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Spatial Quality Determinants for Residential Building Renovation

A Methodological Approach to the Development of Spatial Quality Assessment

Improved spatial quality contributes to the attractiveness and public image of a building, as well as to users' well-being. This article identifies spatial quality determinants that are affected by renovation in residential buildings. We performed a detailed assessment of changes in spatial quality due to mechanical installations in renovation. The article presents two main findings. First we identified common spatial quality determinants in the research literature: view, privacy, lighting, spatiality, spatial arrangements, the transition between public and private spaces, and perceived, built, and human densities. Second we found that the available assessment for the renovation of dwellings covers only partially the impact of mechanical installations on spatiality. We suggest, based on these findings, a general spatial quality checklist to support architects, developers, and building owners. We probed deeper into the impact of mechanical installations on the spatiality of dwellings to propose a spatial quality assessment to be considered before and after renovation. The proposed assessment represents a further step toward the inclusion of spatial quality in building renovation processes, which benefits stakeholders from design professionals to end users.

Keywords: spatial quality, residential building renovation, building performance assessment tools, mechanical services and controls

1. Introduction

Spatial quality can be defined and assessed at the scales of the residential unit, the building, and the block and not only from an urban planning dimension as normally considered in the current literature. Including spatial quality in building renovation assessment and measures contributes to making building renovation more attractive by providing added value to building owners and users. The methodology used to create a spatial quality assessment framework is first to define the spatial quality determinants. The definition results from what is revealed in the literature review in relation to the residential use in building and block scales. The spatial quality determinants found are: (1) view, (2) internal spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built, and human densities. Second, these four determinants were crossed with typical energy-efficiency renovation measures for residential buildings. The goal of this crossing is to identify the main spatial quality determinants influenced by building renovation.

We consider the renovation measures for houses described by Burton (2012) for the building's components of floors, walls, roofs, windows, and mechanical services. We also analyze examples of residential refurbishment to complement the study (Giebeler et al., 2009; Retrokit, 2014; ZenN, 2012). The study of examples of residential refurbishment shows that measures for nondomestic buildings can be applied to residential refurbishment, although this is not traditionally implemented due to high costs. Therefore we also consider renovation measures for nondomestic buildings described by Baker (2009) for the building's components of floors, roofs, windows, and mechanical services. Examples are green roofs, changes in window distribution (by making new apertures to improve daylight distribution), implementation of shading, and the use of photovoltaic elements when recladding panels and roof tiles (Baker, 2009).

We consider these measures because they provide additional spatial quality value despite potentially higher costs. Both Baker (2009) and Burton (2012) consider the context of building renovation in Europe.

Measures such as green roofs, changes in window distribution, and the use of photovoltaic are not commonly found in traditional handbooks for sustainable refurbishment of dwellings; they are mostly applied in refurbishment of nondomestic buildings. However, they have become increasingly implemented in dwelling renovation in Europe in recent years. This is as a result of several incentives in ongoing European research projects such as Proficient (2012) and Retrokit (2014) that include for example photovoltaic and green roofs in the refurbishment of dwellings.

1.1 Spatial quality determinants and renovation of residential buildings

Building renovation measures described by Burton (2012) were linked to the spatial quality determinants. We analyzed the relevance of the potential impact of the building renovation measures on these determinants. Building renovation causes changes in the building's components of floors, external and internal walls, roofs, windows, and mechanical services. These changes affect the spatial quality determinants, as summarized in Table 1 below:

Table 1. The impact of dwelling renovation per building component on the spatial quality determinants, for example, changes on windows affect views

2. Spatial quality definition

Spatial quality is an abstract and complex term due to its diverse physical, perceptual, and social features. Moulaert (2011) identifies various authors who approach the term spatial quality broadly and in different ways: "good city form" (Lynch, 1984), "good design" (Sternberg, 2000), "good architecture" and "urban quality" (Chapman &

Larkham, 1999; Trip, 2007), "delight" (Wootton, 1624), "planning performance" (Friedman, 2004), "effective planning process" and "good planning process" (Conroy & Berke, 2004), "quality planning" (Creedy et al., 2007), "place quality" (Healey, 2004), "experiential quality of urban environment" (Southworth, 2003) or "livable city" (Southworth, 2003), "fulfillments of human needs" (Moulaert, 2009), and "inclusive design" (Lang, 1990). Hence, planning is the main dimension in which spatial quality is considered.

The goal of this study is to conceptualize spatial quality on three scales: the residential unit, the building, and the block. Scientific literature on spatial quality was analyzed to select the most relevant spatial quality determinants for residential use considering these three scales. Therefore we focus on authors who approach spatial quality on these scales, such as Lynch (1960), Chermayeff and Alexander (1966), Ishikawa, and Silverstein (1977/1978), Ashihara (1981), Rapoport (1970, 1971), Weber (1995), Nasar (1992/2000), Russell (1989), Owens (2008), Uytenhaak (2008), Gehl (2010, 2011), and Moulaert (2011).

We identify and aggregate into a common system the most relevant spatial quality determinants discussed by the various authors considered in the literature study. The determinants vary from "a purely adding up of different spatial quality preferences" and general definitions to a "relational definition" (Moulaert, 2011). A determinant can be defined as "a thing that decides whether or how something happens" (Oxford Dictionary, 2013). Hence, we use the word determinant in this article to mean what causes or influences spatial quality.

We are at a disadvantage because there is no clear definition of the term spatial quality that considers the building scale. Spatial quality is an abstract issue, both on city and on neighborhood scales (Moulaert, 2011). However, many of the urban planning issues affect spatial quality on the scale of buildings and blocks in many ways (Gehl, 2010, 2011; Lynch, 1960; Rapoport, 1970/1971; Uytenhaak, 2008). Consequently, a spatial quality definition needs to be extended to include building and block scales, in addition to city and neighborhood scales. Spatial quality cannot be included objectively, consistently, and explicitly in the design process unless a clear definition of the term exists and assessment methods are developed.

The main challenge in building renovation is often increasing efficiency both in technical performance and in terms of costs. However, the human factor involved in the process of building renovation is as relevant as achieving technical and financial benefits (Burton, 2012; Denizou et al., 2011). Encouraging stakeholders to cooperate with and invest in building renovation seems to be one of the hardest aims to tackle. Problems convincing stakeholders to go through with building renovation are usually related to high costs and long-term economic returns. This is because the benefits of building renovation are often not clearly related to the improvement of quality of life and well-being. The main challenge is dealing with the impact of building renovation on the quality of the built environment. The gap between technical performance and the human factor could be undermining the efforts made with both technical and well-being concerns as they become isolated matters.

2.1 Spatial quality determinants

In the literature we found that the following spatial quality determinants were discussed by the various authors who consider building and block scales: view, internal spatial arrangements, transition between public and private spaces, and perceived, built, and human densities (Alexander et al., 1977/1978; Altman & Wohlwill, 1976; Ashihara, 1981; Chermayeff & Alexander, 1966; Gehl, 2010, 2011; Hall, 1966; Lynch, 1960;

Owens, 2008; Rapoport, 1970, 1971; Uytenhaak, 2008; Weber, 1995). These spatial quality determinants also consider indoor and outdoor environments.

Space consists of physical boundaries and elements that are perceived three-dimensionally (Weber, 1995). Therefore we incorporate in our spatial quality definition the five principles of figural segregation defined by Weber (1995). He proposes these principles to complement the two-dimensional principles of figure–ground segregation described by the Gestalt[1] psychologists. However, Weber (1995) illustrates these principles mainly using urban spaces as examples. We propose the use of the five three-dimensional principles of figural segregation on building and block scales:

(1) Centricity. This consists of a perceived center (or centers), which results from the play of forces in the composition of space (for example the placement of openings in a room).

(2) Concavity. This is related to the placement of the entrance to the room. The perception of concavity becomes greater as the entrance gets closer to the geometrical center of the space.

(3) Closure and peripheral density. This principle is here called enclosure and peripheral density instead of closure. This is because the block is the element of analysis in this spatial quality determinant rather than interior spaces. Enclosure is determined by the height to width ratio (proportion) of the enclosed space of the block. Peripheral density expresses the internal articulation of the spatial boundaries (namely building heights and continuity of block borders).

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

(4) Uniformity and coherence of boundaries (facades). This principle is applied to the building scale only. It considers the facade transparency (windows' size) and, the homogeneity and heterogeneity in the composition of facades, namely similarities in materials and formats and in the composition of architectural elements.

(5) Internal division of space and spatial density. This principle concentrates on the articulation of the internal spaces (zoning) resulting from the placement of physical elements (such as columns, stairs, and variations in ceiling heights) and on the nature of the relationships between these spaces within the whole (coordinated or subordinated relationships). Spatial density refers to the volume of the internal walls in relation to the volume of the space.

~~The principles of figural segregation of centricity and concavity are considered in the spatial quality determinant of internal spatiality and spatial arrangements. The principle of closure and peripheral density is considered in the spatial quality determinants of view and perceived, built and human densities. Weber's (1995) principle of uniformity and coherence of boundaries is considered in the spatial quality determinants of view and transition between public and private spaces. The last principle of internal division of space and spatial density is considered in view. All of Weber's (1995) principles of figural segregation are considered in the spatial quality determinant of transition between public and private spaces, namely the consequences of the principles on the facade composition.~~

Emotional experiences and the aesthetics of the physical environment can be studied by the analysis of affective appraisals (Nasar, 1992/2000). Affective appraisal is the evaluation of a place based on individual emotional considerations. The evaluation is based on the dualities "pleasant/unpleasant and arousing/sleepy" (Russell, 1989) (Figure 1). A place experienced by a person as pleasant and arousing gives a sensation of excitement and relaxation. In contrast, a place experienced as unpleasant and uninteresting (sleepy) is considered boring.

Figure 1. Affective appraisals are based on the dualities "pleasant/unpleasant and arousing/sleepy" (Russell, 1989).

In the literature we identify two different types of approaches to define and assess spatial quality: one is the study of physical characteristics of space, such as Weber's principles of figural segregation (1995), and the other is the study of space based on the users' affective appraisals defined by Russell (1989) (Figure 1) (Table 2). This article concentrates on the spatial quality definition based on physical characteristics of the space, which we call spatial quality assessment type B.

Table 2. Complete spatial quality assessment (assessment types A and B)

~~The spatial quality determinants and principles are presented below.~~

2.1.1 *Spatial quality determinant: 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 their view over their world" (Uytenhaak, 2008, p. 80).

