REUSING CONCRETE PANELS FROM BUILDINGS FOR BUILDING: POTENTIAL IN FINNISH 1970S MASS HOUSING

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Abstract

A remarkable share of European mass housing was built with large-panel systems during the 1960s and 1970s. In many countries, this stock is already being demolished or demolition is discussed due to vacancies or social problems. This trend may result in the creation of an unforeseeable amount of concrete waste. Simultaneously, EU has issued the Waste Framework Directive aiming at reuse instead of recycling. Unlike *in situ* cast concrete, reclaimed prefabricated concrete panels from mass housing carry the potential for reuse. The purpose of this study is to review the reuse potential embedded in Finland's mass housing stock from the perspective of the dimensions of the panels and spaces, *i.e.* their suitability for architectural (plan) design. The research material consists of architectural drawings of 276 blocks of flats that contain over 26 000 prefabricated wall panels and nearly 14 000 hollow-core slabs, the dimensions of which are compared to current norms and guidelines for dimensioning living spaces. The technical prerequisites for reuse are reviewed with the help of literature. The study results in identifying an inventory of panels typical to Finnish precast concrete construction, which, in principle, should not exist because the building plans were not standardized but were supposed to be unique. The panels are found to be still usable in architectural (plan) design of detached houses, which form one third of annual residential production in Finland.

1 Introduction

The majority of the Finnish building stock is residential and 1970s was the peak decade in residential construction. At that time, most of the apartments were realized in high-rise mass housing with prefabricated concrete panel construction. This is in common for most European countries with notable mass housing stocks (Turkington, van Kempen & Wassenberg, 2004). During the last ten years, a public discussion on the demolition or preservation of these housing estates has accelerated in Finland. Large-scale demolitions have taken place elsewhere in Europe, especially in the UK, Germany, France and the Netherlands because of vacancies following urban shrinkage and as an attempt to mitigate social segregation (ibid., p. 276; for Germany, Deilmann et al., 2009). Both these circumstances appear in Finland, too, in different parts of the country. Examples of demolitions of public housing with respective motives can be recognized here and there even though the demolitions have so far remained local and small in scale. However, should the demolitions of the contemporary mass housing stock accelerate, an unforeseen amount of concrete waste could be created. This applies not only to Finland but even more so to the countries that are already demolishing mass housing. Therefore, it has been suggested that old buildings should been seen as reserves for resources such as building materials (Agudelo-Vera et al., 2012; Thomsen & van der Flier, 2011).

At the same time, the European Union is tightening the demands for recycling construction and demolition (C&D) waste. The Waste Framework Directive defines a waste hierarchy according to which preparation for reuse is to be prioritized over destructive recycling as material (EU, 2008, p. 10). With its 70%-by-weight utilization target for C&D waste (ibid, p. 13), the directive puts a strong emphasis on recycling of heavy mineral materials. Concrete is a material that is easily recyclable in roadbeds; yet this kind of utilization is downcycling and ranks low in the waste hierarchy (Hiete et al., 2011). Researchers have warned that downcycling or even disposing of concrete will increase in Germany in near future if new sinks, such as new construction, are not promoted (ibid.). Indeed, manufacturing recycled aggregate concrete from crushed concrete is a more refined and higher-ranking option for the recycling of concrete. Unfortunately, it has a carbon footprint worse than virgin aggregate concrete (Asam, 2007); so what is gained on resource depletion is lost for global warming. Unlike in-situ cast concrete, prefabricated concrete panels may carry the potential for reuse. Some systems, such as the Dutch CD-20, have been designed for deconstruction and reuse (Kibert & Chini, 2000, p.103–109; fib, 2008, p.69–70), but the majority of systems do not have this asset. Nevertheless, several experiments on reusing panels from prefabricated housing have proven successful even though the panels were not originally designed for deconstruction. In addition to having a very low carbon footprint, reuse usually reduced the cost of new construction by 20–30%. (Huuhka, 2010a).

The research on reclaiming and reusing panels is most progressed in Germany (see e.g. Mettke, 2003, 2007; Asam, 2005, 2006, 2007; Mettke, Heyn & Thomas 2008). For example, panel inventories have been compiled from most widespread German systems to aid the design of new buildings (Mettke, 2003 & 2007). Some studies have also been conducted in the Netherlands (Coenen et al., 1990; Van Nunen, 1999; Naber, 2012; Glias, 2013) and Finland (Huuhka, 2010a; Saastamoinen, 2013; Lahdensivu et al., 2015) and some experiments have been carried out in Sweden (Addis, 2006, p. 25–26; Huuhka, 2010a, p. 110). While these experiences are generally encouraging, the results acquired from one building system may not be directly applicable to other systems because structural details, degrees of standardization and geographical distributions of systems may vary significantly. For example in East Germany (GDR), there were only a handful of different panel systems; they were used in the whole country; and the systems were highly standardized, including the panels and building plans (Blomqvist, 1996, p. 53–58). In Finland, then again, there were multiple factory-specific panel systems that were used locally; the national standard given in 1969 only aimed at standardizing the connections and the modular grid; and buildings were designed individually at all times (Hytönen & Seppänen, 2009, p. 116).

Although most of the aforementioned research has been published in local languages, the international scientific interest in salvage and reuse has been growing. The latest articles include e.g. Gorgolewski (2008), Gorgolewski et al. (2008), Gravina da Rocha and Aloysio Sattler (2009) and Pongiglione and Calderini (2014). Unlike this paper, none of the aforementioned contributions concentrate on concrete structures. The purpose of the current study is to evaluate the reuse potential embedded in the mass housing of Finnish cities with regard to the dimensions of the concrete panels, i.e. their suitability for new architectural design. Although the study situates in Finland, it may have relevance for other countries as well because Finnish panel systems were based on international examples. The research questions are as follows: What parts (e.g. exterior walls, interior walls, slabs) of mass housing were prefabricated and up to what extent? Do the panels come in recurrent sizes and if, which dimensions? Are these dimensions suitable for new construction and for which purposes?

2 Background

As explained above, knowledge on deconstructing and reusing panels from one system may have a very limited applicability to other systems. Therefore, this section focuses on exploring existing knowledge on Finnish precast concrete construction that acts as the starting point for the current study. The first chapter presents an overview of the large-panel systems used in Finland. The second and third chapters concentrate on the technical opportunities and limitations for reuse. The fourth and last chapter looks into the influence of norms and design guidance.

2.1 Finnish concrete panel systems

Prefabrication came into use in Finland during the 1950s, first in non-residential construction (Hytönen & Seppänen, 2009, p. 38–57). The first fully prefabricated block of flats was constructed in 1959, and several significant construction companies shifted to panel construction in the beginning of 1960s (Hytönen & Seppänen, p. 53). In these early days, each panel factory had its own panel system, many of which were loosely based on French or Swedish systems (Hankonen, 1993, p. 141–145, 158–159; Hytönen & Seppänen, 2009, p. 51, 91). The differences localized in dimensions, connections and other structural details. (Hytönen & Seppänen, 2009, p. 53–54). Architecturally, the differences between the systems were minor. The structural skeleton of lamellae blocks was a crosswall frame, in which crosswalls are load-bearing and longitudinal walls are non-load-bearing (Mäkiö et al., 1994, p. 62). Exterior walls were sandwich panels and floors were solid concrete slabs. Table 1 gives more details on the structures and dimensions. These factory-specific systems (Figure 1) were in use up to 1975 (Mäkiö et al., 1994, p. 72). Nonetheless, partial prefabrication remained the most common practice throughout the 1960s and early 1970s (ibid, p. 66).

Most contractors used prefabricated walls and casted floors in situ while at least one major contractor did the opposite (ibid p. 66; Hankonen, 1993, p. 159). By 1966, 25% of public housing was fully prefabricated and 35% was partially prefabricated (Hytönen & Seppänen, 2009, p. 75).

Building part or structure	Dimension(s), mm
Floor height	2800
Room height	2600–2640
One-room panel, typical width	3000–3900
Two-room panel, typical width	6000–7200
Solid concrete slab, maximum size	3600 by 5400
Solid concrete slab, thickness	160–200
Load-bearing part of exterior sandwich panels, thickness	150–160
Load-bearing interior walls, thickness	150–160

Table 1. Dimensions of structures used in factory-specific panel systems. Sources: Mäkiö et al. (1994); Saastamoinen (2013).

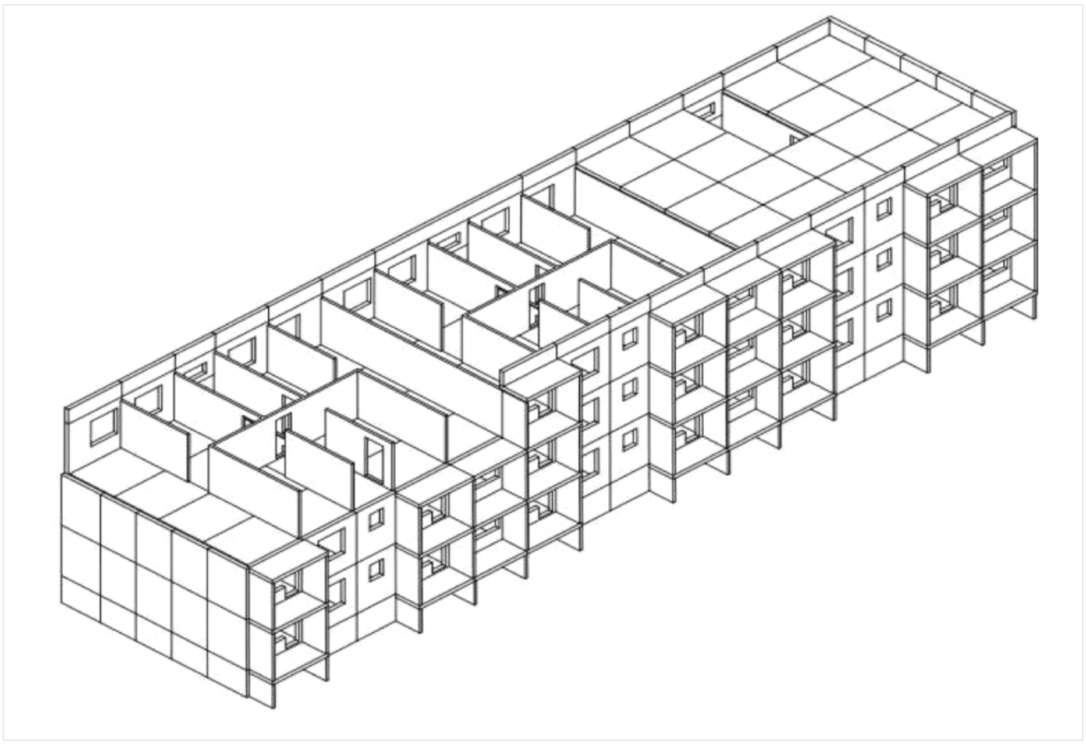

Figure 1. Finnish large-panel system used from 1960s to 1975. Both panels and slabs were room-size. Interior walls between rooms are load-bearing. (Remodeled from Mäkiö et al., 1994, p. 67).

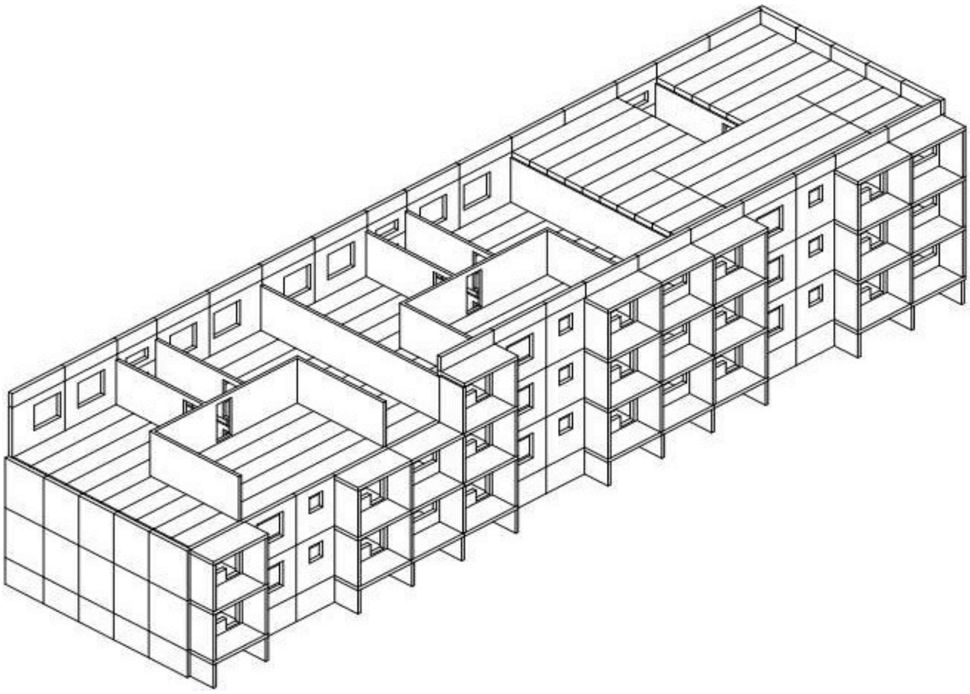

Figure 2. BES system. Main differences to the large-panel system (Figure 2) are the long-spanning hollow-core slabs and the subsequently smaller number of load-bearing interior walls. Only interior walls between apartments are load-bearing. (Remodeled from Mäkiö et al., 1994, p. 68).

