Tectonic Use of Reclaimed Timber

Design principles for turning scrap into architecture

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Abstract

Increasing the use of timber has been proposed as one step towards more sustainable architecture and construction. Timber's renewability and the capability to store carbon have dominated this discussion. At the same time, viewpoints related to material efficiency and recycling, equally important aspects to sustainability, have been neglected. Unfortunately, recycling wood can be challenging, and countries that already build a lot with timber tend to rely on incineration at the end of the life cycle. Reusing wood could, however, save emissions from manufacturing new timber and disposing of demolished timber and prolong the time the carbon stays sequestered. Embedded in new architectural ensembles, salvaged components could also transmit the past to the contemporary viewer and thus, result in more evocative architecture.

Barriers preventing reuse in general have been documented in literature, but few solutions have been proposed. The obstacles include, among other things, inconsistent quality and quantity, difficulty of dimensional coordination and negative perception, which are all issues connected to design. This paper employs literature review and design simulation in addressing the challenges of architectural design from reclaimed timber. With the help of literature, the tectonic nature of reclaimed wood material is elaborated in more detail. The design simulation was conducted during a special timber architecture course with the help of 36 students, whose design projects form the empirical research material of the paper. Engaging in a discussion with literature and the research material, the study results in recognizing how reclaimed timber essentially differs from virgin timber and proposes ten design principles for managing the inconsistencies associated with the salvaged material.

The presented discussion demonstrates that reclaimed materials should be considered as materials of their own; they should not be expected to simply comply with conventional construction methods and design practices. Since the salvaged components already exist, their architectural and structural design cannot be differentiated from each other. Therefore, tectonic expression endogenous to reclaimed materials needs to be developed in order to actuate their more widespread reuse. Whereas historical and vernacular construction methods withhold many insights for architectural design from reclaimed timber, contemporary computer-aided design offers novel tools for the execution of these ideas. The remarks of the paper are not only valid in Western contexts, but may be highly relevant for architects working in developing countries.

Keywords: architectural design, cascading, circular economy, recycling, reuse, salvaged wood

Timber construction has many environmental benefits, but challenges related to its recycling at the end of the life cycle need to be addressed better. This paper discusses the significance of tectonic thinking for architectural reuse of salvaged wood.

PEER-REVIEWED ARTICLE

Introduction

Steel and cement have been identified as two key materials for global carbon emissions (Allwood et al. 2011). Consequently, the building sector is seeking for ways to become more environmentally friendly. Increasing the use of timber has been proposed as one solution, as wood is renewable and wooden products can store carbon in them, slowing down the carbon cycle (Burnett 2006). The concept of 'cascading' wood (Figure 1) has been introduced to further prolong the time carbon remains sequestered in buildings (Sakaguchi 2014). The idea of cascading resonates with the waste hierarchy presented in the European Waste Framework Directive, which prioritizes reuse over recycling and recycling over incineration (EU 2008). In practice, however, countries with strong timber-building traditions are not far-advanced in cascading. In North America, demolished timber is largely landfilled (Diyamandoglu & Fortuna 2015; Teshnizi, 2015), whereas Japan and the Nordic countries rely largely on energy recovery (Nakajima & Nakagawa 2010; Pirhonen et al. 2011, 42).