The main topics of this spatial quality determinant are:

(1) View from the inside (private domain) to the outside (public domain) of dwellings, and from outside to inside (visual privacy)

(2) Distances between public and private domains

(3) Quality of the view

The main topics are represented by the five principles listed in Table 3.

Table 3. Spatial quality checklist for views

Building renovation may affect floor plans and facade composition, for example changes in the size of windows (Figures 2a and 2b) and the addition of balconies to the facade. The perimeter of the block can also change, for example with the addition or removal of buildings. These measures can affect, to some degree, views, privacy, and distances between public and private domains.

Figures 2(a) and 2(b). Changes in windows' size, after (2a) and before (2b) the building renovation. Private house, Bochum, Germany, © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.

The following principles of figural segregation (Weber, 1995) are considered in the spatial quality determinant of view:

(1) Uniformity and coherence of boundaries. Changes in facade transparency affect view and privacy (Figures 2a and 2b).

(2) Internal division of space (layout) and spatial density. The articulation of the internal spaces affects the depth of vision and the degree of sight protection.

(3) Enclosure and peripheral density. Changes in the configuration of the block affect view, depth of vision, and lighting, for example changes in the height to width ratio of the courtyard and the heights of building and block borders.

Facade transparency is the most relevant principle of the spatial quality determinant of view, because it determines how much can be seen from inside and outside spaces. Therefore we focus on provisions that increase "the range and penetration of vision" (Lynch, 1960, p. 106) regarding to view quality. Lynch (1960) lists the following architectural features that he believes increase the efficiency and quality of view: "transparencies, overlaps (as when structures appear behind others), vistas and panoramas which increase the depth of vision (as broad open spaces), and articulating elements (foci) which visually explain a space" (Lynch, 1960, p. 106).

Visual privacy consists of sight protection of the private domain, which is the selective control of access to oneself by others (Altman & Wohlwill, 1976). The level of privacy is also defined by the distance between public and private and the degree of protection (Gehl, 2010). The degree of protection consists of how much control the user has to allow or avoid visual contact with others. This is also related to how much visual contact with the outside domain the facade allows. This control is the desired freedom of choice to open or close for social interaction (Altman & Wohlwill, 1976).

The transparency of facades, the entrance of the house, and the availability of outdoor private spaces are examples of architectural elements that influence privacy (Chermayeff & Alexander, 1966) (Figures 3a and 3b). The inner hall (entry-lock zone) gives “the house as a whole an adequate buffer zone against intrusion” (Chermayeff & Alexander, 1966, p. 219) (Figure 4).

Figures 3(a) and 3(b). View of the entrance from inside of the house, and availability of outdoor private spaces. Private houses, Borneo, Amsterdam, The Netherlands, picture: Author.

Figure 4. Inner hall, the entry-lock zone. Ground floor plan, scale 1:300, private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

The placement of balconies is another example of the effect of the floor plan on privacy. Balconies placed on top of each other (Figure 5a) provide more privacy than staggered balconies. Instead, staggered balconies have more space above, which also improves daylight penetration (Uytenhaak, 2008) (Figure 5b).

Figures 5(a) and 5(b). Balconies placed on top of each other (5a) and staggered balconies (5b). Residential building, Oslo, Norway, picture: Author.

Space is a perceived object (Ashihara, 1981; Gehl, 2010, 2011; Lynch, 1960; Rapoport, 1970; Uytenhaak, 2008; Weber, 1995). The perception of space is “primarily determined by sight, between an object and a human being who perceives it" (Ashihara, 1981). Visual quality is one of the expressions of the perception of space, and it is a consequence of diverse signals. The visual sensations of shape and light are among these signals. The perception of these signals is the so-called legibility or visibility, and this also depends on spatial arrangements (configuration of the plan). It is not only about objects that are able to be seen, but about objects that "are presented sharply and intensely to the senses" (Lynch, 1960, p. 10).

When people are asked to evaluate their surroundings they essentially evaluate image (Nasar, 1992/2000). Monotony, dryness, ugliness, and the sense of order or the lack of it are aspects that define visual quality and that have an impact on how the space is perceived (Nasar, 1992/2000). Authors such as Berman, Jonides, and Kaplan (2008) and Hartig, Evans, Jamner, Davis, and Garling (2003) elucidate the importance of nature in the quality of view. However, Kaplan (1987) stated in an earlier publication that the views that are preferred by people are the ones that could also surprise the observer, for example "the trail that disappear around a bend" (Kaplan, 1987, p. 8). The interest in the promise of additional information mentioned by Kaplan (1987) is the "overlaps" and "vistas and panoramas which increase the depth of vision," and the "articulating elements" mentioned by Lynch (1960, p. 106). In addition to "mystery," the "good view" (Kaplan, 1987, p. 8) needs "symmetry, repeating elements and unifying textures that contribute to a good gestalt" (Kaplan, 1987, p. 10). Lynch (1960), Kaplan (1987), and Weber (1995) name this potential as coherence, which is the "capacity to predict within the scene" (Kaplan, 1987, p. 10).

2.1.2 Spatial quality determinant: 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 main topics of this spatial quality determinant are:

(1) Articulation between space and its boundaries, and between adjacent spaces

(2) Privacy within the dwelling (zoning considering different groups within the family)

(3) Light (access of daylight, layout zoning, and sun orientation of openings)

The main topics are represented by the five principles listed in Table 4.

Table 4. Spatial quality checklist for internal spatiality and spatial arrangements

Changes in the plan resulting from building renovation often affect spatial organization and zoning within the dwelling. Rooms and windows can change in size and entrances can be replaced. New spatial arrangements can be created, such as connections and divisions between rooms. Elements such as stairs and columns can be placed to subdivide spaces and suggest changes in functions. This section explores and defines the elements of internal spatiality and spatial arrangements in dwellings that can be affected by building renovation.

Space is perceived as a void (Weber, 1995). The void can be internal (three planes: a floor, a wall, and a ceiling) or external (two planes: a floor and a wall) (Ashihara, 1981). For this spatial quality determinant we consider three of the principles of figural segregation defined by Weber (1995):

(1) Centricity. Alterations in the plan can change the perceptual centers of rooms (Figures 6a, 6b, and 6c).

(2) Concavity. Rooms can have their entrances changed, which alters the concavity (Figures 7a and 7b).

(3) Internal division of space and spatial density. Changes in spatial organization and zoning within the dwelling (Figures 10a, 10b, 11a, 11b, 13a, and 13b).

Centricity is not only the geometrical center of a shape, but the perceptual center. The perceptual center is defined by the convergence of forces resulting from the entire organization of the shape and the articulation with its boundaries. A shape may have many subcenters (perceptual centers), but the shape is clearer when there are fewer subcenters (Weber, 1995). According to Indraprastha (2012), the placement of perceptual centers starts by defining the geometrical center point of a room (Figure 6a). A Cartesian grid is proposed with its origin on the geometrical center point of the room. Subsequently, the edges of the apertures of entrances and major elements (e.g. stairs) are projected perpendicular to both vertical (y) and horizontal (x) axial lines. The corners are considered spaces without perceptual centers. The space is subdivided into zones of influence according to the projections on the x and y axial lines. The geometrical center point of each zone of influence is determined and numbered (Indraprastha, 2012) (Figures 6a, 6b and 6c).

Figure 6(a). Placement of perceptual centers (Indraprastha, 2012), scale 1:200. Living room in residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

Figures 6(b) and 6(c). Placement of perceptual centers: Plans of the first floor before (6b) and after (6c) the building renovation, scale 1:200. Residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

The location of the entrances enforces the perception of concavity (Weber, 1995). When the entrance of a room is located close to the center of the lateral boundaries of the room, the perceptual concavity is strengthened. This is independent of the shape of the room. That is the effect of "pseudo-convexity," in which "the textural pattern is similar to the one of a convex surface" (Weber, 1995, p. 146). On the other hand, when the entrance of a room is located far from the center at the corner, the perceptual concavity is weakened "because the distances between the picture plane and the perceived corners of the space increase considerably" (Weber, 1995, p. 146) (Figures 7a and 7b).

Figures 7(a) and 7(b). Plans of the first floor before (7a) and after (7b) the building renovation, scale 1:300. Concavity of the living room in a residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

The principle of internal division of space and spatial density (Weber, 1995) considers the placement of physical elements in the space and how this placement can subdivide and articulate space. For example, ceiling heights can vary subdividing spaces and suggest changes in functions (Figures 8a and 8b).

Figures 8(a) and 8(b). Examples of the use of ceilings heights to define spaces and functions, such as a kitchen (8a) and a living room (8b). Figure 8(a): Private house, Herentals, Belgium, © [Toon Grobet]. Reproduced by permission of Toon Grobet. Figure 8(b): Private house, Alvite, Portugal, © [Fernando Guerra]. Reproduced by permission of Fernando Guerra.

Elements such as columns, stairs, and ceilings (variations in ceilings heights) can strengthen the character of the space or become more dominant than the whole. For example elements that emphasize "an otherwise latent perceptual center may draw perceptual attention to the (geometrical) center of the figure, and diminish the importance of its contours" (Weber, 1995, p. 157). Columns can be arranged repetitively and close together so that they can create boundaries within the space (Weber, 1995). Dominant elements can also be placed outside of the geometrical center of the same space, creating competing spatial fulcrums (Figures 9a and 9b).

Figures 9(a) and 9(b). Plans of the ground floor before (9a) and after (9b) the building renovation, scale 1:200. The new connection between rooms, the new kitchen, and the addition of new stairs create competing spatial fulcrums and change circulation patterns. Private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

The relationship between the spaces within the whole can be described as coordinated or subordinated. Spaces are not always “clearly defined units” with clear boundaries and closure (Weber, 1995, p. 170). Both interior and exterior spaces are usually not isolated but part of complex spatial systems. Spaces have similar dominance in the coordinated relationship since they are similar in size, shape, and articulation (Weber, 1995). One or more spaces may have no connection with the main circulation areas in a coordinated relationship (Figures 10a and 10b). This limits the room’s functionality because of the need to cross one room to access another.

Figures 10(a) and 10(b). Plans of the ground floor before (10a) and after (10b) the building renovation, scale 1:300. Coordinated relationship of spaces. Private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.

The subordinated relationship is characterized by hierarchical arrangements between spatial parts, which are diverse in size, format and articulation. The primary space is the dominant space and the ancillary space is the one that is subordinated to the primary space. For example the relation between a balcony and a living room is that the living room is the primary space and the balcony is the subordinate space (Figures 11a and 11b). The living room retains its figural character, but the boundary to which the balcony was added becomes more dominant, because this boundary now contains perceptual centers created by the subordinated space of the balcony (Weber, 1995).