In the end of the 1960s, the concrete industry launched a research project that aimed at the creation of one open standardized panel technology (Figure 2) called the BES (abbreviation of 'betonielementtistandardi', Finnish for 'concrete panel standard'). The main aim was to allow purchasing different elements, such as exterior walls, interior walls, slabs, balconies and stairs from different producers. (BES, 1969). The study, based on benchmarking a remarkable amount of panel systems in other countries, was completed in 1969 (BES, 1969). The first BES blocks of flats were inaugurated in 1971 (Hytönen & Seppänen, 2009, p. 107) and BES superseded the factory-specific systems during the 1970s. The most notable difference to previous systems was replacing solid concrete slabs with hollow-core slabs, similar to those used in Germany and Canada (Hytönen & Seppänen, 2009, p. 50, 104). Swedish-developed Nilcon or U-slabs, which represent prefabricated versions of upstand beams with integrated decks, were also used, but they were in the minority due to multiple weaknesses in comparison to hollow-core slabs (Hytönen & Seppänen, 2009, p. 106). These pre-tensioned slab types enabled longer spans and reduced the amount of load-bearing interior walls

(Neuvonen, 2006, p. 150, 157), as can be seen by comparing Figures 1 and 2. In addition, connections were standardized; the number of alternative connections was reduced; and the pitches of the modular grid were fixed. Table 2 elaborates on the structures and dimensions in this system. BES has remained in use in the construction of blocks of flats and offices ever since. All in all, prefabricated concrete has dominated not only the construction of blocks of flats but also the production of business buildings (Hytönen & Seppänen, 2009, p. 325). Figure 3 shows the share of prefabricated concrete in Finnish building production since 1972.

Building part or structure	**Dimension(s), mm**
Floor height	2800
Room height	2500
Modular dimension, load-bearing structures	1200
Modular dimension, adjoining structures, horizontal direction	300
Modular dimension, adjoining structures, vertical direction	100
Load-bearing panel, possible width	1200, 2400, 3600
Non-load-bearing one-room panel, possible width	3000, 3300, 3600, 3900, 4200
Non-load-bearing two-room panel, possible width	6000, 6300, 6600, 6900, 7200
Hollow-core slab, width	1200
Hollow-core slab, maximum length	13000
Hollow-core slab, thickness	265
Load-bearing part of exterior sandwich panels, thickness	150
Load-bearing interior walls, thickness	180

Table 2. Dimensions of structures used in BES. Sources: BES (1969); Mäkiö et al. (1994).

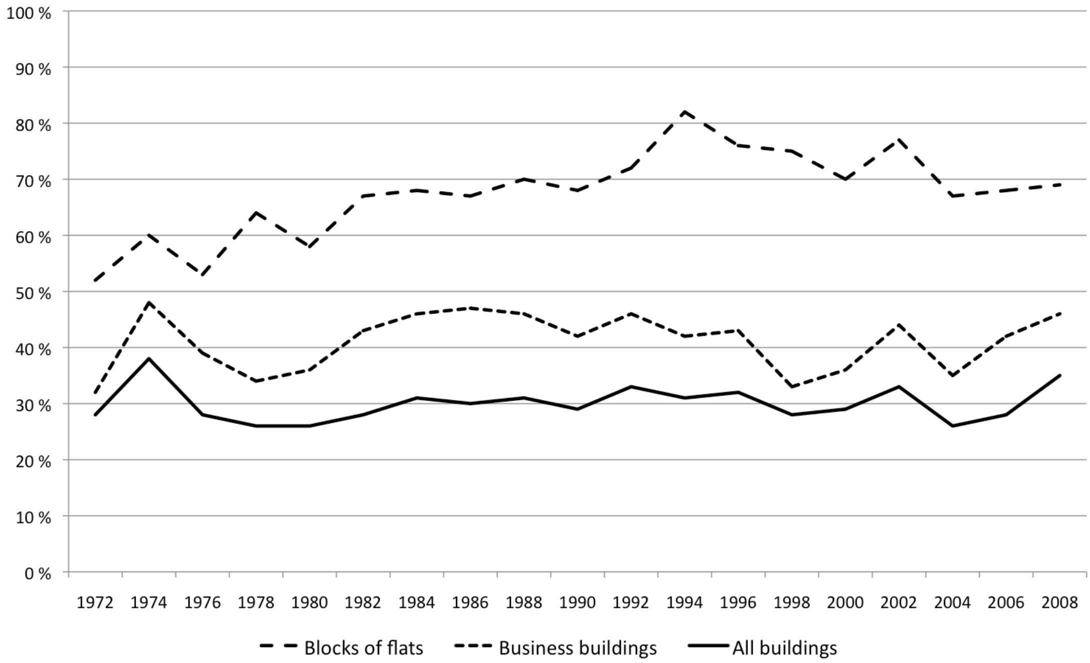

Figure 3. Share of prefabricated concrete in Finnish building production. (Remodeled from Hytönen & Seppänen, 2009, p. 325).

2.2 Connections, deconstruction and re-connection

The connections of the panels affect substantially the deconstruction process as well as the demounting process. Alas, the existing connections could not be studied with research material available for the current study, but the existing knowledge is included in this literary review. The options for connections are well documented in the literature. BES (1969), BES-suositus (1972) and BES-suositus (1979) represent the design guidance of the time, while Mäkiö et al. (1994) and Saastamoinen (2013) are later archival studies. The research materials of Mäkiö et al. (1994) encompasses 270 blocks of flats in Helsinki. Saastamoinen (2013) is a study based on a sample of 29 blocks of flats in Tampere.

The literature shows that in BES buildings, the connections are grouted. The grout transfers the compressive forces; in addition, there are rebars as tensile reinforcement in the joint. Hollow-core slabs are dowelled. Non-load-bearing exterior panels are usually self-supported or, more rarely, suspended from the ends of load-bearing interior walls. In vertical seams of load-bearing panels, there are either vertical steel bars threaded through steel loops that extend from the wall panels (Figure 4, left) or horizontal steel bars that have been bent into the seam (Figure 4, right). (BES-suositus

1979; Mäkiö et al, 1994, p. 100). Prior to BES, welded and grouted as well as bolted and grouted connections were also used. Like hollow-core slabs, solid concrete slabs were dowelled as well. Non-load-bearing exterior panels were usually suspended from load-bearing interior walls. Vertical seams were as in BES. (Mäkiö et al., p. 98–99).

As for the deconstruction of the typical connections, the Finnish experience is twofold. Deconstruction of blocks of flats was first experimented with in 2000, but it was found too laborious to be financially attractive for construction companies (Kauranen, 2001, p. 31–33, 38). Although reuse was neither planned nor attempted, the report concludes that the lack of applications is a barrier for reuse. The second effort took place in 2008–2010 during a neighborhood rehabilitation project in Raahe. In this case, deconstruction and small-scale reuse (Figure 5) were carried out successfully and resulted in savings in the construction costs. (Huuhka, 2010b). The 36% reduction of costs is equivalent to savings achieved in Germany (Huuhka et al., 2015).

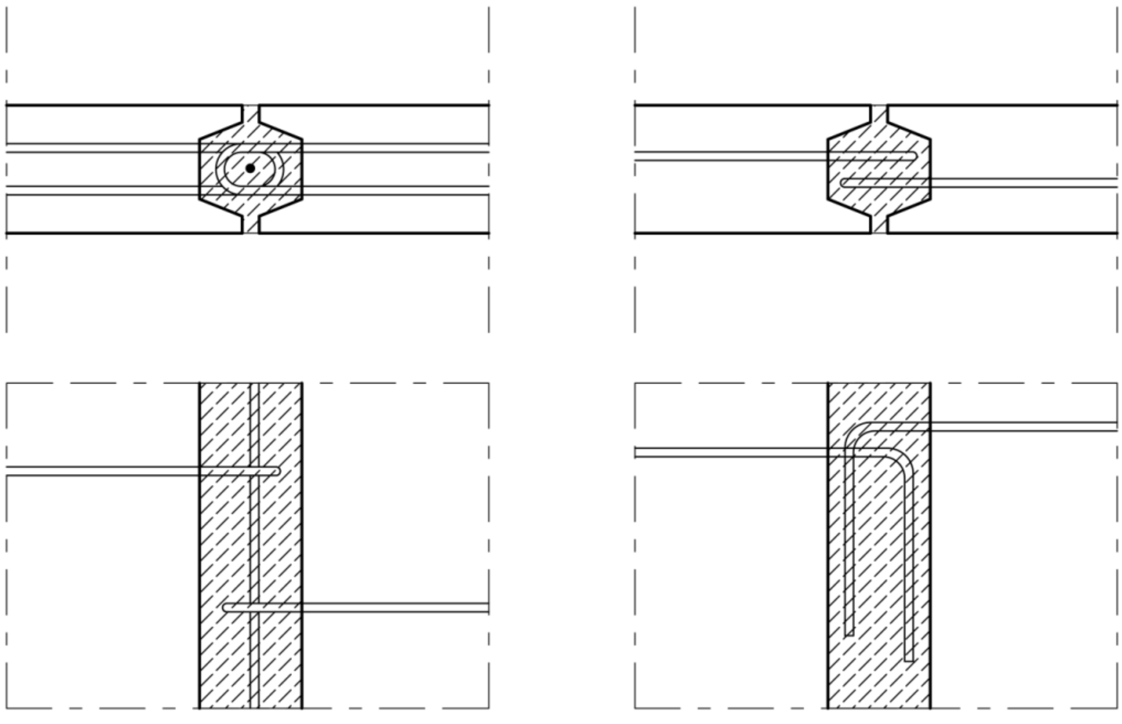

Figure 4. A steel loop connection (left) and a steel hook connection (right). (Redrawn from BES-suositus, 1972).

Figure 5. Construction site of Kummatti housing estate, Raahe. Partial deconstruction of apartment blocks (at the back) and reuse of panels for carports (at the front). Design by architects Harri Hagan and Petri Kontukoski. Photo in the courtesy of Petri Kontukoski.

Saastamoinen (2013, p. 101) estimates that original rebars and connection steels can be used for reconnection of old panels if the grouted joints are chiseled open carefully without cutting the steel bars. Another option is to use a diamond saw, but that may shorten the element and cut the rebars (Saastamoinen, 2013, p. 106–108). If the rebars are cut, new connection steel bars must be grouted to the edges of panels before grouting the panels together again. Non-load-bearing facade panels suspended from the ends of bearing interior walls are the easiest to reconnect (Saastamoinen, 2013, p. 99). According to Mäkiö et al. (1994, p. 78, 98–99, 133–134), this was the most common joint type used in Helsinki. However, according Saastamoinen (2013, p. 35), this technique was in the minority in the city of Tampere. A steel hook connection between load-bearing panels (Figure 4, right) is easier to chisel clean than a steel loop connection (Figure 4, left). The former seems to have been the most usual joint type in Tampere (Saastamoinen, 2013, p. 35) and it was also encountered in the Raahe deconstruction project. Mäkiö et al. (1994) do not report which was more common in their study. Other options for reconnecting are external or embedded steel connectors or encasing the structure in concrete (Lahdensivu et al., 2015). The last option was used in the project in Raahe (Huuhka et al., 2015).

2.3 Durability properties and damage of existing panels

Another issue to consider is the physical condition of the panels, which helps to assess the remaining service life. In a recent study, the durability properties of Finnish concrete facades were considered as poor, but the actual deterioration was found to be rather minor (Lahdensivu, 2012). There are two types of damage that are focal for reinforced concrete structures in the Finnish climate: firstly, frost damage and secondly, corrosion damage. Deterioration occurs as the result of both durability properties and exposure to stress conditions. The desired surface finishing influences the manufacturing technique of panels resulting in differences in the durability properties regarding both the degradation phenomena.

In Finland, concrete is considered to be fully frost-resistant if the material has a protective pore ratio of 0.2 and completely non-frost-resistant if the ratio is below 0.10. In 70% of existing concrete facades, this ratio is less than 0.15. The frost resistance varies depending on the surface type (Figure 6), and the manufacturing year. The worst properties are found in exposed aggregate concrete, ceramic tiles and uncoated patterned concrete. In addition, concrete facades made before 1980 generally have poorer frost resistance than newer facades.

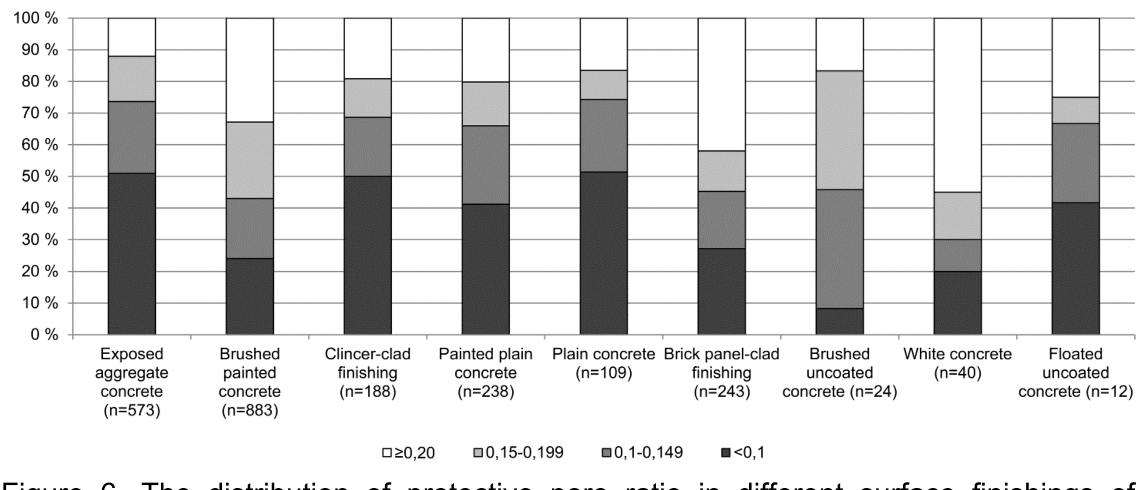

Figure 6. The distribution of protective pore ratio in different surface finishings of concrete facades (Lahdensivu, 2012).

As said, the actual frost damage depends on moisture behavior and stress conditions, such as the existence of proper waterproofing and the prevailing wind direction during rain (Lahdensivu et al., 2013). In most cases, insufficient frost resistance has not lead to far-advanced or widespread frost damage. Widespread frost damage has been observed in only 7.3% of studied facades.

The situation is very similar with corrosion as well. Widespread corrosion damage has been observed in only 5.7% of studied buildings. Due to higher amounts of annual rain, much more visual corrosion damage was observed in the coastal area than inland. (Lahdensivu et al., 2011). The corrosion has been induced by three factors: the use of corroding steel for reinforcement, too small cover depths of reinforcement and the carbonation of concrete.

The depth of the concrete cover on top of the reinforcement depends on the manufacture of concrete panels and the quality of work. Typically, 5–10% of reinforcement has crucially small cover depths (less than 10 mm). The smallest cover depths usually occur in ceramic tile finished facades, where the reinforcement is situated just behind the tiles.