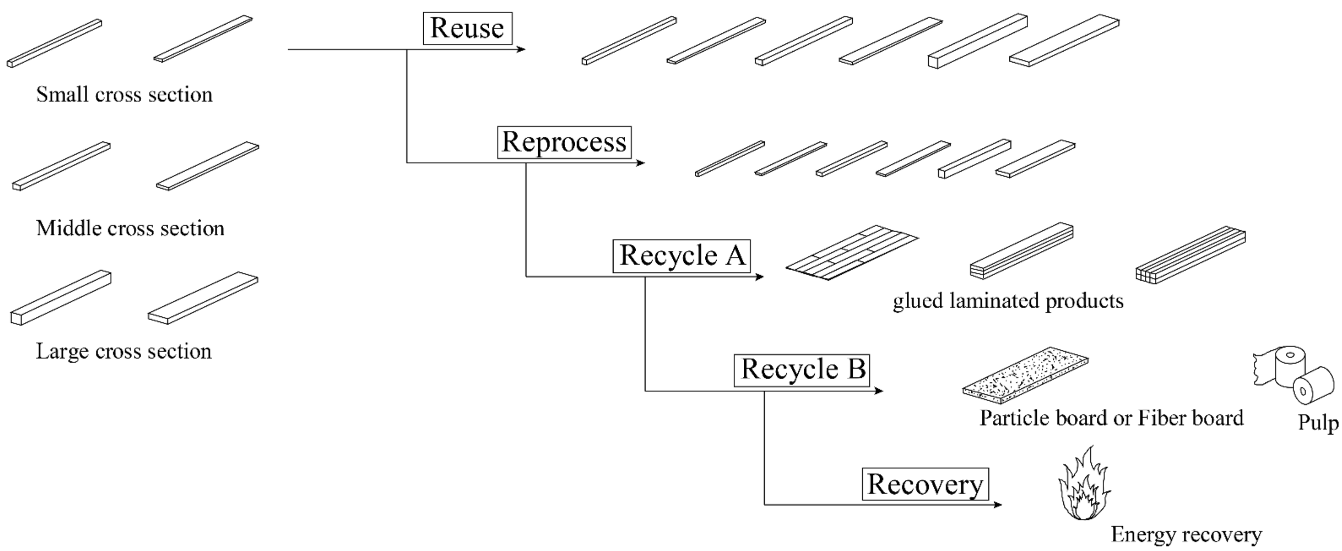


Figure 1. An ideal cascading chain for timber. It proceeds from reuse with or without reprocessing through recycling to incineration (Sakaguchi 2014). Image courtesy of Daishi Sakaguchi.

In Finland, where the current study is situated, wood is the most prominent construction material with 45% of the building stock's area situated in wood-framed buildings (Statistics Finland 2014). Nevertheless, none of the waste wood originating from demolished buildings is recycled, i.e. processed into particleboards or other engineered wood products (Meinander & Mroueh 2012, 26). In fact, Pirhonen et al. (2011, 47) have estimated that the opportunities to recycle are very limited with the techniques and structures that are currently used. They (p. 30) have, however, attributed architects with the possibility to increase the demand and supply for reclaimed timber, i.e. whole timber products deconstructed from buildings.

This kind of activity already exists in Finland, but to an extent not significant enough to show in the statistics, since it is currently limited to artisanal and do-it-yourself construction. Salvage yards that gather, store and sell reclaimed materials and products are mostly run by public operators or the third sector, but also by private companies. Most yards concentrate on hand-made historical building parts and associate themselves with heritage conservation. Historical log frames are also sold for relocation, even though the market is minor. Prices remain relatively low for both historical components and entire frames. Thus, salvage yards that take in industrially mass-produced components with even smaller monetary value are usually non-profit efforts that provide employment or training for marginalized groups.

Since the salvaged components already exist, their architectural and structural design cannot be differentiated from each other. A study situated in Canada suggests that salvaged timber has different properties than virgin timber with regard to both mechanical performance and dimensions (Teshnizi 2015). Thus, this paper looks at architectural design from reclaimed timber components as a tectonic question. 'Tectonic' refers here to a view that the properties of a building's construction materials should define the nature of its architectural and structural expression. The paper uses tectonics as the starting point to discuss findings from literature and empirical material. The objectives of the paper are to exemplify the role of architectural design in the reuse process and to provide practicing architects with practical design guidelines, derived from the empirical material. Understanding the nature of reclaimed wood better may help to scale the activity up from its current niche.

Figure 2. Demolished wood in an ordinary sorting facility: inconsistent in quantity, quality, dimensions, availability and compatibility. Photo courtesy of Paavo Huuhka.