Figures 11(a) and 11(b). Plans of the first floor before (11a) and after (11b) the building renovation, scale 1:300. Subordinated relationship of spaces. Residential building, Chur, Switzerland, © [DETAIL]. Reproduced by permission of DETAIL.

The perception of space is the result of the interaction between different elements that constitute the space. Weber (1995) proposes a close connection between space form and composition and the perception of spatiality. Proportion (ratio between height and width of the enclosed volume) plays an essential role in the perception of space (Weber, 1995). The analysis of the proportion of the bounded volume reveals the degree of space closure (Figures 12a and 12b).

Figures 12(a) and 12(b). Plans of the first floor before (12a) and after (12b) the building renovation, scale 1:300. Space closure of the hall area. Residential building, Chur, Switzerland, © [DETAIL]. Reproduced by permission of DETAIL.

Internal spatiality and spatial arrangements resulting from the floor plans are essential for the sense of privacy within the dwelling. There are many ways to provide privacy within dwellings regarding the visual contact. Bedrooms and living rooms can be accommodated according to desired levels of privacy, for example zoning that considers the needs of different groups within the family (children's area and adults' area) (Chermayeff & Alexander, 1966) (Figures 13a and 13b). "Sightlines and details such as the turning direction of doors" (Uytenhaak, 2008, p. 79) are other examples of how to protect the visual privacy of different groups within the family.

Figures 13(a) and 13(b). Changes in zoning (children's and adults' areas), plans of the first floor before (13a) and after (13b) the building renovation, scale 1:300. Private house, Bochum, Germany, © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.

~~Table 5. The "basic questions for a critical appraisal of privacy" within the dwelling are quoted and adapted from "anatomy of privacy" (Chermayeff & Alexander, 1966, pp. 213 to 220).~~

Lighting essentially influences human perception of spatiality in both internal and external spaces (Ashihara, 1981; Millet & Barrett, 1996). Daylight in particular influences the impression of size (Matusiak, 2008). The impression of the dimensions of a room depends both on the windows' form and on their placement on the walls (Baker & Steemers, 2002; Matusiak, 2006). The daylighting quality also depends on the surface reflectance and the organization of the floor plan. Therefore the three main factors to do with lighting in relation to internal spatiality and spatial arrangements are access of daylight, the distribution of light in the space, and the internal zoning of the diverse functions according to sun orientation (Table 4).

Daylight penetration in an enclosed space can be quantified through the daylight factor (DF) (Hopkinson et al., 1966). The DF consists of a ratio between the internal illuminance and the external unobstructed illuminance[2] (Baker & Steemers, 2002). The DF considers three components: the direct light from the sky (sky component), the light reflected from the exterior into the interior space (ERC—externally reflected component), and the originally external light inter-reflected from interior surfaces (IRC—internally reflected component)[3] (Goulding et al., 1992). According to Baker and Steemers (2002), daylight is to do with light distribution rather than the quantity of light entering a room. Therefore luminance[4] distribution is included in the principle of lighting for the spatial quality assessment (Table 13). Spaces are considered to be

[2] DF = Ei/ Eo x 100% (Baker & Steemers, 2002, p. 60).

[3] DF = SC + ERC + IRC (Goulding et al., 1992, p. 117).

[4] Luminance represents the relation between illuminance and reflectance of surfaces (Baker & Steemers, 2002).

unfurnished, and reflectance values of ceilings and floors have to be determined when the analysis is performed before and after the renovation.

We propose the use of the concept of the passive zone of Baker and Steemers (1996) to calculate the percentage of the floor area that benefits from daylight. The passive zone corresponds to 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 nonpassive zones that require artificial lighting. Baker and Steemers (1996) adopt a passive zone depth from the perimeter to twice the floor to ceiling height. The ratio between the passive zone and the nonpassive zone represents the efficiency of the building regarding daylight access.

2.1.3 Spatial quality determinant: 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 main topics discussed in this spatial quality determinant are:

(1) Physical barriers between public and private spaces

(2) Outdoor private spaces

(3) 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 the five principles listed in Table 5.

Table 5. Spatial quality checklist for transition between public and private spaces

Boundaries between public and private are where indoor and outdoor spaces interact. Physical elements that separate the public from the private "work as a joint" (Chermayeff and Alexander, 1966, p. 213). Therefore the transition between public and private spaces should be gradual and physically clear through flexible boundaries that allow privacy control. A clear structure with a gradual route from public to private spaces gives a greater feeling of security and a stronger sense of belonging and responsibility (Gehl, 2011). “The experience of entering a building influences the way you feel inside the building, if the transition is too abrupt, there is no feeling of arrival and the inside of the building fails to be an inner sanctum” (Alexander et al., 1977/1978, p. 549).

Gehl (2010) proposes the terms soft and hard edges to refer to transitions between public and private domains. Soft edges are characterized by a high possibility of controlled visual interaction between inside and outside spaces and the presence of private outdoor spaces. Private outdoor spaces are essentially desirable at street level (Gehl, 2010; Uytenhaak, 2008). That is where activities inside of the buildings can move out into the common space of the city. Most opportunities for sitting and standing are at the street level, where exchanges between the private and the public are mainly promoted. The opposite of soft edges, hard edges (Gehl, 2010), are characterized by the absence of private outdoor spaces and the low visual permeability of facades at street level. The possibility of casual meetings among people is low: “nothing happens because nothing happens because nothing happens” (Gehl, 2011, p. 75).

Entrances and exterior spaces are “crucial to the sense of privacy” (Uytenhaak, 2008, p. 79) and territory in dwellings. For example the distance between public and private domains slightly increases in a secluded entrance where the front door is set back from the sidewalk: “people want their house, and especially the entrance, to be a private domain” (Alexander et al., 1977/1978, p. 550) (Figures 2b, 3b, 14a, and 14d).

Figures 14(a) to 14(d). Dwelling’s entrances, outdoor private spaces, and gradual and physically clear transition between private, semipublic, and private domains.

Residential building, Oslo, Norway, picture: Author.

Outdoor private spaces are, for example, balconies, roof terraces, front yards and backyards, or any other outside space with a secluded character. The private front yard on the street level is mentioned by Gehl (2011) and Rapoport (1971) as an example that efficiently softens boundaries between public and private spaces. Private outdoor spaces are considered to be even more efficient in promoting gradual transitions and social interaction, compared to semipublic or public spaces (Alexander et al., 1977/1978; Gehl, 2011; Rapoport, 1971; Uytenhaak, 2008). This is because of the possibility of casual meetings among people: "something happens because something happens because something happens" (Gehl, 2011, p. 73). The notion of responsibility for maintenance can be blurred in semi-public spaces (Figures 3b, 14b, and 14c).

The facade is a key element in building image. Weber's (1995) principle of uniformity and coherence of boundaries considers the degree of both homogeneity and heterogeneity of facade composition. When some parts are more dominant than others, the overall figural strength of the enclosed space weakens. Weber (1995) states that homogeneity of spatial boundaries (facades) does not mean that all the facades should be identical, but it should be possible to identity formal similarities such as those between architectural elements, scale, and materials (Figures 15a and 15b).

Figures 15(a) and 15(b). Changes in materialization of facades and windows' size and composition. Residential blocks, Zürich, Switzerland. Residential block after renovation (15a) © [Andrea Helbling, Arazebra]. Reproduced by permission of Andrea Helbling, Arazebra, Zürich. Residential block before renovation (15b) © [Schneider Studer Primas GmbH]. Reproduced by permission of Schneider Studer Primas GmbH.

Facades consist of walls (ground) and openings such as widows, balconies, and projected bounces (figures). Weber (1995) describes the principle of figure (window) and ground (wall) articulation to analyze the relations between architectural elements in the facade composition. For example the ratio between wall and openings areas is an element of figure and ground articulation in the analysis of facade composition. ~~The facade is a key element in building image: “its textural appearance and the organization of components into figure and ground are of predominant importance” (Weber, 1995, p. 229).~~ The roughness of the facade (Serra, 1997) is one of the characteristics of the building skin that is relevant for the uniformity and coherence of the facade composition. Roughness is the presence of projected bounces on the facade, such as balconies and bay windows.

We propose the use of one of the principles of figural segregation defined by Weber (1995), namely internal division of space and spatial density, to also analyze the impact of building renovation (from the inside) on facade composition (to the outside). For example changes in inside spaces during building renovation can affect the facade composition (uniformity and coherence of boundaries) such as the addition of balconies (Table 5).

2.1.4 Spatial quality determinant: 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 ingredients above” (Uytenhaak, 2008, p. 10).

The main topics discussed in this spatial quality determinant are:

(1) Block physical boundaries (peripheral density and contour)

(2) Height to width ratio (proportion) of internal block spaces (such as courtyards) and the sense of enclosure

(3) Functions, and built and human densities

The main topics are represented by the five principles listed in Table 6.

Table 6. Spatial quality checklist for perceived density, built and human densities

This determinant considers the block scale. The overall configuration of the block and the balance between the existing buildings and new additions are among the main topics of this determinant. Large-scale renovation projects can include changes to the block, such as the demolition of part of the block and the construction of new buildings. This spatial quality determinant considers the changes made to the contour of the block (such as the mass and heights of new buildings) and the impact and pressure of the interventions on the internal open spaces of the block (height to width ratio of courtyards). The addition of new buildings increases the built area as well as the human density (people per square meter of block area), and it might also result in the addition of functions other than the ones present in the block before the renovation. Following increases in human density, further analysis is needed of the capacity to house new inhabitants and functions in terms of both space and facilities. Built density or area is the two-dimensional expression of the built space in quantitative terms (for example the area in square meters).

The guidelines defined by Lynch (1960) for the design of urban environments offer valuable hints about how to assess complexity on a block scale. The principle of complexity (Lynch, 1960) refers to surface contrasts, form simplicity and dominance, and function. Surface contrasts relate to the quality of continuity: "continuance of edges or surfaces (skyline or setbacks); nearness of parts (as a cluster of buildings); similarity, analogy, harmony of surface, form and use (as a common building material, repetitive pattern of windows, similarity of market activity, use of common signs)" (Lynch, 1960, p. 106) (Table 6).

Form simplicity and dominance are among the "qualities" defined by Lynch (1960) for the design of urban environments. Form simplicity considers the geometry and shape of building blocks. Pure forms are "easily incorporated in the image, and there is evidence that observers will distort complex facts to simple forms" (Lynch, 1960, p. 105). The characteristics of compactness, porosity, and slenderness of the building shape are considered in relation to the block composition and to the access of daylight. Compactness is the relation between the external surface and the built volume. Porosity is the presence of voids such as courtyards and patios that permeate the built volume. Slenderness is the relation between the height and the footprint area of the volume (Serra, 1997). Dominance refers to the impact of one part over others "by means of size, intensity, or interest, resulting in the reading of the whole as a principal feature with an associated cluster" (Lynch, 1960, p. 106) (Table 6).