In new concrete, the alkalinity of the material protects the reinforcement from corrosion. When concrete ages, it reacts with air and the alkalinity reduces. This process is called carbonation, and it makes the reinforcement more vulnerable to corrosion. Carbonation has widely achieved the reinforcement in all over 30 year old concrete facades and corrosion has already been possible for 20–30 years.

As stated, despite the poor durability properties of existing concrete panels, there is relatively little visible damage in them. The damage is typically local and can be repaired rather easily with patch repairs and protective coatings. This kind of repair extends the service life with 20–25 years (Mattila & Pentti, 2004). It should also be noted that concrete panels exposed to outdoor climate are not equally damaged because they are exposed to wind-driven rain (WDR) differently. For instance, North facades get approximately 80% less WDR than South to West facing surfaces (Pakkala et al. 2014; Lahdensivu et al. 2013).

Finally, it should be remarked that according to several studies, the demolition of buildings does not seem to depend on the condition of buildings (as summarized in Huuhka & Lahdensivu, 2014). Rather, behavioral factors, such as economics, tenure and use nowadays are considered as decisive for demolition decisions.

2.4 Norms and design guidance: then and now

As shown above, the existing literature focuses on technical issues but takes little stance on the dimensions of panels or their suitability for new architectural design, which is in the focus of the current study. Nevertheless, some insight can be gained by looking at the evolution of construction norms and design guidance. In the 1960s and 70s, construction was guided by authorities' norms and guidelines (Mäkiö et al., 1994, p. 240). The guidelines were mostly intended for publicly subsidized buildings, but in practice, they were also adopted in privately financed production (Korpivaara-Hagman, 1984; Keiski, 1998, p. 40; Neuvonen, 2006, p. 210). In addition to the 'official' guidelines, good construction practices have been promoted in Finland since 1940s in design instructions called the RT Building Information Files. These documents are published by a non-profit organization and they are widely used in architectural education and profession.

In the 1960s and 70s, the norms only defined the minimums for floor height and room height (Mäkiö et al., 1994, p. 242). The guidelines for publicly subsidized flats gave minimum widths for two rooms: the living room and the hall (Mäkiö et al., 1994, p. 194). In addition, the RT File provided exemplary layouts for bedrooms and bathrooms but not for other rooms (Kaasalainen & Huuhka, in press). The former came in in 27 different widths and the latter in 26 different dimensions (RT 935.50; RT 936.50). Table 3 presents a summary of the aforementioned dimensions. The situation is rather similar even today, apart for the fact that the minimum floor height has increased. There still are no binding norms for room widths, but the RT Files now provide recommendations for the dimensions of all kinds of rooms. Table 4 summarizes the current requirements and guidelines. Unsurprisingly, the technical requirements for residential buildings have also changed. Table 5 presents the evolution of norms for thermal insulation and Table 6 for sound insulation.

Building part or room	**Dimension(s), mm**
Floor height, minimum	2800
Room height, minimum	2500
Living room, minimum width	3300 (–1970), 3600 (1970–)
Hall, minimum width	1500
Bedroom, instructional widths	1650–4900
Bathroom, instructional dimensions	800–2800

Table 3. Norms for heights and required and/or recommended widths for different rooms in 1960–70s. Sources: Mäkiö et al. (1994); RT 935.50 (1966); RT936.50 (1965).

Building part or room	Dimension(s), mm
Floor height, minimum for blocks of flats	3000
Room height, minimum for blocks of flats	2500
Floor height, minimum for detached and terraced houses	not defined
Room height, minimum for detached and terraced houses	2400
Bedroom (one person)	2200–3100
Bedroom (two person)	3000–4000
Living room	3600–4200
Dining room	2000–3800
Kitchen	2300–3200
Staircase (shared)	2600–2800
Staircase (private)	1800–2100
Auxiliary spaces	1800–2400

Table 4. Norms for heights and recommended widths for different rooms in 2015. Sources: RakMK G1, 2005, p. 4–5; RT 93-10925, 2008, p. 4–7; RT 93-10926, 2008, p. 3–4; RT 93-10536, 1994; RT 93-10929, 2008, p. 6–7; RT 91-10440, 1990, p. 11–12; RT 93-10932, 2008, p.4–5; RT 93-10937, 2008, p. 3; RT 93-10945, 2008, p. 2, 4; RT 93-10950, 2008, p. 4–5; RT 93-10953, 2009, p. 3; RT 88-11018, 2011, p. 6.

Building part	1969	1974	1976	1978	1985	2003	2007	2010
Exterior wall	0.70–0.81	0.35	0.40	0.29	0.28	0.25	0.24	0.17
Roof	0.47	0.29	0.35	0.23	0.22	0.16	0.15	0.09
Base floor	0.47	0.41	0.40	0.40	0.36	0.25	0.24	0.16
Windows	-	-	2.10	2.10	2.10	1.40	1.40	1.00
Doors	-	-	0.70	0.70	0.70	1.40	1.40	1.00

Table 5.U-values (W/m2K) in Finnish building regulation from 1969 on (Lahdensivu et al., 2015, p. 50).

Acoustic index	1955	1960	1967	1998
Sound reduction, vertical structures	51	52	52	55
Sound reduction, horizontal structures	51	52	53	55
Impact-sound level	62	56	58	53

Table 6. Acoustic indexes (dB) in Finnish building regulation from 1955 on (Lahdensivu et al., 2015, p. 51).

3 Research material and methods

The research material of the current study consists of photos of façade, plan and section drawings of 276 blocks of flats that received public funding between 1968 and 1985. Both lamellae blocks (192 buildings) and point blocks (84 buildings) are included. Figure 7 presents a typical building and Figure 8 shows exemplary drawings. The material was collected from the archives the Housing Finance and Development Centre of Finland (ARA), which is the successor of the erstwhile funding agency for public housing. A table was created in which the types and dimensions of the structures were recorded. Their examination was conducted with SQL queries.

Figure 7. A typical precast 1970s slab block.

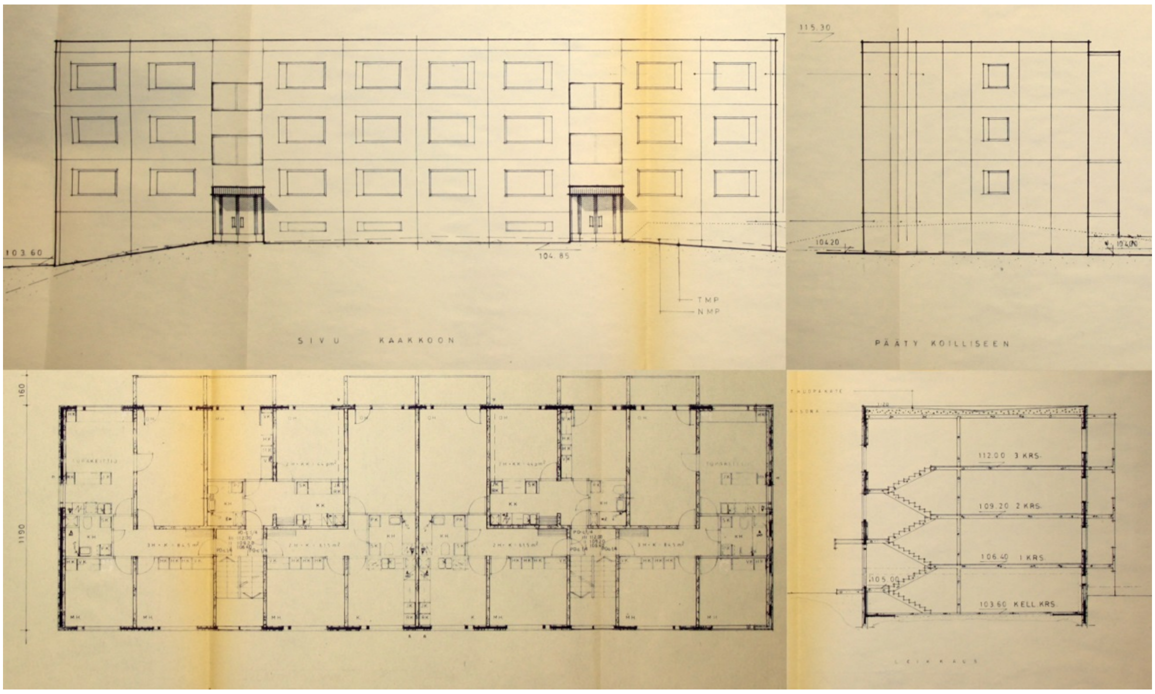

Figure 8. An example of original facade, plan and section drawings of a building.

3.1 Quality of the research material

The set of drawings that forms the research material does not represent the building permit drawings or the final drawings of the buildings but the drawings that were used in applying public funding for the building project. The decision to collect the material from the ARA archives was based on the fact that the drawings were available from all Finnish municipalities. The data set contains buildings from 28 cities. As the examination period is renowned for fast and efficient construction, it is very unlikely that building plans would have been changed essentially after applying for the funding. Unfortunately, neither ARA nor cities store structural drawings in a consistent manner, which is why the current authors had to settle for architectural drawings only.

Some drawings had gauge lines with the dimensions of the façade panels that could be transferred to the data table, but most dimensions had to be measured from the photos. The photos were stretched to scale using some dimension given in the drawings, e.g. the height or the width of the building. This allowed measuring the panels with the precision of 0.1m. The numbers and types of panels were calculated and recorded to the data table. The numbers were calculated only for floors consisting of apartments. Attics, basements and ground floors with secondary spaces were excluded. The reasons for the exclusion are as follows. Firstly, basements and ground floors are often in situ cast. Secondly, only a minority of the buildings has attics and basements. When these spaces exist and are precast, the panels are usually less than one meter high, which means their reusability for new purposes is very limited. Thirdly, panels of ground floors without residential spaces usually differ from the panels of the above residential floors because they are either blind or have doors and small windows to the storages and other secondary spaces. Recording them would have denoted recording a large number of singular individual panels. The exclusion does not affect the distribution of panel widths significantly, as the excluded panels do not vary in width from the panels above or below them.

The precast parts were identified by reading the drawings. Embedded texts usually list the main structures, i.e. exterior walls and intermediate floors, and elaborate on their prefabrication. Load-bearing walls (both interior and exterior) could be distinguished from non-load-bearing ones by the thickness of the wall. Facade drawings nearly always present the borders of the facade panels, and sometimes so do the plan drawings. However, it could not be identified if the load-bearing interior walls were prefabricated or in situ cast.

Similarly, the floor structures were identified from section drawings or embedded texts. There were 18 buildings for which the floor structure could not be verified. In those cases, it was assumed to be in situ cast concrete because other materials have not been used in the floors of blocks of flats during the examination period (Mäkiö et al., 1994, p. 57–62; Neuvonen, 2006, p. 153–157, 218–219). The investigation of slabs was limited to hollow-core slabs for the following reasons: First of all, the number of other prefab slab types is small in the data, although room-size solid slabs have been more common in other studies such as Mäkiö et al. (1994) and Saastamoinen (2013). Secondly, unlike hollow-core and U-slabs that were always 1200 mm wide, room-size solid slabs were manufactured in different widths and the research material does not indicate this division. Thirdly, U-slabs were quite rare and they broke easily in assembly (Hytönen & Seppänen, 2009, p. 106). They would very likely break in deconstruction, too, and therefore, they are not of interest for the current study. Very few plan drawings showed how the floor is actually divided into hollow-core slabs, but this could be deduced from the location of the load-bearing interior walls.

4 Results and discussion

4.1 Degree of prefabrication

In all, 242 or 88% of 276 buildings in the data are at least partially made of prefabricated concrete panels. The share is greater than the previous literature imply (Mäkiö et al., 1994, p. 53; Hytönen & Seppänen, 2009, p.325). The remaining 34 buildings have most often in situ cast concrete exterior walls with bricks as a cladding and in situ cast concrete slabs. When it comes to the fully or partially prefabricated buildings, ten buildings have strip panels or a mix of strip and square panels while 232 buildings (84%) represent typical panel construction with only room-size square panels. The share of square panel facades is greater in the data than in Mäkiö et. al. (1994, p. 56). 130 buildings have fully prefabricated exterior walls but in situ cast floors, while in 100, both exterior walls and floors are fully prefabricated. The share of fully prefabricated buildings in the current study (36.2%) is clearly greater than Mäkiö et al. (1994, p. 53). Even though Hankonen (1993, p. 159) has found that at least one major contractor in a major city prefabricated slabs while casting walls in situ, no such buildings were included in the data. The use of this technique was likely confined to a small geographical area.

4.2 Floor and room height

The floor height is 2800mm for all buildings in the data, and the room height depends on the thickness of the slab. 90% of hollow-core slabs are 265mm thick, which equals a room height of roughly 2500m with finished flooring. In situ cast floors range from 150mm to 250mm resulting in room heights from 2550mm to 2650mm. Most often they are 200mm thick equaling to 2600mm high rooms.

The old panels do not fulfill the current norm for floor height in blocks of flats (3000 mm) although they would conform to the room height minimum (2500 mm). In detached, semi-detached and terraced houses, there are no norms for the floor height as long as apartments are not located on top of each other (RakMK G1, 2005, p.4–5). However, the NBCoF does not limit the number of floors in these building types. This enables reusing old panels in e.g. 3–4 floor townhouses.

4.3 Walls

83% of the buildings in the data have fully prefabricated square panel facades. On average, there are 1200 running meters of one-floor-high load-bearing facade and 3100 meters of one-floor-high non-load-bearing facade per a prefabricated building. The height of the load-bearing part of the sandwich panels as well as load-bearing interior walls depends on the thickness of the slab and ranges from 2500mm to 2650mm.

All buildings have load-bearing interior walls from concrete but it could not be verified with the data whether they are prefabricated or in situ cast. Although in situ casting is known to have been the more usual way, both techniques have been in use and can be expected to occur in the buildings of the data (Mäkiö et al., 1994, p. 66–68). The number of load-bearing interior walls is the largest when solid slab elements were used and smallest with long-spanning hollow-core slabs, i.e. BES buildings. In the latter, the number and length of load-bearing interior wall elements may be nearly half of that in the former (see Figures 1 and 2). The thickness of these walls varies from 150mm to 220mm in the 226 buildings from which the dimension could be determined. Walls that are at least 180mm thick fulfil the current requirement for partition walls that separate different apartments (Lietzén & Kylliäinen, 2014). In 47% of the studied buildings, this requirement is met. Walls thinner than 180mm can be used as partition walls inside an apartment.

