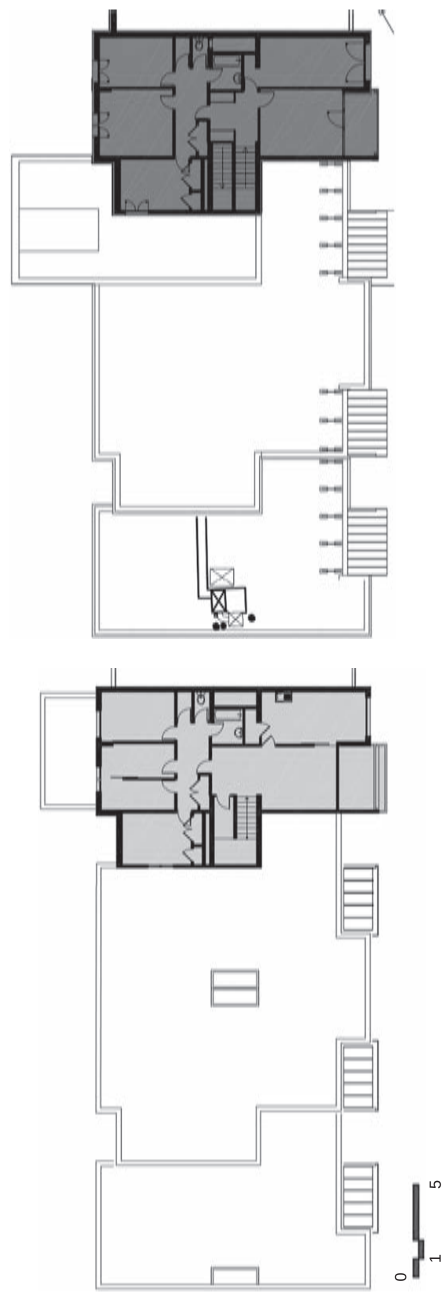

Figure A7.
Plans Group D,
before and after
renovation

About the authors

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