Theoretical framework and research design

Barriers for reuse

Several authors have studied barriers for reuse in different contexts. Some studies are focused specifically on timber while others touch upon all materials used in a certain country. Either way, the barriers are very similar, with some local aspects related to natural conditions and legislation. Many barriers are connected to the market condition and economic viability of deconstruction and reuse, which are better in the developing countries due to the availability of cheap labour and low-income customers (Gravina da Rocha & Aloysio Sattler 2009; Storey et al. 2005; Teshnizi 2015). Some barriers appear, however, matters related to design as well. These include inconsistent and often substandard quality and quantity, problems in availability and compatibility (Figures 2 and 3), as well as bad perception, knowledge and awareness (Gravina da Rocha & Aloysio Sattler 2009; Huuhka & Hakanen 2015; Storey et al. 2005; Teshnizi 2015).

Figure 3. Deconstructed wood in a salvage yard: organized based on length and component type, but still varying in many respects.

Inconsistent quantity and problems in availability refer to the lack of similar components and unawareness of what kind of components will be available at a given time. Inconsistent quality suggests that properties of salvaged components are not similar; their dimensions, strength, surface treatment and colors vary. Even if parts come from one source, the properties of originally similar components may have changed during use or deconstruction. When it comes to historical hand-made parts, seemingly similar components tend to have slightly different dimensions. Moreover, it is usually not possible to extract all materials and components from a building, but some loss is bound to occur due to damage from use, exposure or deconstruction. Interfaces of components that come from different buildings and systems need special attention. Of course, no original specifications are normally available. When elaborated on this way, it seems that these aspects are all more or less intertwined and inherent to the material. It has therefore been concluded that the design of reuse needs to possess flexibility to accommodate for this variability (Gorgolewski 2008; Gorgolewski et al. 2008). The purpose of the current study is to elaborate on the properties of salvaged timber and to suggest strategies for designing with it.

Tectonic architecture

Tectonic architecture is the kind of architectural expression that derives from its making, including the implications of the material, function and stresses. The word 'tectonic' originates from Greek, where it refers to carpentry and building (Harper 2016). The term entered architecture theoretical discourse in the early 19th century, its emergence relating to the unearthing of ancient Greek monuments. The monuments, taken as a model for classical design ideals, were first believed to have been white; thus, the derived aesthetic dogma relied on the beauty of the 'acromatic' form. Discovering their polychromatic nature triggered

Figure 4. Wood is lightweight and linear, i.e. a tectonic material. A lookout tower in Wil, Switzerland, designed by Julius Natterer. Photo by Touristinforwil, downloaded from Wikimedia Commons and published under the license CC-BY-SA 3.0.

theorists to ponder the relation between inner structure and outer surface. (Mallgrave 1989).

The theme was highly topical due to the emergence of new materials and construction methods, and the contradiction between them and traditional ornamentation. In the 1840s, Karl Bötticher developed a seminal theory for 'tectonics' in his book 'Die Tektonik der Hellenen', distinguishing between the 'core-form' of the structure and the 'work-form' of the plan, and their architectural representation on the surface, i.e. the 'art-form'. The surface ornamentation was to communicate the building's static and functional characters. He applied these ideas later to iron architecture. (Schwarzer 1993).

In the next decade, Gottfried Semper (1851) introduced a universal architectural theory in which the crafts of building explicated the outcome. Studying primitive construction, Semper identified four fundamental 'elements' of architecture, i.e. the foundation, hearth, roof and envelope that constituted form. He associated these elements with the crafts of their making: foundation with masonry, hearth with ceramics, roof with timber and envelope with textiles, and suggested that the way they were made contributed to the building's architectural expression. (Semper 1851). In a later piece, 'Style', Semper made an effort to explain later stylistic features with the descendance of traits intrinsic to earlier crafts, and considered these features to withhold symbolic meaning stemming from the primordial world even in their converted form. Semper, however, titled only wood, a linear lightweight material as 'tectonic' (Figure 4) and masonry, i.e. heavyweight substances, as 'stereotomic'. (Mallgrave 1989).