4.4 Width of wall panels

Although the facades of 230 buildings were fully made of room-size square panels, the division of panels could not be determined explicitly from the drawings of 26 buildings (e.g. facade drawings had not been archived or the division of the facade was not shown in the drawings). Therefore, the final number of buildings that could be examined for panel widths and amounts is 204. In total, there are 26 287 square panels in this data that range from 800mm to 9600mm wide. 9 387 of the panels are load-bearing and 16 900 are non-load-bearing. On average, there are 129 panels per prefabricated building: 46 load-bearing and 83 non-load-bearing panels.

In all, 116 different widths were observed for panels, but some are clearly very common and some extremely rare. Load-bearing panels, i.e. usually panels on the short side of the building, show 73 different widths, 16 of which only occur in one building. Non-load-bearing panels, i.e. usually panels on the long side of the building, come in 98 different widths, 34 of which only occur in one building. In all, 20 most common panel widths cover 70% of all panels in the data; the top ten widths cover over half of the panels and the top five one third of them.

When the widths were rounded to the nearest 100mm, the number of different widths was halved to 68. Figure 9 presents a histogram of the widths and Figure 10 shows their occurrence in the buildings, distinguishing between load-bearing and non-load-bearing panels. As a rule, the occurrence of most common widths is more frequent than their share of all panels. For example, the most common panel width for non-load-bearing panels, 3000mm, covers less than 10% of all panels but occurs in every third building.

The modular arrangement of BES and the lack of that in the earlier panel systems appear to show in the figures. In BES, the modular pitch was 1200mm for load-bearing structures, and there is, indeed, a clear peak for 2400mm wide load-bearing panels in Figure 9. Similarly, there are notable peaks for non-load-bearing panels (between 3000mm and 4500mm and for 6000mm) that follow the 300mm modular pitch of BES for adjoining structures in horizontal direction.

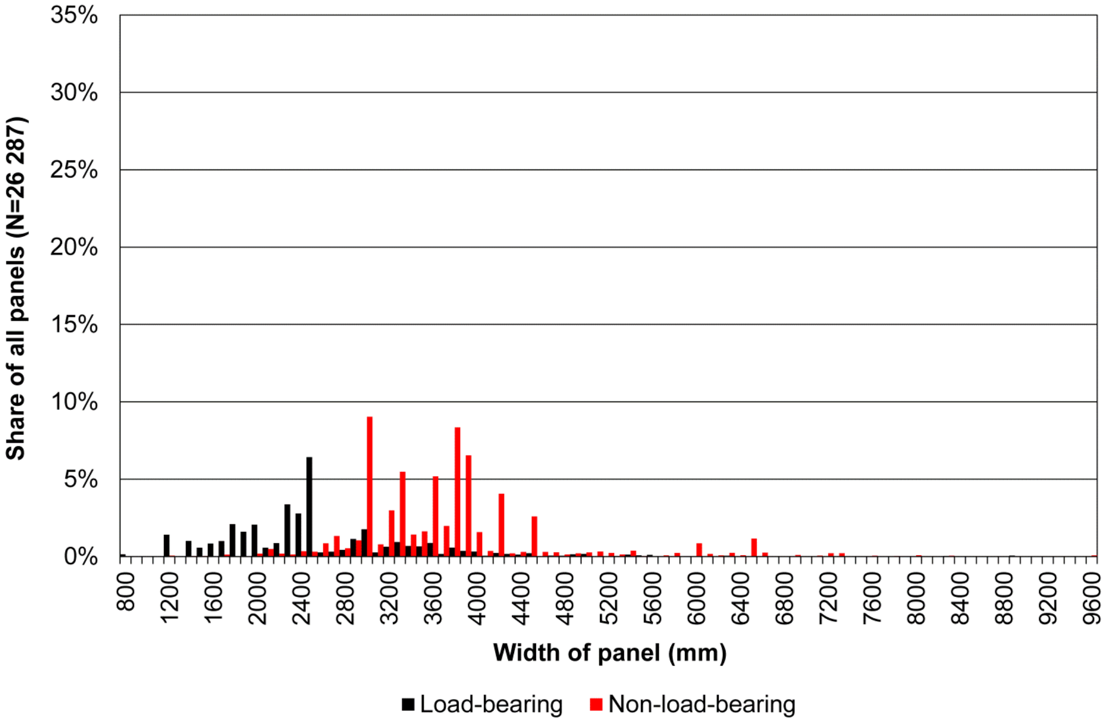

Figure 9. Width distribution of panels (N=26 287 panels).

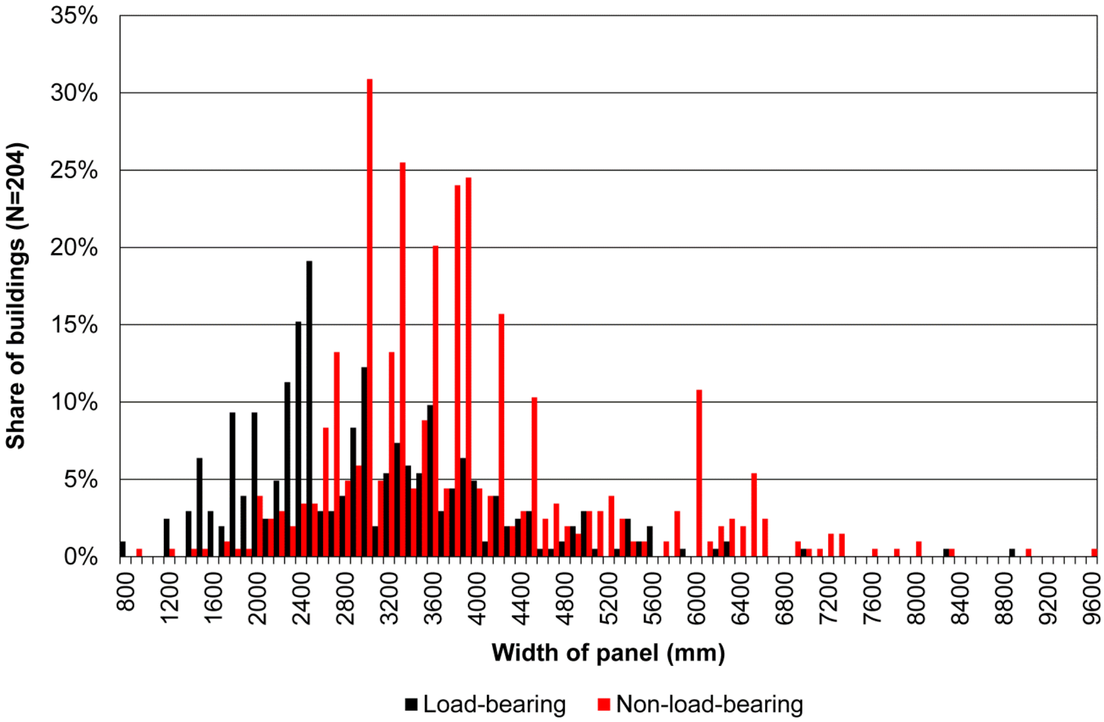

Figure 10. Occurrence of the widths in the in buildings (N=204 buildings).

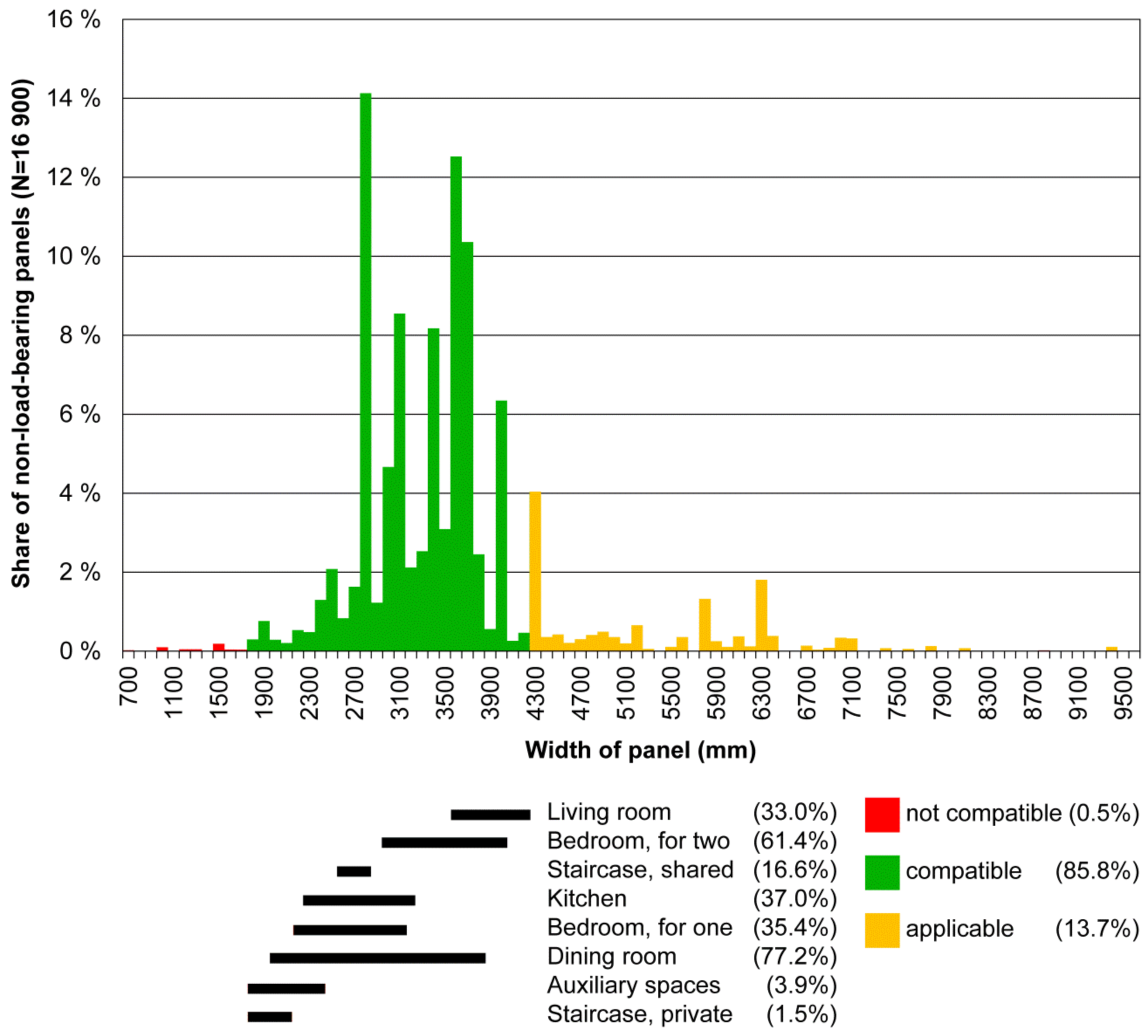

Figure 11. Compatibility of non-load-bearing panels to currently recommended dimensions for different rooms (N=16 900 panels).

Like Mäkiö et al. (1994, p. 66–68; 82–84) imply, load-bearing panels are generally shorter than non-load bearing panels, i.e. less than a room wide. The load-bearing façade of a room is typically put together from two or more panels. Therefore, only non-load-bearing panels were studied for the compatibility with current recommendations for room widths. 150mm was reduced from the panel dimension to acknowledge the loss of width resulting from the connections with crosswalls. As seen in Figure 11, only 0.5 of all non-load-bearing panels are not wide enough in the light of the present recommendations. 85.8% comply directly with the recommendations to one or more rooms, and 13.7% are wider than recommended and, thus, applicable as well. When it comes to the main rooms of a flat, the majority of panels are compatible with two-person bedrooms and dining rooms, while circa one-third of panels are appropriate for living rooms, kitchens and one-person bedrooms. It should be noted that a loss of width from possible external connectors and their casing (Saastamoinen, 2013, p. 96) was not considered in Figure 11, but it would hardly exceed 100mm.

4.5 Types of wall panels

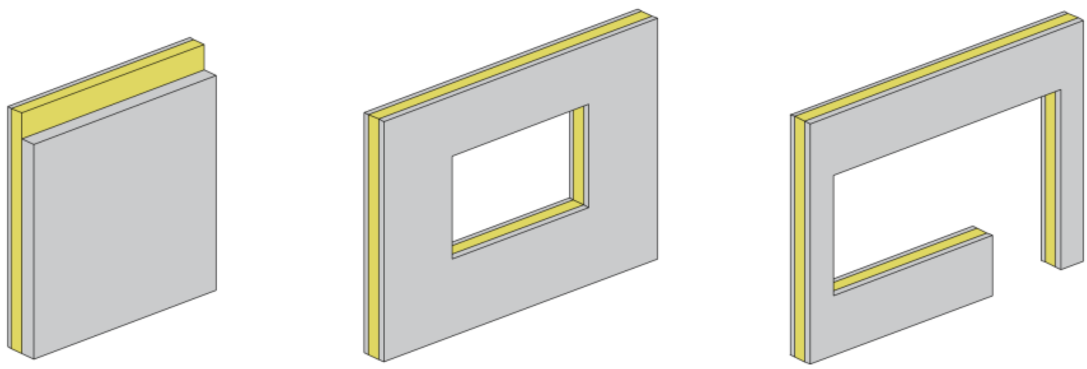

Figure 12. Main panel types from left to right: blind load-bearing panel; typical non-load-bearing panel with a normal window, non-load-bearing balcony back wall panel.

Figure 12 shows the three main types of panels in the data. Figure 13 shows the overall amounts of panels of different types and Figure 14 presents the numbers of panels with individual type and width. Load-bearing panels are most often blind. Non-load-bearing panels nearly always have a window; or a window and a door if they are balcony back walls. Figure 15 shows the width and type distribution for load-bearing panels, and Figure 16 shows how often they occur in the buildings of the data. Figures 17 and 18 present the same figures for non-load-bearing panels. Although the number of individual panels can be expected to grow with the increase of the sample size, the results indicate a strong repetitive nature. For example, as little as 20 most common individual panels cover 50% of all panels in the data, and the 10 most common individual panels in each type cover as much as 64–83% of the panels in that type.