The principle of enclosure and peripheral density considers the physical characteristics of an urban block. The size and mass of the physical boundaries create contours that define the space between buildings as a figure (for example a courtyard). Space is perceived as enclosed due to physical boundaries, and this depends considerably on the height to width ratio (proportion) of the enclosed space (Weber, 1995). However, the sense of enclosure is not only a consequence of proportion, but of "the internal articulation of the periphery specifically its perceived density" (Weber, 1995, p. 151). That is, the sense of enclosure depends on the way the built density is distributed around the block, for example courtyards surrounded by buildings with strong contrasting heights. The sense of enclosure also depends on the continuity of space boundaries, that is, how much of the perimeter is built and whether the boundaries are enough to ensure an enclosed character to the block (Figures 16a and 16b).

Figures 16(a) and 16(b). Residential block, Chur, Switzerland. Figure 16(a): Plan of residential block after renovation, scale 1:2000. Buildings "A" are existing; buildings "B" are additions that close the perimeter of the block, © [DETAIL]. Reproduced by permission of DETAIL. Figure 16(b): Residential block before renovation, © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.

3. Spatial quality determinants checklist

On the basis of the state-of-the-art literature, we propose a definition of spatial quality on the building scale as the combination of four determinants and their respective principles:

Table 7. Spatial quality determinants checklist

The spatial quality determinants presented above are deeply dependent on each other. Ignoring one of the determinants (for example having poor lighting) or potential conflict between them (such as excessive transparency of the facades, disturbing privacy) affects spatial quality as a whole.

4. Spatial quality determinants and dwelling renovation

The four spatial quality determinants of (1) view, (2) internal spatiality and spatial arrangements, (3) transition between public and private spaces, and (4) perceived, built and human densities undergo the effects of dwelling renovation with respect on mechanical services and controls. However, we only present in this article the impact of mechanical services and controls on the determinant of internal spatiality and spatial arrangements (Table 8).

Table 8. The impact of dwelling renovation per building component on the spatial quality determinants. The impact of mechanical services and controls on the determinant of internal spatiality and spatial arrangements is analyzed in this article

4.1 *Mechanical services and controls and the spatial quality determinant of internal spatiality and spatial arrangements*

The spatial quality principle of internal spatiality and spatial arrangements is affected by the measures considered by Burton (2012) for the building component of mechanical services and control in dwelling renovation (Tables 9 and 10). The measures affect two principles of this determinant, namely (C) spatial complexity and (E) lighting (Table 7).

Spatial arrangements and hierarchies (coordinated and subordinated spatial relationships) can be affected when space needs to be used to accommodate technical equipment for heating such as gas and oil boilers, heat pumps, biomass systems and micro combined heat and power (CHP) systems as well as the technical equipment necessary for the provision of domestic hot water (DHW). Solar water systems, gas and oil boilers, heat pumps, and storage cylinders are the options considered by Burton (2012) for the provision of DHW in dwellings.

The degree of space closure is affected by the space needed in order to provide adequate heating and ventilation. The space needed and the sizes of the equipment vary according to the system chosen and the number of occupants (Burton 2012), and therefore the impact on spatiality also varies. The installation of a ventilation system in dwellings can lower ceiling heights and this affects the ratio between spaces' height and width, and therefore the degree of space closure.

The effect on lighting is a consequence of changes in the size of windows and the implementation of shading devices and vegetation (to avoid overheating). The measures considering lighting in the building component of mechanical services aim to increase solar gain and minimize the use of artificial lighting as well as to improve natural ventilation (Baker, 2009).

Table 9. Description of technical measures and their characteristics for mechanical

services and controls

Table 10. Impact of technical measures for dwelling renovation for mechanical services and controls on internal spatiality and spatial arrangements

4.2 *Available assessment that includes internal spatiality and spatial arrangements principles*

We looked for current available spatial quality assessment in building performance assessment tools such as SBTool (2012), BREEAM 2008 for Major Refurbishment and Multi-residential Use, BREEAM Refurbishment Domestic Buildings (2012), LEED 2009 for Existing Buildings, and LEED 2008 for Homes (updated in 2013). We searched for indicators in the tools that could be used to assess the impacts of mechanical installations on internal spatiality and spatial arrangements. Daylight indicators are the only indicators available in the assessment tools that can be used to partially evaluate the impact of dwelling renovation on internal spatiality and spatial arrangements (Tables 11 and 12).

Table 11. Principles of internal spatiality and spatial arrangements (daylight) taken into consideration in assessment schemes such as the building performance assessment tools BREEAM 2008 for Major Refurbishment and Multi-residential Use, BREEAM Refurbishment Domestic Buildings (2012), LEED 2009 for Existing Buildings, LEED 2008 for Homes (updated in 2013), and SBTool (2012)

Table 12. Aims of the available assessment of internal spatiality and spatial arrangements

4.3 *Assessment of the impact of mechanical installations on internal spatiality and spatial arrangements, ranking and minimum requirements*

It is often a challenge to improve spatial quality in dwellings renovation. This is due to the limitations of existing conditions of both the site and the building that can hinder improvements in spatial quality. New requirements about, for example, overheating and maximum primary energy demand per square meter set by the European Union (European Union, 2011) represent additional challenges in building renovation. The challenges are to comply with the new EU building regulations as well as to ensure an overall quality than goes further than technical performance and energy efficiency.

Due to the diversity of existing conditions and to the specificity of contexts, it is not realistic to propose best practices and standards with respective scores for spatial quality analyses. Therefore we consider an assessment based on the comparison of the dwelling before and after renovation to evaluate the improvements or declines in spatial quality. Scores need to be set before the assessment and according to the renovation case and context.

We propose a spatial quality assessment to evaluate the impact of renovation measures for mechanical installations on internal spatiality and spatial arrangements. The principles of (C) spatial complexity and (E) lighting are the ones that undergo the most impact of changes in mechanical installations during dwelling renovation. Therefore we developed these principles further (highlighted in gray in Table 13) to set the minimum requirements for the assessment of this specific impact. Three assessable characteristics (a, b and c) were identified per subprinciple. The characteristics consist of either quantifiable features or features that can be assessed through yes or no questions (Table 13).

Table 13. Minimum requirements for the assessment of the impact of mechanical services and controls on internal spatiality and spatial arrangements

5. Conclusion and further work

Further research is needed to extend the work done so far in this little-developed field of research. We have only discovered a limited number of books and articles in this field, and there is room for further interpretation and definitions of spatial quality. Spatial quality determinants are waiting to be proposed and developed. Further research will consist of developing spatial quality indicators, namely a spatial quality assessment, to evaluate the four determinants in renovation of dwellings. Spatial quality assessment will be applied to renovation of dwellings to suggest improvements for the cases, as well as for the assessment.

We propose a spatial quality definition as a starting point for the spatial quality assessment. The definition is extended to consider building and block scales. The theoretical discussion brings awareness and understanding of the impact of building renovation on spatial quality. In practice, the spatial quality checklist calls for alternatives in building renovation that do not consider technical performance only. The assessment is particularly valuable for evaluating the impact of building renovation prior to renovation. That is when adjustments in the renovation project are still possible. The assessment is also helpful for selecting optimal renovation strategies that contribute to increase spatial quality, when there are diverse alternatives. An example of the use of the spatial quality assessment is when a municipality needs to select the best alternative among a number of proposals for renovation of dwellings.

This work is connected to the ZenN Project ("Nearly Zero Energy Neighbourhoods") funded by the European 7th Framework Programme (grant agreement no: 314363) in relation to several cases of dwelling renovation in the cities of Malmö, Oslo, Grenoble, and Eibar. The contribution of this work will be to 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" (Nearly Zero Energy Neighbourhoods [ZenN], 2012).

The spatial quality assessment will be applied to the ZenN cases to assess the impact of renovation on spatial quality in dwellings. The goal is to validate and improve the spatial quality definition and to further develop the assessment. The assessment works as a set of guidelines for dwelling renovation, leaving designers, developers, and building owners freedom for individuality and creativity.

Acknowledgements

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Table 1. The impact of dwelling renovation per building component on the spatial quality determinants, for example, changes on windows affect views

Spatial Quality Assessment				
Building Refurbishment Dwellings	Spatial Quality Determinants			
	Building Scale			Block Scale
Building Components	View	Internal Spatiality and Spatial Arrangements	Transition Public and Private Spaces	Perceived, Built and Human Densities
Floors	x	x		
External walls	x	x	x	x
Internal walls	x	x		
Roofs		x	x	
Windows	x	x	x	x
Mechanical services and controls	x	x	x	x
Built area				x
Renewable energy options	x	x	x	x

Table 2. Complete spatial quality assessment (assessment types A and B)

Spatial Quality Assessment	
Assessment type A Analysis of users' affective appraisal in order to assess spatial quality (users' evaluation is based on the dualities pleasant/unpleasant and arousing/sleepy) (Figure 1)	Assessment type B Analysis of physical features of space in order to assess spatial quality (Table 7)

Table 3. Spatial quality checklist for views

Spatial Quality Checklist I
(1) Spatial quality determinant: view (building and block scales)
(A) Facade transparency
(B) Distance and degree of sight protection (visual privacy and protection of the private domain)
i. View of arriving visitors and entrace (Figures 3a and 3b), and entry-lock (hall) to house (Figure 4)
ii. Availability and configuration of private outdoor spaces (Figure 3b)
iii. Placement of balconies (Figures 5a and 5b)
(C) Depth of vision
i. Visibility
ii. Quality of the view
iii. Internal division of space (configuration of the plan that affects views from inside to outside, and from outside to inside)
(D) Lighting (Access of daylight due to facade transparency and composition)
(E) Enclosure and peripheral density (configuration of the block that affect views)

Table 4. Spatial quality checklist for internal spatiality and spatial arrangements