Ideas related closely to the ontological and representational aspects of buildings, often referred to as 'honesty' of architecture, were discussed simultaneously by John Ruskin and E. E. Viollet-le-Duc. Ruskin (1849) suggested that materials should appear as they are and structures should convey transfer of stresses. Viollet-Le-Duc (1863) called for logical reasoning behind form-giving and its communication through design, 'an alliance' of the form and its making. In the 1960s, Eduard Sekler (1965) defined tectonics quite similarly in relation to structure (an abstract order) and construction (a making activity), so that a structure comes into being, in a physical sense, through construction and, in a visual sense, through tectonics, largely stripping tectonics from such spiritual aspects as Semper associated with it.

However, mainstream architectural theory in the 20th century was rather preoccupied with immaterial spaces than material structures, as the roles of the spatial and aesthetic designer (the architect) and the structural designer (the engineer) became separated in the beginning of the century. It was not until 1995 that architectural theory properly reengaged with tectonics, when architectural historian Kenneth Frampton released the book 'Studies in tectonic culture: The poetics of construction in 19th and 20th century architecture'. Building on the work of the previous theorists, Frampton (1995) suggested that architecture should be seen as a technical craft whose symbolic meanings derive from the way buildings are made, their structural expression and the bodily experience of the material space. A lot has since been written about the new tectonics brought upon by the digitalization of architectural design (e.g. Liu & Lim 2005; Oxman 2012). The current paper, however, identifies more with recent ideas of Danish scholars, who have proposed that sustainability should be an integral part of tectonic thinking in the 21st century (Beim 2012).

As the practical underlies the symbolic in the tectonic theory, one crucial starting point for tectonic architecture is the nature of the material, which defines what kind of structures may be constructed to border and form spaces that will, then, make symbolic references. Although the symbolic level is a focal aspect in tectonics, the current paper will operate mostly on the practical level and limit the