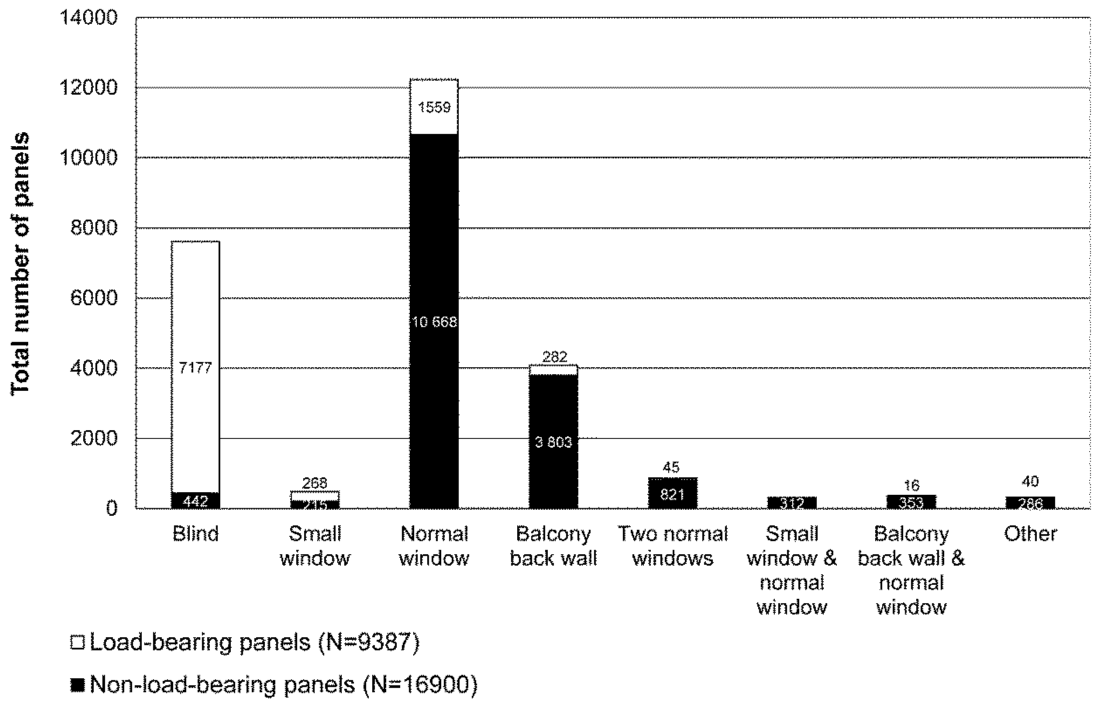

Figure 13. Total numbers of panels for different panel types (N= 26 287 panels). 'Other' includes rare types such as two-room wide panels with three windows, panels with Juliet balconies, etc.

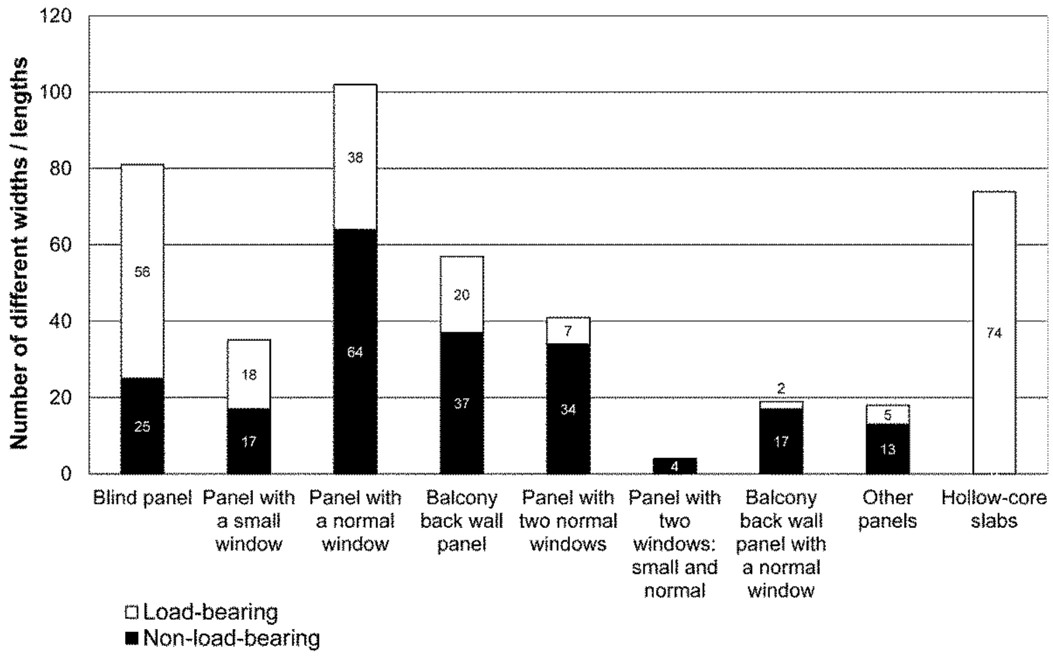

Figure 14. Numbers of individual widths for different panel types (N=431 width-type combinations).

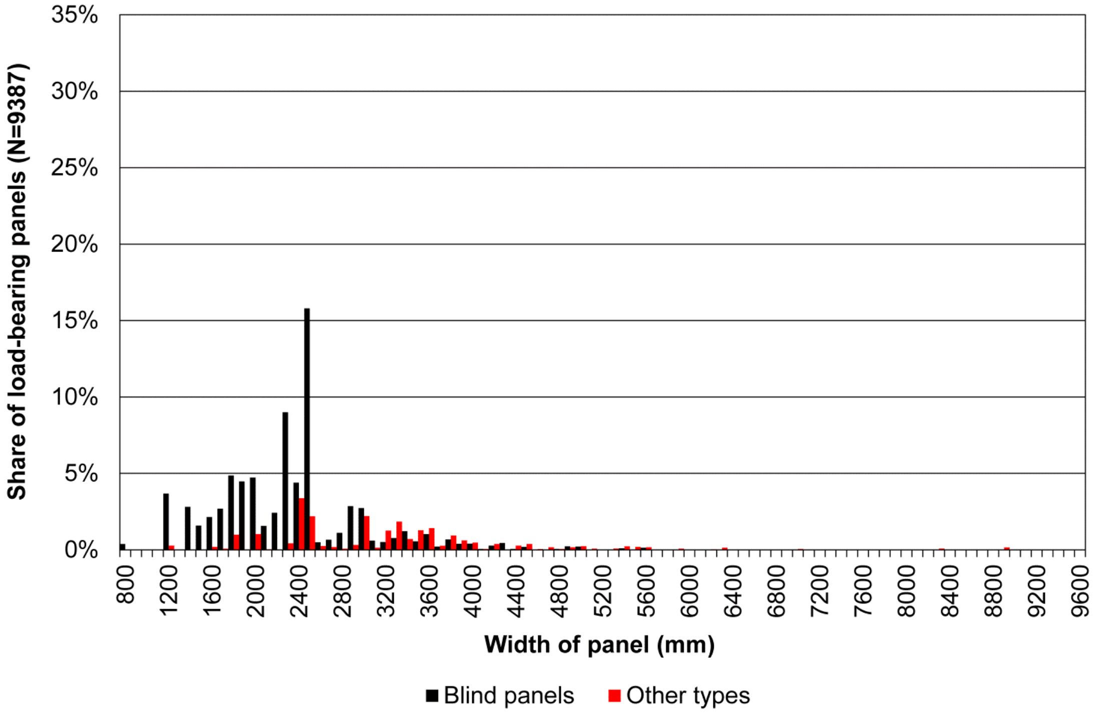

Figure 15. Width distribution of load-bearing panels according to the type (N=9 387 panels).

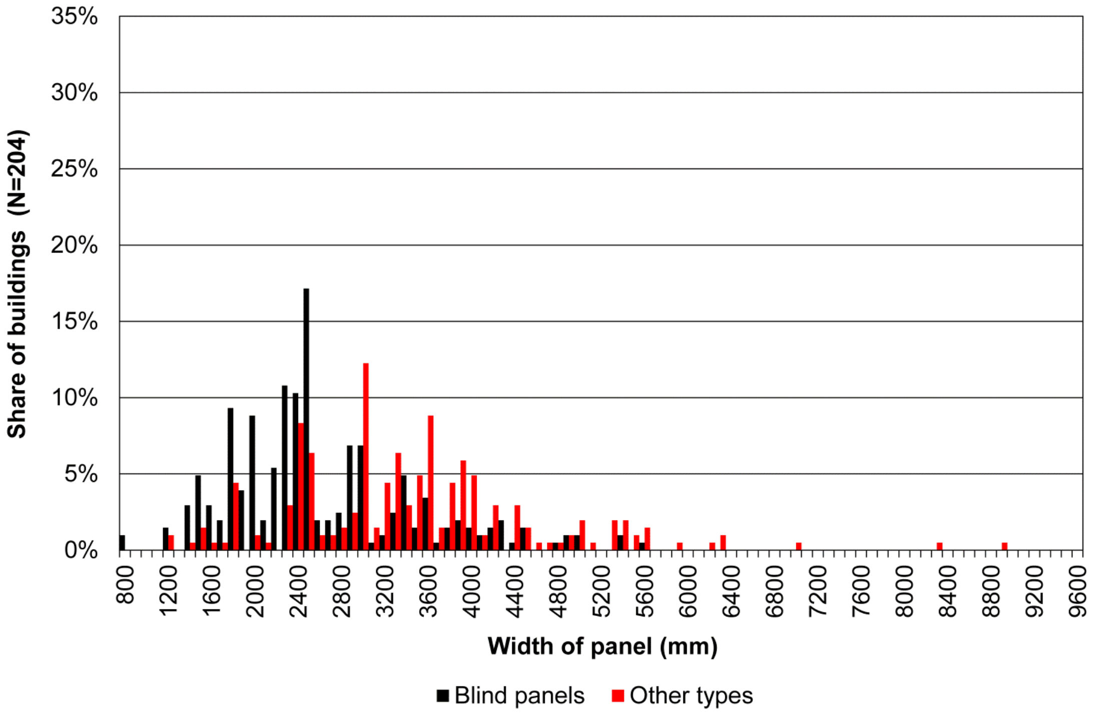

Figure 16. Occurrence of the load-bearing panels in the buildings (N=204 buildings).

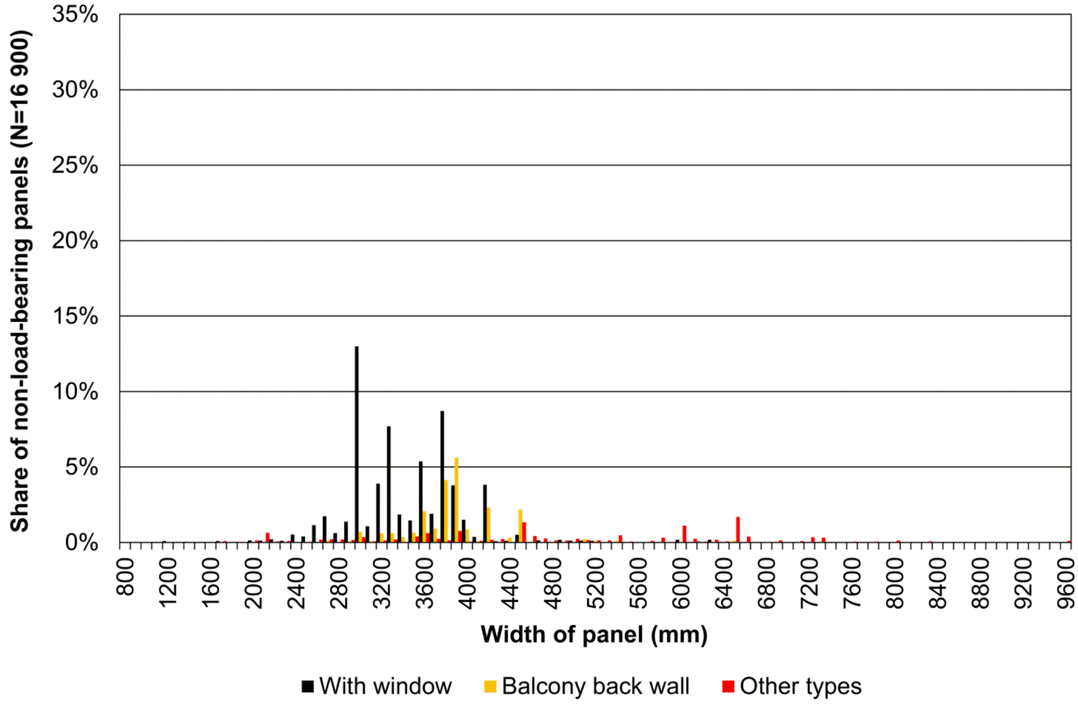

Figure 17. Width distribution of non-load-bearing panels according to the type (N=16 900 panels).