Spatial Quality Checklist II
(2) Spatial quality determinant: internal spatiality and spatial arrangements (building scale)
(A) Centricity and concavity
i. Geometric centre of the space (Figures 6a, 6b and 6c)
ii. Perceptual centres of the space (Figures 6a, 6b and 6c)
iii. Placement of entrances (concavity) (Figures 7a and 7b)
(B) Internal division of space and spatial density (ceiling height differences and placement of physical elements in the space)
i. Placement of columns
ii. Placement of stairs (Figure 9a and 9b)
iii. Ceilings heights (Figures 8a and 8b)
(C) Spatial complexity (spatial hierarchies)
i. Coordinated spatial relationship (spaces with similar dominance) (Figures 10a and 10b)
ii. Subordinated sptial relationship (primary and secondary spaces) (Figures 11a and 11b)
iii. Degree of space closure (Figures 12a and 12b)
(D) Privacy within the dwelling (zoning according to different family group members) (Figures 13a and 13b)
(E) Lighting
i. Access of daylight
ii. Light distribution in the space
iii. Internal zoning of the diverse functions according to orientation

Table 5. Spatial quality checklist for transition between public and private spaces

Spatial Quality Checklist III
(3) Spatial quality determinant: transition between public and private spaces (building and block scales)
(A) Private entrance to dwelling as protected and sheltered standing space (Figures 2b, 3b, 14a and 14d)
(B) Clear boundaries between the private and semi-public domains (neighbor to neighbor, tenant to management, interaction house and front yard); Clear boundaries between private, semi-public and public domains (relation between front yard and street) (Figures 3b, 14a to 14d)
(C) Outdoor private spaces as effective staying areas (Figures 3b and 14b)
(D) Uniformity and coherence of boundaries (Figures 15a and 15b)
i. Similarity (similar formats of facades or architectural elements, similarities in scale, proportion, facade decoration and materialization)
ii. Rhythm of facade composition (ordered repetition to achieve an overall unified effect)
iii. Figure (window) and ground (wall) articulation, and facade roughness
(E) Internal division of space and spatial density and the facade composition (uniformity and coherence of boundaries)

Table 6. Spatial quality checklist for perceived density, built and human densities

Spatial Quality Checklist IV
(4) Spatial quality determinant: perceived density, built and human densities (block scale)
(A) Principle of complexity
i. Surface contrasts: quality of continuity (continuance of edges or surfaces); nearness of parts (such as a cluster of buildings); harmony (similarity) of surface and form (building materials and use of common signs such as repetitive pattern of windows)
ii. Form simplicity (geometry and characteristics of the building shape of compactness, porosity and slenderness)
iii. Dominance (impact of one part over others by means of size and proportion)
(B) Enclosure and peripheral density
i. Height to width ratio of the enclosed space (relation between the dimensions of the courtyard and the heights of the peripheral buildings)
ii. Articulation of space boundaries (contrast between the heights of the peripheral buildings)
iii. Continuity of space boundaries (perimeter of the block) (Figures 16a and 16b)
(C) Built density (square meter)
(D) Human density (people per square meter of block area)
(E) Functions (use of the space)

Table 7. Spatial quality checklist with the four determinants

Spatial Quality Checklist
(1) Spatial quality determinant: view (building and block scales)
(A) Facade transparency
(B) Distance and degree of sight protection (visual privacy and protection of the private domain)
i. View of arriving visitors and entrace (Figures 3a and 3b), and entry-lock (hall) to house (Figure 4)
ii. Availability and configuration of private outdoor spaces (Figures 3b and 14a to 14d)
iii. Placement of balconies (Figures 5a and 5b)
(C) Depth of vision
i. Visibility
ii. Quality of the view
iii. Internal division of space (configuration of the plan that affects views from inside to outside, and from outside to inside)
(D) Lighting (Access of daylight due to facade transparency and composition)
(E) Enclosure and peripheral density (configuration of the block that affect views)
(2) Spatial quality determinant: internal spatiality and spatial arrangements (building scale)
(A) Centricity and concavity
i. Geometric centre of the space (Figures 6a, 6b and 6c)
ii. Perceptual centres of the space (Figures 6a, 6b and 6c)
iii. Placement of entrances (concavity) (Figures 7a and 7b)
(B) Internal division of space and spatial density
i. Placement of columns
ii. Placement of stairs (Figure 9a and 9b)
iii. Ceilings heights (Figures 8a and 8b)
(C) Spatial complexity (spatial hierarchies)
i. Coordinated spatial relationship (spaces with similar dominance) (Figures 10a and 10b)
ii. Subordinated sptial relationship (primary and secondary spaces) (Figures 11a and 11b)
iii. Degree of space closure (Figures 12a and 12b)
(D) Privacy within the dwelling (zoning according to different family group members) (Figures 13a, 13b)
(E) Lighting
i. Access of daylight
ii. Light distribution in the space
iii. Internal zoning of the diverse functions according to orientation
(3) Spatial quality determinant: transition between public and private spaces (building and block scales)
(A) Private entrance to dwelling as protected and sheltered standing space (Figures 2b, 3b, 14a and 14d)
(B) Clear boundaries between the private and semi-public domains (neighbor to neighbor, tenant to management, interaction house and front yard); Clear boundaries between private, semi-public and public domains (relation between front yard and street) (Figures 3b, 14a to 14d)
(C) Outdoor private spaces as effective staying areas (Figures 3b and 14b)
(D) Uniformity and coherence of boundaries (Figures 15a and 15b)
i. Similarity (similar formats of facades or architectural elements, similarities in scale, proportion, facade decoration and materialization)
ii. Rhythm of facade composition (ordered repetition to achieve an overall unified effect)
iii. Figure (window) and ground (wall) articulation, and facade roughness
(E) Internal division of space and spatial density and the facade composition (uniformity and coherence of boundaries)
(4) Spatial quality determinant: perceived density, built and human densities (block scale)
(A) Principle of complexity
i. Surface contrasts: quality of continuity (continuance of edges or surfaces); nearness of parts (such as a cluster of buildings); harmony (similarity) of surface and form (building materials and use of common signs such as repetitive pattern of windows)

ii. Form simplicity (geometry and characteristics of the building shape of compactness, porosity and slenderness)

iii. Dominance (impact of one part over others by means of size and proportion)

(B) Enclosure and peripheral density

i. Height to width ratio of the enclosed space (relation between the dimensions of the courtyard and the heights of the peripheral buildings)

ii. Articulation of space boundaries (contrast between the heights of the peripheral buildings)

iii. Continuity of space boundaries (perimeter of the block) (Figures 16a and 16b)

(C) Built density (square meter)

(D) Human density (people per square meter of block area)

(E) Functions (use of the space)

Table 8. The impact of dwelling renovation per building component on the spatial quality determinants. The impact of mechanical services and controls on the determinant of internal spatiality and spatial arrangements is presented in this article

Spatial Quality Assessment				
Building Refurbishment Dwellings	Spatial Quality Determinants			
	Building Scale			Block Scale
Building Components	View	Internal Spatiality and Spatial Arrangements	Transition Public and Private Spaces	Perceived, Built and Human Densities
Floors	x	x		
External walls	x	x	x	x
Internal walls	x	x		
Roofs		x	x	
Windows	x	x	x	x
Mechanical services and controls	x	**x**	x	x
Built area				x
Renewable energy options	x	x	x	x

Table 9. Description of technical measures and their characteristics for mechanical services and controls

Building Refurbishment - Housing[1]			
Technical Measures			**Technical Characteristics**
Mechanical services and controls	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 adequade/ 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	Efficient space heating	Oversizing should be avoided
	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. For larger dwellings with larger heat demand, biomass boilers with a wet system will be necessary
	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 storange are used, mounted on rooftops. Such system are not used in many countries for visual and planning reasons
		Gas and boilers	Where gas is available, a modern room-sealed as condensing boiler will provide efficient domestic hot water
		Heat pumps	
		Storange 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

Building Refurbishment - Housing[1]			
Technical Measures			**Technical Characteristics**
Mechanical services and controls	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; but 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	Maximise the use of daylight by architectural means in order to minimise artificial lighting energy[2]	Increasing daylight in rooms and corridors will reduce the use of artificial lighting, but it must 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.

[1] Burton, S. (2012). *The handbook of sustainable refurbishment: Housing* . Abingdon, Oxon: Earthscan

[2] Barker, N. (2009). *The handbook of sustainable refurbishment: Non-domestic buildings* . London: Earthscan

Table 10. Impact of technical measures for dwelling renovation for mechanical services and controls on internal spatiality and spatial arrangements

Mechanical services and internal spatiality and spatial arrangements			
Building Refurbishment - Housing[1]			Spatial Quality Determinant of Internal Spatiality and Spatial Arrangements
Technical Measures			
Mechanical services and controls	Improving the airtightness of the structure (to reduce air leakage)		
	Provision of adequade ventilation	Passive ventilation	
	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	Measures can lead to changes on: E. Lighting ei. Access of daylight eii. Light distribution in the space
	Heating	Efficient space heating	Measures can lead to changes on: C. Spatial complexity (spatial hierarchies) ci. Coordinated spatial relationships cii. Subordinated spatial relationships ciii. Degree of space closure
		Gas and oil boilers, heat pumps, biomass systems and micro CHP systems	
	Domestic hot water (DHW)	Efficient provision of DHW	
		Solar water systems	
		Gas and boilers	
		Heat pumps	
		Storange cylinders	
	Avoiding overheating	External heat gains	Measures can lead to changes on: E. Lighting ei. Access of daylight eii. Light distribution in the space
	Avoiding overheating	Planting and vegetation	
		Ventilation for cooling	
	Lighting installations	Maximise the use of daylight by architectural means in order to minimise artificial lighting energy[2]	

[1] Burton, S. (2012). *The handbook of sustainable refurbishment: Housing* . Abingdon, Oxon: Earthscan

[2] Barker, N. (2009). *The handbook of sustainable refurbishment: Non-domestic buildings* . London: Earthscan

Table 11. Principles of internal spatiality and spatial arrangements (daylight) taken into consideration in assessment schemes such as the building performance assessment tools BREEAM 2008 for Major Refurbishment and Multi-residential Use, BREEAM Refurbishment Domestic Buildings (2012), LEED 2009 for Existing Buildings, LEED 2008 for Homes (updated in 2013) and SBTool (2012).