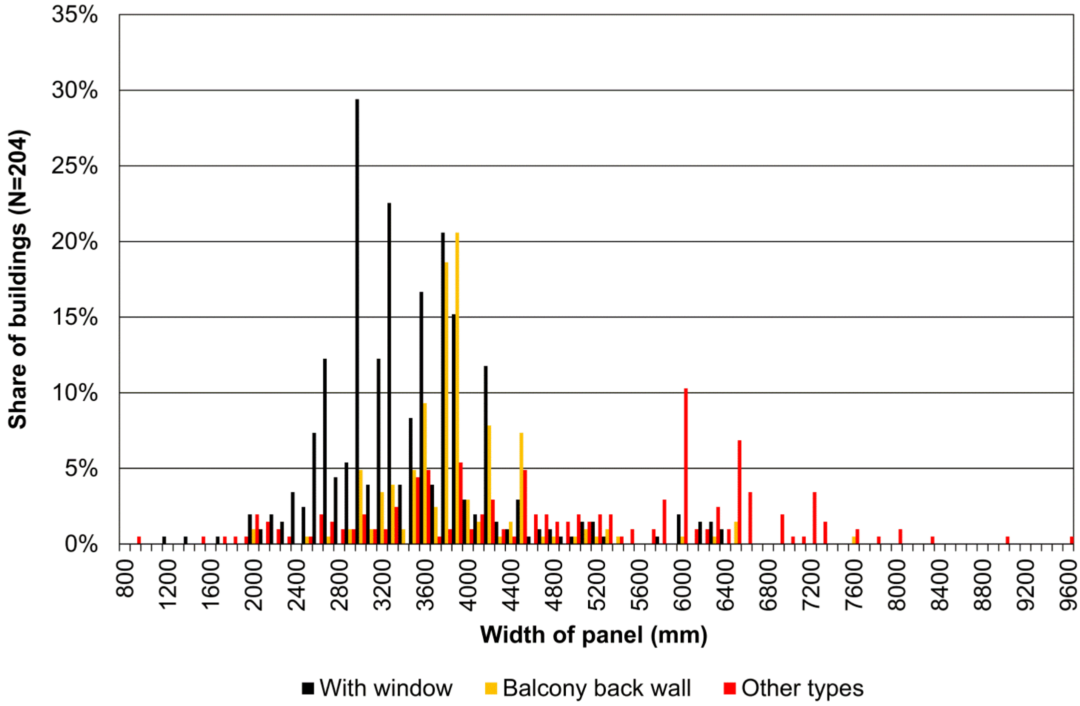

Figure 18. Occurrence of the non-load-bearing panels in the buildings (N=204 buildings).

4.6 Composition of facades

The minimum number of different types of panels that occurred in one fully prefabricated building is three and the maximum 18. Buildings do not usually have more than six different panels: one or two individual load-bearing panels and two to four individual non-load-bearing panels. The most typical building is one with one load-bearing panel and three different non-load-bearing panels. Figure 19 shows the numbers of panels in the buildings of the data.

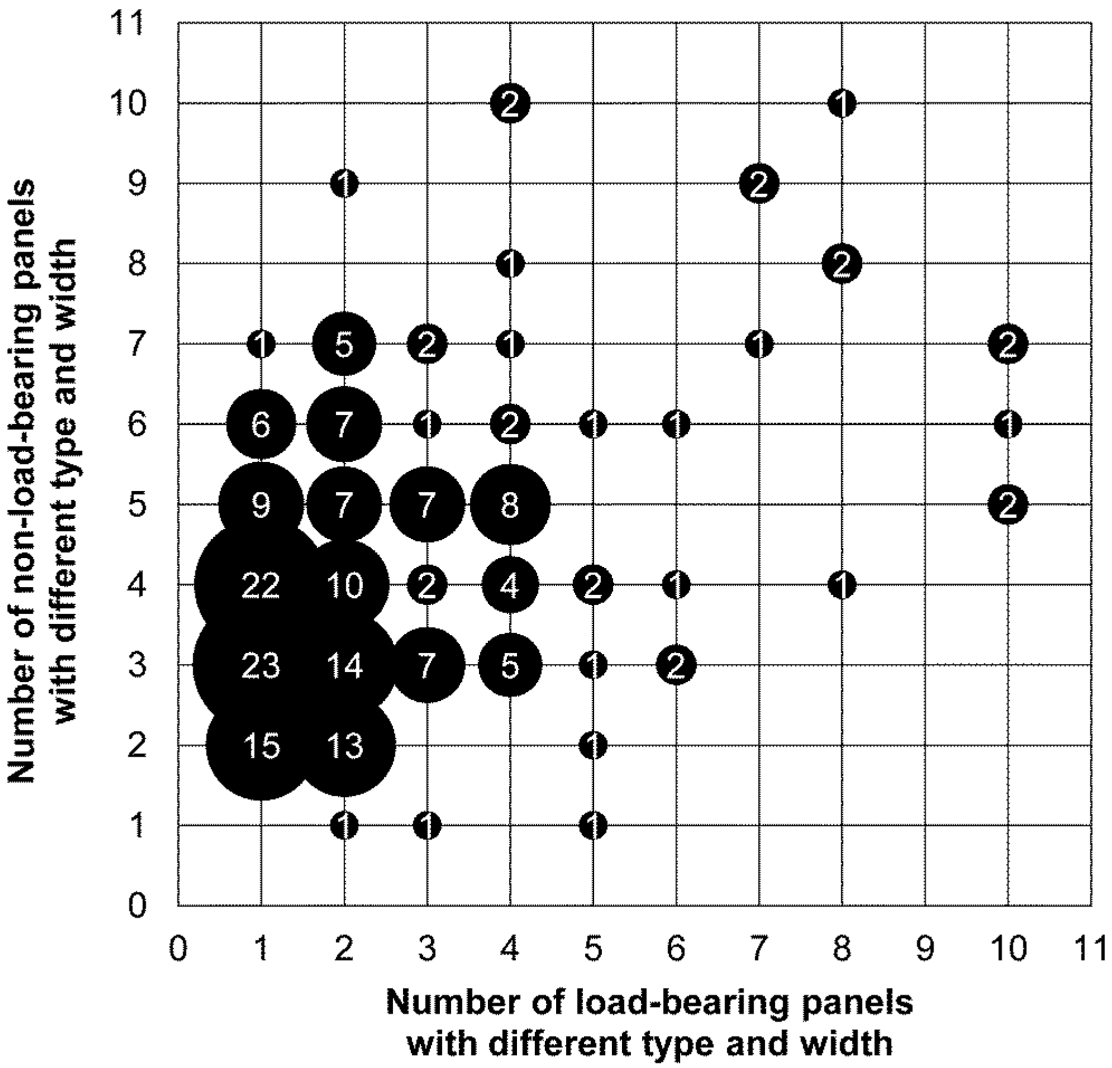

Figure 19. Number of buildings with different number of panels (N=204 buildings).

4.7 Thermal insulation of wall panels

In the vast majority of panels, the designed thickness of thermal insulation is 120mm of mineral wool. Typically, the actualized amount is smaller than that due to the insulation having compressed circa 10mm in the casting of the panel (Lahdensivu, 2012). The insulation equals to a U-value of 0.40 W/m2K, which does not comply with the present-day norm, 0.17 W/m2K (RakMK C4, 2003). The required U-value can be achieved by adding 150mm of new insulation on the surface of the reused panels. Because additional insulation prevents moisture from entering the concrete, corrosion and frost damage, which are common phenomena in old panels (Lahdensivu et al., 2011 & 2013; Lahdensivu, 2012), can be brought to halt as well. Due to the need to add insulation, the surface type of a panel has little significance for reuse, although it has been found to affect the panel’s durability properties (Lahdensivu, 2012). Only if a panel would be reused in a cold or a semi-warm structure without adding any new cladding, would the durability properties play a greater role. In that case, the knowledge on the exposure conditions and different durability properties of surface types presented in Lahdensivu (2012) could be used for evaluating which panels to select for reuse. However, a review of the existing reuse projects shows that this kind of usage is very rare, likely due to architectural reasons (Huuhka, 2010a).

4.8 Slabs

In comparison to wall panels, floors have smaller potential for reuse due to the fact that in the data, 64% of them are in situ cast. Of the 100 fully prefabricated buildings in the data, 75 (27% of all buildings) have 1200mm wide hollow-core slabs; 15 (5% of all buildings) have room-size solid prefabricated concrete slabs; and 10 (4% of all buildings) have 1200m wide U-slabs. The share of solid slabs is much smaller in this study than in Mäkiö et al. (1994) or Saastamoinen (2013), while the share of in situ cast floors is larger than in the literature.

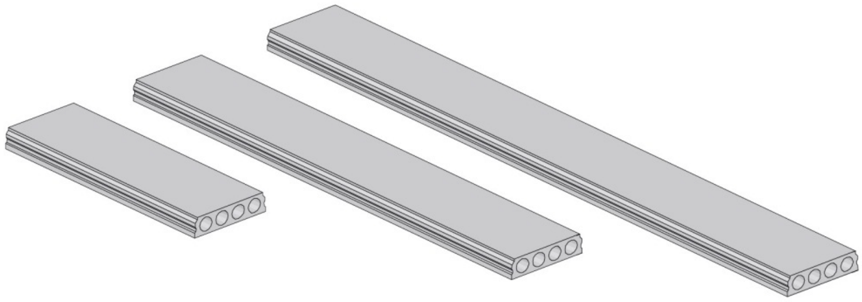

Figure 20. Typical hollow-core slabs: one, two or three rooms long

On average, there are 1410 m2 of hollow-core slab floor per a building, or 180 slabs. Due to typical apartment layouts in the plans, the slabs come in the lengths of one, two or three rooms (Figure 20). In all, there are 74 different lengths that range from 2400mm to 10800mm, or 68 lengths when rounded to the nearest 100mm. Figure 21 shows a histogram about the length distribution and Figure 22 lists the occurrence of the lengths in the buildings of the data. Unsurprisingly, the slab lengths are connected to the panel widths. For example, the most common slab length, 6000mm, is compatible with two panels of the most common width, 3000mm. This study does not consider the possible incompatibility situations that may result if the slabs are shortened in diamond sawing as suggested by Saastamoinen (2013, p. 108).

In 90% of the cases, the thickness of the hollow-core slab was 265mm, which is in line with previous findings such as Mäkiö et al. (1994). Due to the tightening of the norms for impact sound insulation in 1998, the 265mm slab is no longer usable as a floor separating different apartments from each other (Lietzén & Kylliäinen, 2014). It can only be utilized within apartments.

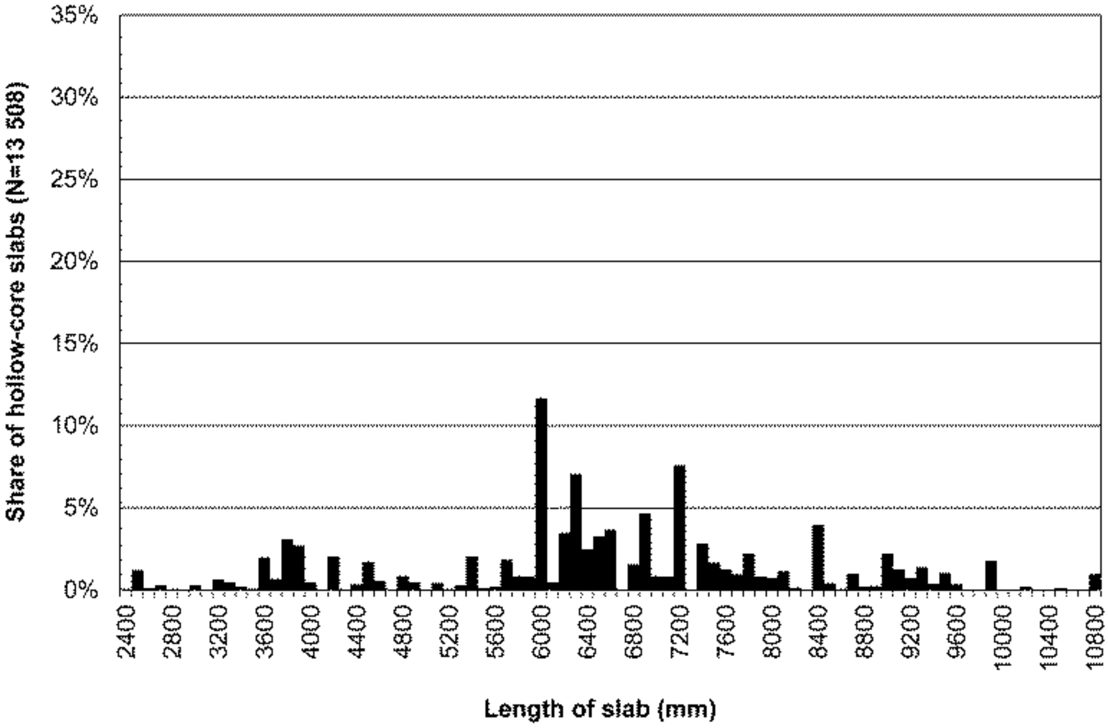

Figure 21. Length distribution of hollow-core slabs (N=13 508 slabs).

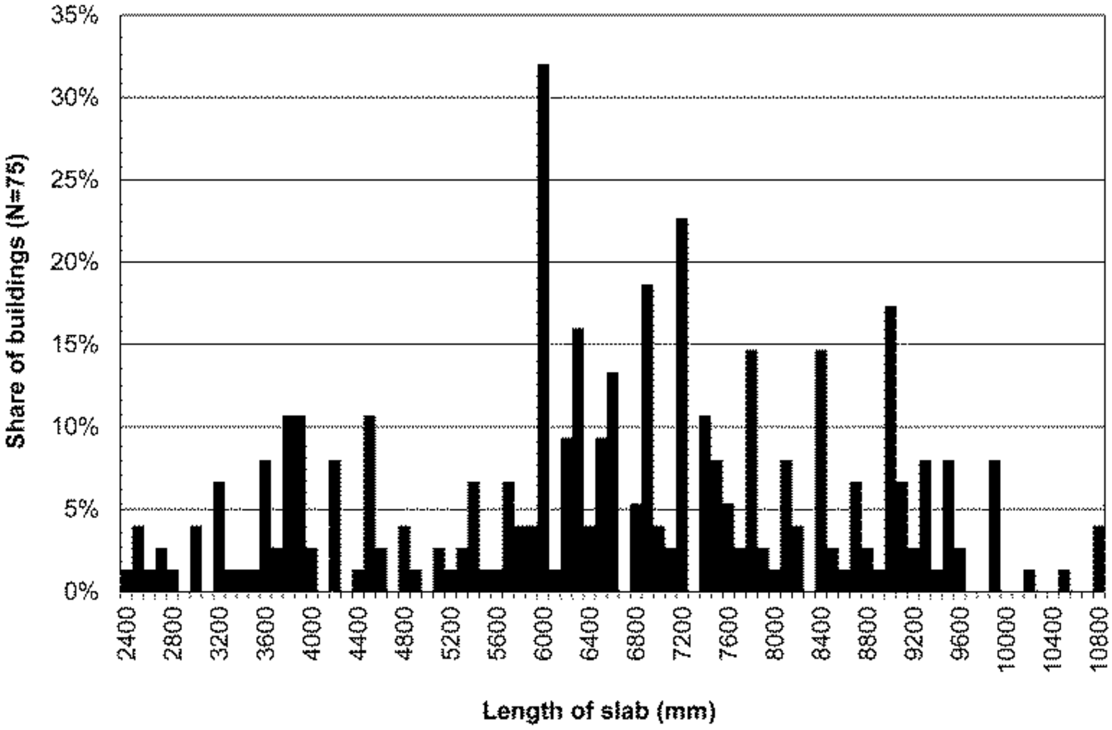

Figure 22. Occurrence of the lengths in the in buildings (N=75 buildings).