Assessment Tools → **Spatial Quality Determinants ↓**	**BREEAM 2008 Major Refurbishment/ Multi-residential Use**	**BREEAM Refurbishment/ Domestic Buildings (2012)**	**LEED 2009 Existing Buildings**	**LEED 2008 for Homes (update 2013)**	**SBTool (2012)**
Internal spatiality and spatial arragements	Hea 1 Daylight	Hea 01 Daylight	IEQ Credit 2.4 Daylight/ Views	HSA Home Size Adjustment	F1 Social Aspects (Sunlight) D3 Daylight/ Illumination

Table 12. Aims of the available assessment of internal spatiality and spatial arrangements

Spatial Quality Determinant → **Assessment Tool ↓**	**Available assessment of internal spatiality and spatial arrangements**
BREEAM 2008 Major Refurbishment and Multi-residential Use	Hea 1 Daylight: To give building users sufficient access to daylight" (BREEAM 2008, P. 57).
BREEAM Refurbishment of Domestic Buildings (2012)	Hea 01 Daylight: "To improve the quality of life in homes through the provision of good daylighting and to reduce the need for energy to light the home" (BREEAM 2012, P. 73).
LEED 2009 Existing Buildings	IEQ Credit 2.4 Daylight/ Views: "To provide building occupants with a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building" (LEED 2009, P. 72).
LEED 2008 for Homes (update 2013)	HSA Home Size Adjustment
SBTool (2012)	F1 Social Aspects (Sunlight) D3 Daylight/ Illumination

Table 13. Minimum requirements for the assessment of the impact of mechanical services and controls on internal spatiality and spatial arrangements (principles C, D and E)

Spatial Quality Assessment - Checklist II
(2) Spatial quality determinant: internal spatiality and spatial arrangements (building scale)
(A) Centricity and concavity
(B) Internal division of space and spatial density
(C) Spatial complexity (spatial hierarchies)
i. Coordinated spatial relations (spaces with similar dominance) (Figures 10a and 10b)
(a) Areas of boundary spaces are similar (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)
ii. Subordinated spatial relations (primary and secondary spaces) (Figures 11a and 11b)
(a) Areas of boundary spaces are significantly dissimilar (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)
iii. Degree of space closure (Figures 12a and 12b)
(a) Ratio between the height and the width of the enclosed space
(b) Ratio between the width and the length of the enclosed space
(c) Space consists of area of long permanence (yes or no question)
(D) Privacy within the dwelling itself (zoning according to different family group members)
(E) Lighting
i. Access of daylight
(a) Placement of windows adjacent to side walls (yes or no question)
(b) Placement of windows adjacent to horizontal surfaces (yes or no question)
(c) Ratio between window's height and width (window form) and daylight factor
ii. Light distribution in the space
(a) Ratio between apertures area and room area
(b) Luminance distribution
(c) Ratio between the passive zone and the non-passive zone
iii. Internal zoning of the diverse functions according to orientation
(a) Internal zoning considers sun orientation (yes or no question)
(b) Minimun of 80% of the floor area of the room is day lit[1] (yes or no question)
(c) Direct access of sunlight to living areas[1] (yes or no question)

[1]SBTool 2012

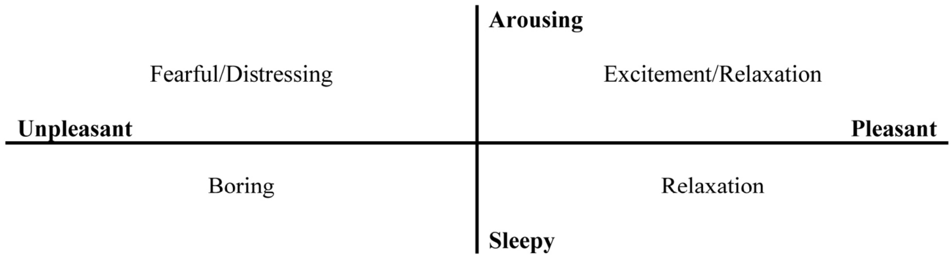

Figure 1. Affective appraisals are based on the dualities "pleasant/unpleasant and arousing/sleepy" (Russell, 1989).
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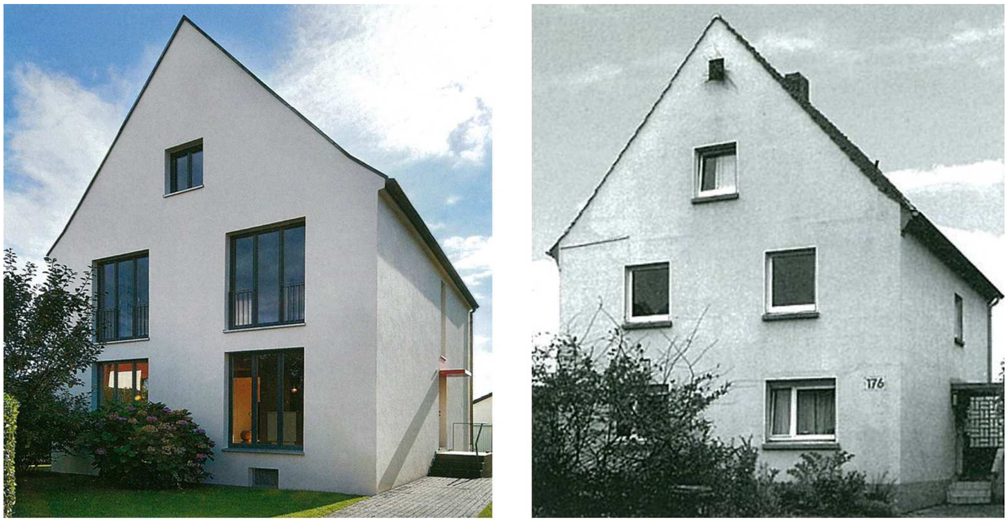


Figures 2(a) and 2(b). Changes in windows' size, after (2a) and before (2b) the building renovation. Private house, Bochum, Germany, © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.
126x65mm (300 x 300 DPI)

Figures 3(a) and 3(b). View of the entrance from inside of the house, and availability of outdoor private spaces. Private houses, Borneo, Amsterdam, The Netherlands, picture: Author.
120x65mm (300 x 300 DPI)

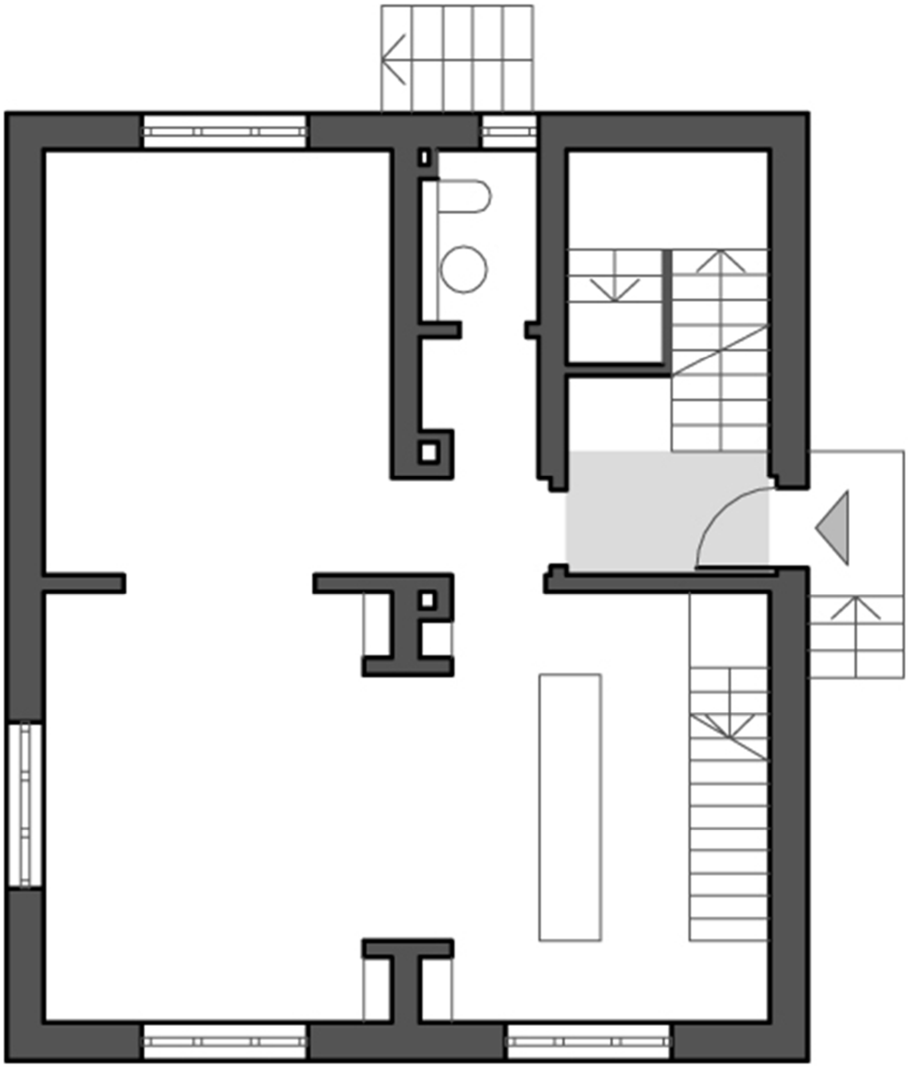
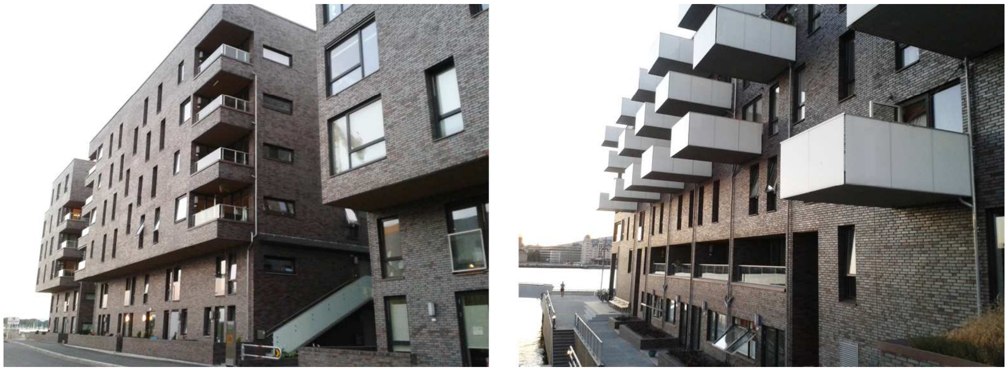


Figure 4. Inner hall, the entry-lock zone. Ground floor plan, scale 1:300, private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
38x44mm (300 x 300 DPI)



Figures 5(a) and 5(b). Balconies placed on top of each other (5a) and staggered balconies (5b). Residential building, Oslo, Norway, picture: Author.
178x65mm (300 x 300 DPI)