5 Generalizability of the results

5.1 Difference between public-funded and privately financed housing production

During the examination period (1968–1985), 42% of new flats were publicly funded, the rest naturally being privately financed (Laine, 1993; Kakko, 2011, p. 120–121). As the research material of this study consists solely of publicly financed projects, it is important to consider whether they display differences to privately funded apartment blocks. Keiski (1998, p.40) and Neuvonen (2006, p. 210) have found that the instructions for public housing were adopted in privately financed construction as well. Mäkiö et al. (1994, p. 46) state that the difference between privately and publicly financed construction was often only in the materials, and Neuvonen (2006, p. 210) takes the statement even further by specifying that the difference could be as minor as the finishing materials. In addition, Neuvonen (2006, p. 180) states that the widespread use of modular grid in plan design also promoted the uniformity of dimensions between different buildings and constructors regardless of the financing method. Based on these assertions, it can be expected that the financing method does not make a major difference in the use or properties of prefabricated components. Therefore, with regard to the scope of this study, the results obtained by studying publicly financed buildings can be expected to apply well to all apartment blocks of the era.

When it comes to the prefabricated components per se, the correspondence between the research material and the prefabricated building stock in general can be evaluated by applying two of the original research questions to both groups: what are the prefabricated parts — their structure and distribution — and what are their possibly recurring dimensions. As there is no all-encompassing database on such parts, the largest comparable sample is Mäkiö et al. (1994), which consists of 270 randomly selected apartment blocks from the years 1960–1975 in Helsinki. Mäkiö et al. (1994, p. 36) remark that the timing of the shift to prefabricated construction varied geographically. Based on the current paper's research material, which consists of buildings from all over the country, there is no reason to believe that the location has had any significant effect on the buildings themselves. Table 7 presents the distribution of facade panel types and structures in this study and in Mäkiö et al. (1994). The sample sizes are very similar, but due to the difference in studied years, a direct comparison can only be performed for a limited year range. The differences between the full ranges can, however, be used for examining trend changes.

In both studies, the degree of prefabrication rises considerably towards the ends of the studied time periods. A similar shift occurs with the frame types, as the concrete crosswall frame becomes more common towards the 1970s, replacing other types such as brick walls or in situ cast concrete frames (Mäkiö et al., 1994). Considering the convergence the two studies have — and that BES-buildings, which are prefabricated and use a crosswall frame, started to take over in late 1970s (Mäkiö et al., 1994, p. 68) — it appears that the differences would be likely to even decrease after 1975.

	Research Material		**Mäkiö et al. (1994)**	
Number of compared buildings	276 / 101		270	
Partially or fully prefabricated facades, % of all buildings	(1968-1985) 87.7 %		(1960-1975) 61.2 %	
Partially or fully prefabricated facades, % of all buildings, 1970-1975	80.2 %		87.8 %	
Crosswall frame, % of all studied buildings	(1968-1985) 90.9 %		(1960-1975) 61.1 %	
Crosswall frame, % of all studied buildings, 1970-1975	90.1 %		84.4 %	
Structure, non-load-bearing façade:				
Number of compared buildings*	275 / 101		270 / 122	
Concrete sandwich, %	(1968-1985) 88.0 %		(1960-1975) 74.3 %	
Concrete sandwich, % 1970-1975	80.2 %		91.0 %	
Structure, load-bearing façade:				
Number of compared buildings*	272 / 101		270 / 119	
Concrete sandwich, %	(1968-1985) 85.7 %		(1960-1975) 84.5 %	
Concrete sandwich, % 1970-1975	77.2 %		93.7 %	
Distribution of panel types, prefabricated non-load-bearing façade:				
Number of compared buildings*	242 / 82		270 / 122	
Distribution of panel types	Square	Strip	Square	Strip
% of buildings, all studied buildings	95.8 %	0.4 %	70.6 %	29.4 %
% of buildings, 1970-1975	96.3 %	1.2 %	90.5 %	9.5 %
% of m² built, 1970-1975	97.0 %	3.0 %	91.0 %	9.0 %

*Buildings where the relevant information could be determined from the research material

Table 7. Comparison of structures between research material and Mäkiö et al. (1994).

As for facade panels, the following comparison with Mäkiö et al. (1994) has been limited to buildings with crosswall frames because they constitute the overwhelming majority and the study covers them best. In both studies, concrete sandwich is by far the most common panel structure on both load-bearing and non-load-bearing facades. The share of concrete sandwiches increases in both studies towards the ends of the examination periods. The distribution of panel types on non-load-bearing facades (as strip panels do not occur on load-bearing facades) is heavily weighted towards square panels in both data. A similar shift in shares is seen in the distribution of panel types. Looking at both studies, it becomes clear why Mäkiö et al. (1994, p. 52) regard a building with a crosswall frame and facades with square panels as the typical Finnish apartment block for 1960–1975, though it appears that this statement can be extended beyond the year 1975.

Table 8 presents the distribution of the most common prefabricated floor structures in the research material of the current paper. Of these, the hollow core slab is clearly in the majority, increasing notably for the last five of the studied years. Mäkiö et al. (1994) do not present actual numbers on the distribution of different floor types over the years, but the general trends appear as similar to the current study with in situ cast floors dominating the 1960s and the early 1970s before giving way to prefabricated solid slabs and hollow-core slabs. The dominance of the hollow-core slab coincides with the statements by Mäkiö et al. (1994, p. 41) and Neuvonen (2006, p. 218), both of which mention this slab type as eventually becoming the most common choice.

Year range	1968-1985	1968-1975	1976-1980	1981-1985
Prefabricated floors, % of all*	36.2 %	15.5 %	41.7 %	71.4 %
Hollow core slab, % of all*	27.2 %	10.1 %	26.2 %	63.5 %
Hollow core slab, % of all prefabricated	75.0 %	65.0 %	62.9 %	88.9 %
Solid precast floor panels, % of all*	5.4 %	4.7 %	9.5 %	1.6 %
Solid precast floor panels, % of all prefabricated	15.0 %	30.0 %	22.9 %	2.2 %

*Buildings where the floor structure could be determined

Table 8. Distribution of the most common floor structures in the research material.

All in all, based on the comparison with Mäkiö et al. (1994) and the various descriptions of contemporary construction in literature, the structures in the research material appear to correspond closely to the general stock of similar buildings at that time. Although a year range for a direct comparison with Mäkiö et al. (1994) is somewhat limited, the decrease in diversity towards the end of that time frame suggests even greater uniformity for the later years.

Due to such data not being available for the general building stock, considering the actual dimensions of the panels is limited to comparing the research material's measurements to more general statements found in literature. The heights of square panels are determined by the minimum floor height and therefore, they are not likely to have any variation regardless of the sample. This height is, according to the research material as well as Mäkiö et al. (1994), 2800mm. The thicknesses of the panels are dictated by structural requirements and therefore, they should not vary significantly by sample, either. This leaves the width of the panels as the main dimension to consider. As the width of a non-load-bearing facade panel depends on the distance between the load-bearing walls it is suspended from or propped against, the dimension should be one or more rooms wide. In addition, due to the widespread use of modular coordination, this dimension should most often be multiples of 300mm. As shown in Tables 1 and 2, Mäkiö et al. (1994, p. 78, 82) state that the panel width is 3.0–3.9 m in case of one-room panels or 6.0–7.2 m in case of two-room panels, and most commonly 3.3–3.6 m. Figures 9 and 11 show the width distribution of non-load-bearing facade panels in the research material. 55.6% of the panels in the research material were between 3.0m–3.9m and 3.5 % between 6.0m–7.2m, totaling up to 59.1%. 21.1% of the panel widths landed in the range of 3.3m–3.6 m. 58.0% of panel widths were multiples of the 300mm module, with 3.0m, 3.9m and 3.3m being the most common in a respective order. Overall, the dimensions of the panels fit the ranges given in Mäkiö et al. (1994). This shows as clear peaks in Figures 9 and 11 in one-room width and, to a much smaller extent, in two-room width. As stated previously, the figures also show the prevalence of 300mm module.

5.2 An estimation of resources embedded in the apartment building stock

In all, 30 378 multi-story apartment buildings were built in Finland between 1960 and 1989. This represents 52% of the stock. During the most representative decade with regard to the year range of this study, the 1970s, 12 652 apartment blocks, i.e. 22% of the stock, were erected. (Statistics Finland, 2013). The following calculation intends to give a rough estimate about the panel and slab resources embedded in this stock. If a 95% share of prefabricated facades and a 27% share of hollow-core slab floors are assumed, over 12 000 1970s buildings would have prefabricated facades and 3400 would have hollow-core slab floors. If the average amounts of panels are taken as such, this stock would contain over 500 000 load-bearing panels, over 900 000 non-load-bearing panels and over 600 000 slabs (or 5.3 million m2 of floor). If these figures are extended to include the previous and the following decade, the numbers are as follows: nearly 2 200 000 non-load-bearing panels, over 1 200 000 load-bearing panels and over 1 400 000 slabs (or nearly 12.9 million m2 of floor). The true numbers will be lower, because the degree of prefabrication was not as high in the beginning of the 1960s, although it kept rising the whole of 1980s until the mid-1990s (Hytönen & Seppänen, 2009, p. 325).

There are several norms that currently prohibit the use of reclaimed concrete panels in erecting new blocks of flats in Finland. These include requirements for floor height and acoustic properties of walls and slabs that separate apartments. However, these factors do not delimit the reuse of panels in the design of detached houses, which in 2013 represented a notable share of 34% of all residential building production in Finland. Between 2000 and 2013, an average of 12 300 detached houses with 2 160 000 m2 were built annually. Thus, the average area of a new detached house was 175 m2. (Statistics Finland, 2013). When the average gross floor area of an apartment block is 1570m2, a condemned building could possibly contribute to the structures of up to nine detached houses. Therefore, the 1970s apartment building stock could be seen as a reserve of components for nearly 108 000 detached houses (the building needs of nearly nine years at the current pace), and if the previous and following decades are considered similarly, up to 260 000 houses (the needs of 21 years). Of course, the calculation is very rough and does not take into consideration possible damage that could occur in the old structures or during deconstruction. However, it does give an indication of the magnitude of this reserve, which is to be considered remarkable.

Conclusions

The study has been conducted with an extensive data set that represents well Finnish multi-story housing construction between 1968 and 1985. With regard to the size of the stock, the degree of prefabrication and the dimensions of the panels and slabs, the mass housing of the time represents a notable reserve for building components. There are, however, fewer slabs available than wall panels, as the majority of floors were *in situ* cast. Only a fraction (0.5%) of the panels are clearly incompatible with current recommendations for room widths. As norms related to floor height and acoustics do not allow using most of the elements in new multi-family housing, the use would be limited to detached houses. These form one-third of all apartments erected in Finland annually. The magnitude of the component reserve is roughly ten to 20 times the annual housing construction in this building type.

Although plans of apartment buildings were never standardized in Finland, the inventory of elements recognized in this study shows that the dimensions of panels and slabs are highly uniform. To this end, Finnish precast construction does not come across more variable than, for example, the fully standardized German panel systems (for those, see e.g. Mettke, 2003 & 2007). While standardization of buildings was not an aim in developing the BES system, it was clearly already embedded in the corporate culture of the building industry. Even though 357 individual panels were recognized in the current study when the type and width were considered, one building usually has only two to six individual panels. In fact, the 20 most common individual panels cover 50% of all panels in the data, and the 10 most common individual panels in each type cover as much as 64–83% of the panels of the type. In addition, the most common dimensions and individual panels typically occur more frequently in the buildings of the data than what is their relative frequency of the panels of the data. For example, the most common panel width covers less than 10% of all widths but is found in every third building.

The elements from one average-sized apartment building could make up to nine detached houses. Although a number of structural details were in use, which resulted in discrepancies in the vertical dimensioning of panels, this has little significance because panels and slabs from a single building are, of course, compatible with each other. The inventories of typical dimensions of components collected hereby provide a starting point for conceptualizing new housing from reclaimed elements. As neither architects nor their clients would likely want to reuse old apartment plans, new plan design from old elements should be the subject of a new study.

Acknowledgements

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References

Addis, B. (2006). *Building with Reclaimed Components and Materials: A Design Handbook for Reuse and Recycling*. London: Earthscan.

Agudelo-Vera, C. M., Leduc, W.R.W.A., Mels, A.R. & Rijnaarts, H.H.M. (2012). Harvesting urban resources towards more resilient cities. *Resources, Conservation and Recycling, 64*, 3–12. doi:10.1016/j.resconrec.2012.01.014

Asam, C., Dallman, J., Djahani, M., Fakhro, A., Kerz, N., Mann, B., Peters, D., Roessner, I., Biele, H., Kochendörfer, B. & Liebchen, J. (2005). *Untersuchung der Wiederverwendungsmöglichkeiten von demontierten Fertigteilelementen aus Wohnungsbautypen der ehemaligen DDR für den Einsatz im Wohnungsbau* (Bericht Nr. 1-5/2005). Berlin: Institut für Erhaltung und Modernisierung von Bauwerken e.V. an der TU Berlin.

Asam, C. (2006). *Recycling prefabricated building components for future generations* (IEMB Info 1/2006). Berlin: Institute for Preservation and Modernisation of Buildings at the TU Berlin. Available: http://www.bbsr.bund.de/BBSR/EN/Publications/CompletedSeries/IEMB/2006_2007/DL_1_2006.pdf;jsessionid=F38A63E638DB03D51CFB0F39E487A11A.live2053?__blob=publicationFile&v=3

Asam, C. (2007). *Recycling Prefabricated Concrete Components - a Contribution to Sustainable Construction* (IEMB Info 3/2007). Berlin: Institute for Preservation and Modernisation of Buildings at the TU Berlin. Available: http://www.bbsr.bund.de/BBSR/EN/Publications/CompletedSeries/IEMB/2006_2007/DL_3_2007.pdf?__blob=publicationFile&v=2

BES: Tutkimus avoimen elementtijärjestelmän kehittämiseksi [A study for developing an open element system]. (1969). Helsinki: Suomen Betoniteollisuuden Keskusjärjestö.

BES-suositus 1972 [BES guidelines 1972]. (1972). Helsinki: Suomen Betoniteollisuuden Keskusjärjestö.

BES-suositus 1979 [BES guidelines 1979]. (1979). Helsinki: Suomen Betoniteollisuuden Keskusjärjestö.

Blomqvist, A. (1996). *Raportti DDR:n lähiöistä, niiden historiasta ja nykypäivästä* [A report on the history and current situation of GDR mass housing estates]. (Unpublished master's thesis).

Coenen, M., Lentz, G. & Prak, N. (1990). *De Kop is Eraf: Evaluatie van de aftopping van een flat in Middelburg.* Delft: Onderzoeksinstituut voor Technische Bestuurskunde, TU Delft.

Deilmann, C., Effenberger, K.-H., Banse, J. (2009). Housing stock shrinkage: vacancy and demolition trends in Germany. *Building Research and Information, 37*, 660–668,http://dx.doi.org/10.1080/09613210903166739

European Union. (2008). *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. Available: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF

fib. (2008). *Structural connections for precast concrete buildings* (fib bulletin no 43). Lausanne: International Federation for Structural Concrete fib.

Glias, A. (2013). *The "Donor Skelet": Designing with reused structural concrete elements.* (Unpublished master's thesis). Available: http://repository.tudelft.nl/assets/uuid:20002372-1d7d-4824-8217-bdff4b60ecb5/Alexandros_Glias_Msc_Graduation_Thesis.pdf

Gorgolewski, M. 2008. Designing with Reused Building Components: Some Challenges. *Building Research and Information, 36*, 175–188. doi: 101080/09613210701559499

Gorgolewski, M., Straka, V., Edmonds, J. & Sergio-Dzoutzidis, C. 2008. Designing Buildings Using Reclaimed Steel Components. *Journal of Green Building, 3*, 97–107.

Gravina da Rocha, C. & Aloysio Sattler, M. 2009. A Discussion on the Reuse of Building Components in Brazil: An Analysis of Major Social, Economical and Legal Factors. *Resources, Conservation and Recycling, 54*, 104–112. doi:10.1016/j.resconrec.2009.07.004

Hankonen, J. (1993). *Lähiöt ja tehokkuuden yhteiskunta* [Neighbourhood units and the society of efficiency]. Helsinki: Gaudeamus Kirja, Otatieto & TTKK Arkkitehtuurin osasto.

Hiete, M., Stengel, J., Ludwig, J. & Schultmann, F. (2011). Matching construction and demolition waste supply to recycling demand: a regional management chain model. *Building Research and Information, 39*, 333–351. doi: 10.1080/09613218.2011.576849

Huuhka, S. (2010a). *Kierrätys arkkitehtuurissa: Betonielementtien ja muiden rakennusosien uudelleenkäyttö uudisrakentamisessa ja lähiöiden energiatehokkaassa korjaus- ja täydennysrakentamisessa* [Recycling in architecture: Reusing reclaimed prefabricated concrete panels and other second-hand structural components when building new and rehabilitating and infilling mass housing districts]. (Unpublished master's thesis). Available: http://URN.fi/URN:NBN:fi:tty-201004161101

Huuhka, S. (2010b). Purkubetoni kierrätetään tienpohjiksi – tulevaisuudessa ehkä myös taloiksi [Demolished concrete reused in road base courses – maybe also in houses in future]. *Betoni 2010:2*, 50–55. Available: http://www.betoni.com/Download/22493/BET1002%2050-55%20.pdf

Huuhka, S. & Lahdensivu, J. (2014). Statistical and geographical study on demolished buildings. *Building Research and Information,* advance online pulication. doi: 10.1080/09613218.2014.980101

Huuhka, S., Naber, N., Asam, C. & Caldenby, C. (2015). *Urban transformation through deconstruction and reuse: The first experiences.* Unpublished manuscript.

Hytönen, Y., Seppänen, M. (2009). *Tehdään elementeistä: Suomalaisen betonielementtirakentemisen historia* [Let's prefabricate it: The history of Finnish precast concrete construction]. Helsinki: SBK-säätiö.

Kaasalainen, T. & Huuhka, S. (In press). The homogenous homes of Finland: 'Standard' flats in non-standardized blocks. *Building Research and Information,* advance online publication. doi: 10.1080/09613218.2015.1055168

Kakko, K. (2011). *Muunneltava lähiöasunto: Lähiökorjaamista asunnon ja asujan näkökulmasta* [Transformable housing estate apartment: housing estate renovation from the dwelling and dweller's point of view]. Tampere: Tampereen teknillinen yliopisto.

Kauranen, H. (Ed.) (2001). *Kerrostalon purkaminen: Menetelmät – kustannukset – turvallisuus – hyötykäyttö* [Demolition of blocks of flats: Methods – costs – safety – recycling]. Helsinki: Rakennusteollisuuden keskusliitto.

Keiski, S. (1998). *Ikääntymisen ihmemaa: Vertailututkimus vanhusten kokemuksista standardikotikeittiössä, koekeittiössä ja käyttäjälähtöisesti suunnitellussa kotikeittiössä* [Wonderland of aging: A comparative study on the experience of the elderly in a standard home kitchen, a test kitchen and a user-based home kitchen]. Helsinki: Taideteollinen korkeakoulu.

Kibert, C.J. & Chini, A.R. (Eds). (2000). *Overview of Deconstruction in Selected Countries* (CIB Report, Publication 252). Rotterdam: CIB International Council for Research and Innovation in Building Construction. Available: http://cibworld.xs4all.nl/dl/publications/TG39.html

Korpivaara-Hagman, A. (1984). *Asuntohallituksen suunnitteluohjeet asuntorakentamisen ohjausvälineenä* [National Housing Board's design standards as an instruction tool in housing production]. Oulu: Suunnittelurengas.

Laine, A. (1993). *Arava, asuntohallitus ja asuntopolitiikka 1949–1993* [Arava, national housing board and housing politics 1949–1993]. Helsinki: Asuntohallituksen tutkimus- ja suunnitteluosasto.

Lahdensivu J. (2012). *Durability Properties and Actual Deterioration of Finnish Concrete Facades and Balconies*. Tampere: Tampere University of Technology.

Lahdensivu, J., Huuhka, S., Annila, P., Pikkuvirta, J., Köliö, A., & Pakkala, T. (2015). *Betonielementtien uudelleenkäyttömahdollisuudet* [Reuse possibilities of concrete panels] (Rakennustekniikan laitos, Rakennetekniikka, Tutkimusraportti 162). Tampere: Tampereen Teknillinen yliopisto. Available: http://urn.fi/URN:ISBN:978-952-15-3461-4

Lahdensivu, J., Mäkelä, H., Pirinen, P. (2013). Corrosion of reinforcement in existing concrete facades. In de Freitas, V. P., Delgado, J. M. P. Q. (Eds.) *Durability of building materials and components* (Building pathology and rehabilitation 3) (pp. 253–274). Berlin: Springer.

Lahdensivu, J., Tietäväinen, H., Pirinen, P. (2011). Durability properties and deterioration of concrete facades made of insufficient frost resistant concrete. *Nordic Concrete Research, 44*, 175–188. Available: http://www.tekna.no/ikbViewer/Content/870534/A12%20-%20F49%20Lahdensivu%202011-12-08_FINAL.pdf

Lietzén, J. & Kylliäinen, M. (2014). *Asuinkerrostalojen ääneneristävyyden vertailu vanhojen mittaustulosten perusteella* [Comparison of sound insulation in multi-storey apartment buildings on the basis of old measurement results] (Ympäristöhallinnon ohjeita 1/2014). Helsinki: Ympäristöministeriö. Available: http://hdl.handle.net/10138/42668

Mattila, J. & Pentti, M. (2004). *Suojaustoimien tehokkuus suomalaisissa betonijulkisivuissa ja parvekkeissa* [Performance of protective measures in Finnish concrete facades and balconies] (Talonrakennustekniikan laboratorio, tutkimusraportti 123). Tampere: Tampereen teknillinen yliopisto.

Mettke, A. (Ed.) (2003). *Elementekatalog. Übersicht: Elementesortiment des Typs P2*. Cottbus: TU Cottbus.

Mettke, A. (Ed.) (2007). *Elementekatalog. Übersicht: Elementesortiment des Typs WBS 70 am Beispiel Gebäudetyp WBS 70/11*. Cottbus: TU Cottbus.

Mettke, A,, Heyn, S. & Thomas, C. (2008). *Rückbau industrieller Bausubstanz – Großformatige Betonelemente im ökologischen Kreislauf. Teil 2: Wieder- und Weiterverwendung großformatiger Betonbauteile.* Cottbus: Brandenburgische Technische Universität Cottbus. Available: http://www.tu-cottbus.de/fakultaet4/fileadmin/uploads/altlasten/files/bauliches_recycling/2_Wiederverwendung.pdf

Mäkiö, E., Malinen, M., Neuvonen, P., Vikström, K., Mäenpää, R., Saarenpää, J. & Tähti, E. (1994). *Kerrostalot 1960–1975* [Blocks of flats 1960–1975]. Helsinki: Rakennustieto.

Naber, N.R. (2012). *Reuse of hollow-core slabs from office buildings to residential buildings.* (Unpublished master's thesis). Available: http://repository.tudelft.nl/assets/uuid:a04416b7-e8c0-499d-81c7-48c51b5e7fda/Msc_Thesis_N.R._Naber.pdf

Neuvonen, P. (ed). (2006). *Kerrostalot 1880–2000: Arkkitehtuuri, rakennustekniikka, korjaaminen* [Blocks of flats 1880–2000: Architecture, construction technology, renovation]. Helsinki: Rakennustieto.

Pakkala, T., Köliö, A., Lahdensivu, J. & Kiviste, M. (2014). Durability demands related to frost attack for Finnish concrete buildings in changing climate. *Building and Environment*, *82*, 27–41. doi: 10.1016/j.buildenv.2014.07.028

Pongiglione, M. & Calderini, C. 2014. Material savings through structural steel reuse: A case study in Genoa. *Resources, Conservation and Recycling, 86,* 87–92. doi: 10.1016/j.resconrec.2014.02.011

RakMK C4. Lämmöneristys: ohjeet [National Building Code of Finland, part C4. Thermal insulation, guidelines]. (2003). Helsinki: Ympäristöministeriö. Available: http://www.finlex.fi/data/normit/1931-C4s.pdf

RakMK G1. Asuntosuunnittelu: määräykset ja ohjeet [National Building Code of Finland, part G1. Housing design: regulation and guidelines]. (2005). Helsinki: Ympäristöministeriö. Available: http://www.finlex.fi/data/normit/28204-G1su2005.pdf

RT 88-11018 Portaat ja luiskat [Stairs and slopes]. (2011). Helsinki: Rakennustieto.

RT 91-10440 Sauna 2: Saunan tilojen suunnittelu [Spatial design of saunas]. (1990). Helsinki: Rakennustieto.

RT 93-10536 Asunnon keittiö [The kitchen of an apartment]. (1994) Helsinki: Rakennustieto.

RT 93-10925 Asuntosuunnittelu: Lepo ja työskentely [Residential design: Sleeping and working]. (2008). Helsinki: Rakennustieto.

RT 93-10926 Asuntosuunnittelu: Oleskelu ja vapaa-ajan vietto [Residential design: Sejour and free-time]. (2008). Helsinki: Rakennustieto.

RT 93-10929 Asuntosuunnittelu: Ruoanvalmistus ja ruokailu [Residential design: Cooking and dining]. (2008). Helsinki: Rakennustieto.

RT 93-10932 Asuntosuunnittelu: Hygienianhoito [Residential design: Personal hygiene]. (2008). Helsinki: Rakennustieto.

RT 93-10937. (2008). Asuntosuunnittelu: Eteinen ja kulkuyhteydet [Residential design: Halls and passages]. Helsinki: Rakennustieto.

RT 93-10945 Asuntosuunnittelu: Säilytys [Residential design: Storage]. (2008). Helsinki: Rakennustieto.

RT 93-10950 Asuntosuunnittelu: Vaatehuolto [Residential design: Laundry]. (2008). Helsinki: Rakennustieto.

RT 93-10953 Asuntosuunnittelu: Porrashuoneet ja kulkutilat [Residential design: Stairhalls and corridors]. (2009). Helsinki: Rakennustieto.

RT 935.50 Asuminen, makuuhuoneiden pinta-alan tarve [Housing, area requirements for bedrooms]. (1966). Helsinki: Rakennustietosäätiö.

RT 936.50 Asunnon WC- ja peseytymistilat, tilantarve ja huonesovellutuksia 1:50. [Housing, WCs and bathrooms, space requirements and applications]. (1965). Helsinki: Suomen Arkkitehtiliitto, Standardoimislaitos.

Saastamoinen, K. (2013). *Lähiökerrostalon osittaisen purkamisen rakennetekniset haasteet* [Challenges of structural engineering of partial demolition of precast concrete houses in Finnish suburbs]. (Unpublished master's thesis).

Statistics Finland. (2013). *PX-Web StatFin database in English*. Available: http://pxweb2.stat.fi/database/StatFin/databasetree_en.asp. Reference date 30.12.2014.

Thomsen, A. & van der Flier, K. (2011). Understanding obsolescence: a conceptual model for buildings. *Building Research and Information, 39*, 352–362. doi: 10.1080/09613218.2011.576328

Turkington, R., van Kempen, R. & Wassenberg, F. (Eds.). (2004). High-rise housing in Europe. Current trends and future prospects (Housing and urban policy studies 28). DUP Science: Delft. Available: http://repository.tudelft.nl/assets/uuid:87b875ba-46fa-4edf-97df-deeaf189d0a5/OTB2004%20HUPS028%20web.pdf

Van Nunen, H. (1999). *Hergebruikt Bouwen: Demontage en hergebruik van geprefabriceerde betonelementen van naoorlogse (montage-) systeembouwwoningen.* (Unpublished master's thesis).