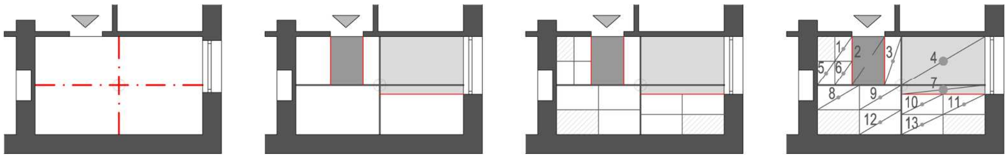
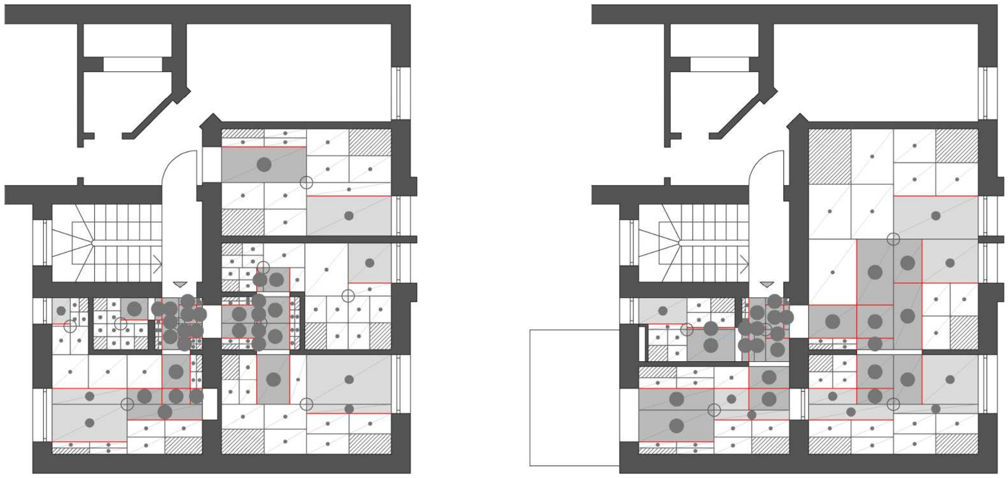
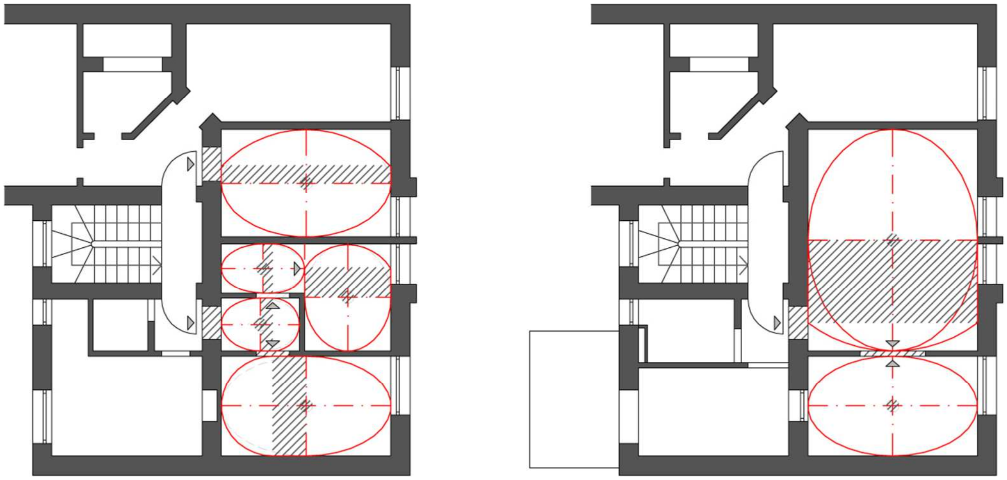


Figure 6(a). Placement of perceptual centers (Indraprastha, 2012), scale 1:200. Living room in residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
172x25mm (300 x 300 DPI)

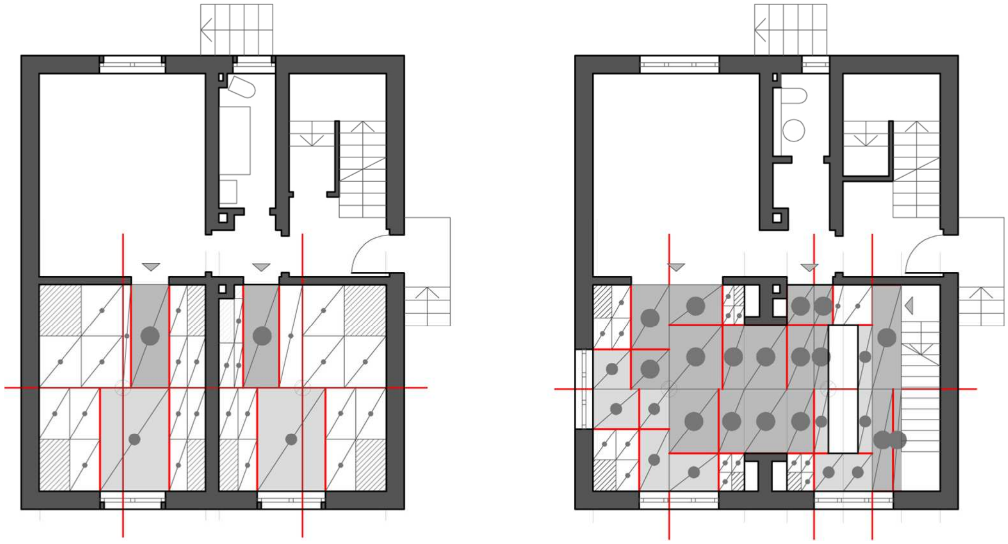


Figures 6(b) and 6(c). Placement of perceptual centers: Plans of the first floor before (6b) and after (6c) the building renovation, scale 1:200. Residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
170x80mm (300 x 300 DPI)

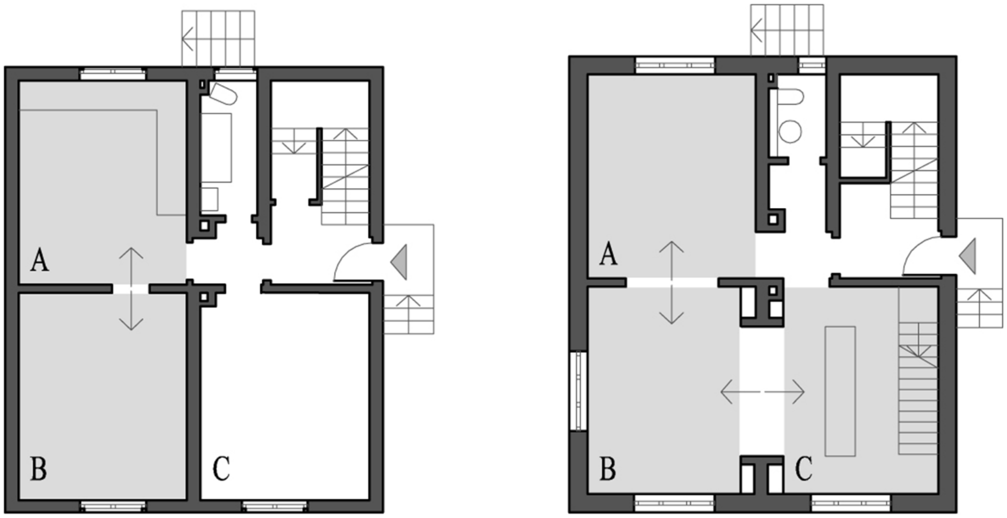


Figures 7(a) and 7(b). Plans of the first floor before (7a) and after (7b) the building renovation, scale 1:300. Concavity of the living room in a residential building, Cologne, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
113x53mm (300 x 300 DPI)

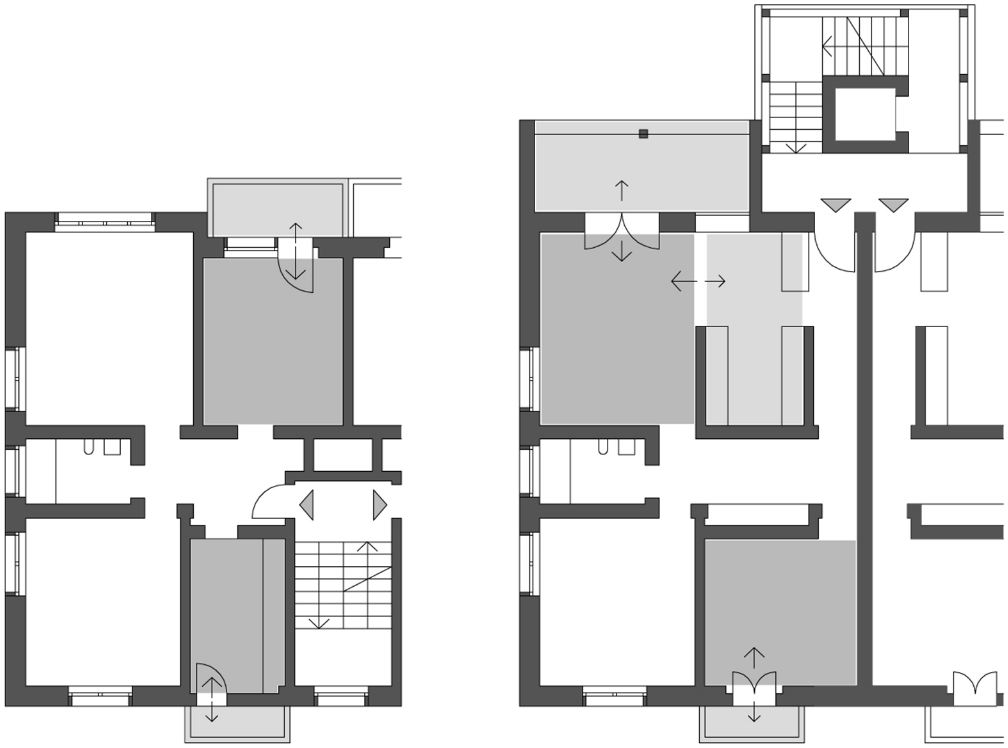
Figures 8(a) and 8(b). Examples of the use of ceilings heights to define spaces and functions, such as a kitchen (8a) and a living room (8b). Figure 8(a): Private house, Herentals, Belgium, © [Toon Grobet]. Reproduced by permission of Toon Grobet. Figure 8(b): Private house, Alvite, Portugal, © [Fernando Guerra]. Reproduced by permission of Fernando Guerra.
161x65mm (300 x 300 DPI)



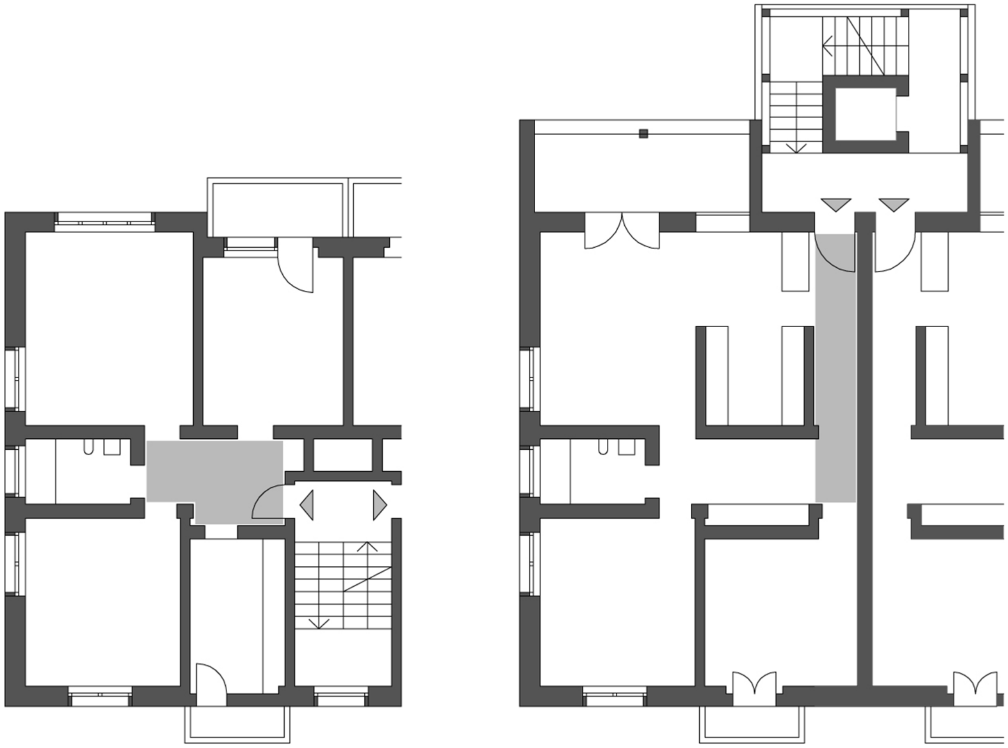
Figures 9(a) and 9(b). Plans of the ground floor before (9a) and after (9b) the building renovation, scale 1:200. The new connection between rooms, the new kitchen, and the addition of new stairs create competing spatial fulcrums and change circulation patterns. Private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
132x71mm (300 x 300 DPI)



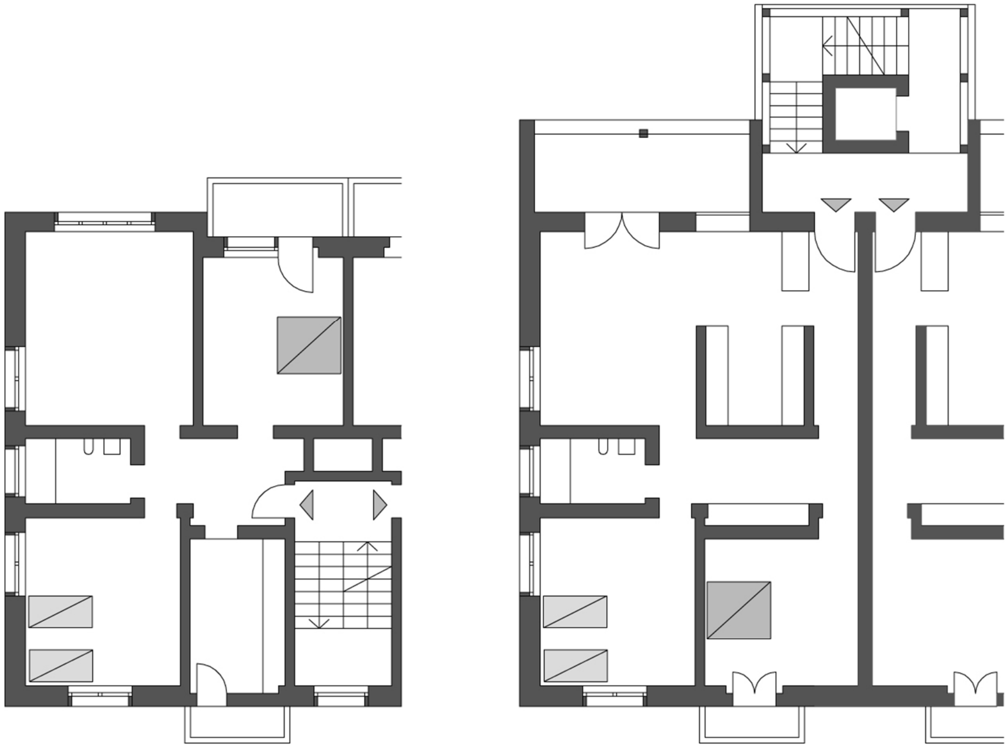
Figures 10(a) and 10(b). Plans of the ground floor before (10a) and after (10b) the building renovation, scale 1:300. Coordinated relationship of spaces. Private house, Bochum, Germany, © [DETAIL]. Reproduced by permission of DETAIL.
87x44mm (300 x 300 DPI)



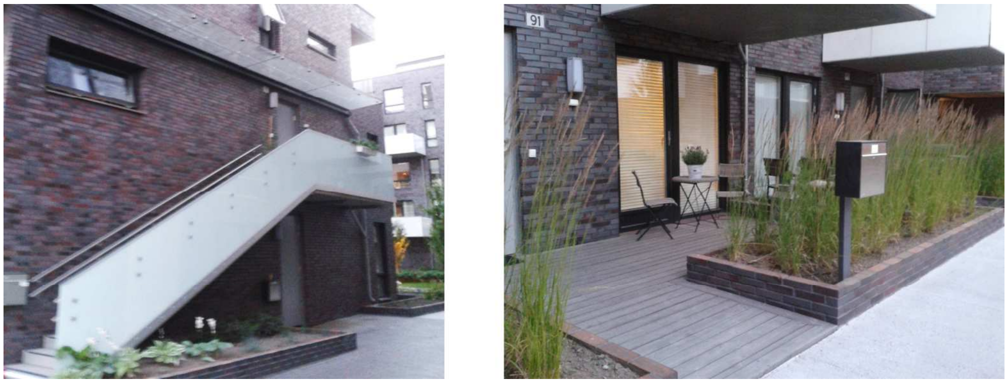
Figures 11(a) and 11(b). Plans of the first floor before (11a) and after (11b) the building renovation, scale 1:300. Subordinated relationship of spaces. Residential building, Chur, Switzerland, © [DETAIL]. Reproduced by permission of DETAIL.
105x78mm (300 x 300 DPI)



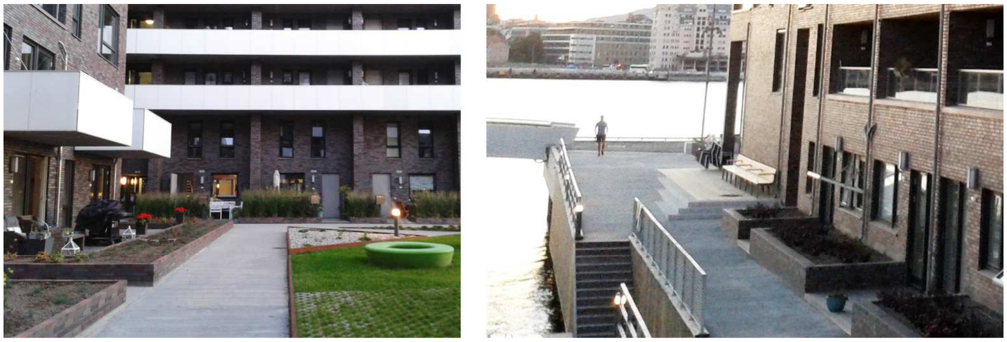
Figures 12(a) and 12(b). Plans of the first floor before (12a) and after (12b) the building renovation, scale 1:300. Space closure of the hall area. Residential building, Chur, Switzerland, © [DETAIL]. Reproduced by permission of DETAIL.
105x78mm (300 x 300 DPI)



Figures 13(a) and 13(b). Changes in zoning (children's and adults' areas), plans of the first floor before (13a) and after (13b) the building renovation, scale 1:300. Private house, Bochum, Germany, © [Jörg Hempel]. Reproduced by permission of Jörg Hempel.
105x78mm (300 x 300 DPI)

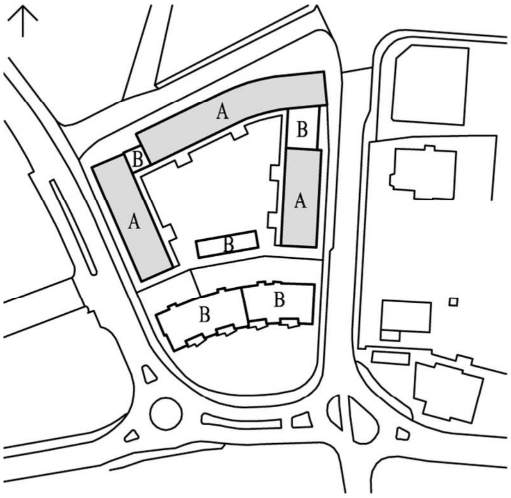


Figures 14(a) to 14(d). Dwelling’s entrances, outdoor private spaces, and gradual and physically clear transition between private, semipublic, and private domains. Residential building, Oslo, Norway, picture: Author.
173x65mm (300 x 300 DPI)



Figures 14(a) to 14(d). Dwelling’s entrances, outdoor private spaces, and gradual and physically clear transition between private, semipublic, and private domains. Residential building, Oslo, Norway, picture: Author.
194x65mm (300 x 300 DPI)

Figures 15(a) and 15(b). Changes in materialization of facades and windows' size and composition. Residential blocks, Zürich, Switzerland. Residential block after renovation (15a) © [Andrea Helbling, Arazebra]. Reproduced by permission of Andrea Helbling, Arazebra, Zürich. Residential block before renovation (15b) © [Schneider Studer Primas GmbH]. Reproduced by permission of Schneider Studer Primas GmbH.
197x65mm (300 x 300 DPI)



Figures 16(a) and 16(b). Residential block, Chur, Switzerland. Figure 16(a): Plan of residential block after renovation, scale 1:2000. Buildings "A" are existing; buildings "B" are additions that close the perimeter of the block, © [DETAIL]. Reproduced by permission of DETAIL. Figure 16(b): Residential block before renovation, © [Ralph Feiner]. Reproduced by permission of Dieter Jüngling and Andreas Hagmann.
118x57mm (300 x 300 DPI)