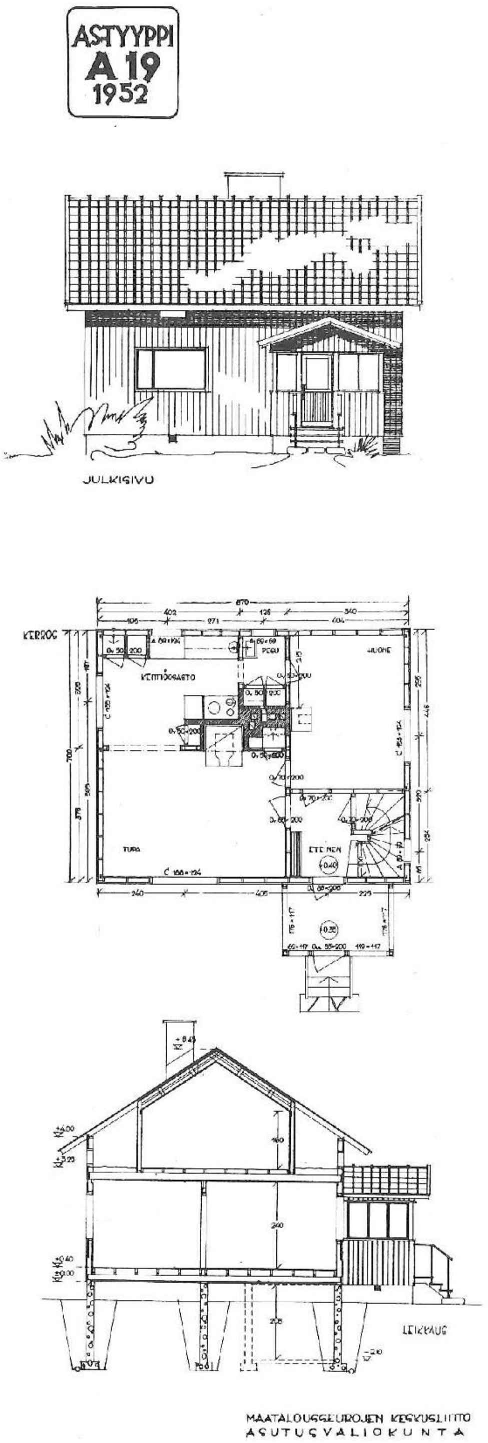


Figure 5. Type plans for balloon-framed 1950s houses. Public domain, archived in the National Archives of Finland, collection "Maa- ja metsätalousministeriön tyyppitalo-piirustukset, unit "Ieb. A 19, A 19 P", available through Digital Archives (digi.narc.fi/ digi/slistaus.ka?av=49796)

representational largely outside its scope at this time. With regard to reuse of wood, the main question of the paper is, whether reclaimed timber is in fact the same material as virgin timber, and if not, how should it be built with.

Research material and methods

Literature: Reclaimed timber as a building material

In the first part of the research, I review global literature to reveal challenges related to the reuse of timber from a tectonic perspective. The literature I analyse consists of publications acquired through Scopus and Google on reclamation and reuse of timber. I compare the findings from the literature to the Finnish circumstances and evaluate their significance for Finland. My evaluation is based on my expert knowledge on Finnish building customs as well as observations I have carried out as a long-time salvage yard client.

Empirical material: Design solutions

In the second part, I examine projects utilizing reclaimed timber. I analyse the designers' strategies to enable reuse, i.e. to overcome barriers identified in the previous stage, from a tectonic viewpoint, and translate them into design principles. As there are very few realized timber reuse projects that I could have studied, I took advantage of the students that I teached in Tampere University of Technology in creating the research material. They – 36 international master's students in architecture – drew up the material as their design assignment during a special timber architecture course I arranged in 2014.

I perceive the course assignment as a simulation of a real commission aiming at realization. As construction involves significant economic interests, a design simulation, capitalizing on the creativity of numerous designers, can be an inexpensive way to experiment with unestablished ideas such as reuse. However, the imaginary nature of the assignment stripped the task from real-life constraints such as tight project schedules. While being an obvious deviation from reality, it is also an asset since it enables innovation by emphasizing freedom of creativity instead of project management and 'safe' solutions.

The course participants studied design from deconstructed timber with two different cases. I assigned half the students to design allotment garden cottages as examples of small reproducible architectural 'products', whereas I made the other half to design café pavilions, i.e. unique buildings with a public character. The purpose of the former task was to represent a case capitalizing on typical waste streams, whereas in the latter task, students could also study the use of parts from only one atypical building. I gave instructions for the area, spatial program, foundation type and insulation of the buildings, but apart for that, the students had free hands with regard to architecture and structures. I arranged lectures and tutoring to share knowledge about timber architecture and construction in general and the challenges of reclaimed wood identified from literature.

I provided the students with drawings and photos of representative Finnish houses for estimating the amounts, quality and dimensions of typically available structures (Figure 5). I also instructed them to browse an online salvage portal for log frames and secondary parts; and I visited a demolition waste treatment facility and a local salvage yard with the class in initiating the design task in order to see how demolished wood is handled currently. In addition, I enlisted gluelam post-beam structures of a condemned big-box furniture store for the students to be used in the design of the public café pavilion. I chose this specific building for its accessible location. My colleague inventoried the columns and beams in-situ and I listed them in the assignment handout. Thus, the students could begin with a list of known components or to source the parts themselves; these are the two

Figure 6. Scots pine, the most typical species of construction wood in Finland.

starting points for reuse projects that the literature has recognized (Gorgolewski 2008; Gorgolewski et al. 2008).

The content analysis of the simulated designs is qualitative, and I base it on the close reading of the verbal and graphical material created during the course, aiming at understanding the design solutions and their implications for reuse even if all their aspects have not been explicitly expressed (as is often the case with architecture, let alone student projects). The graphical material encompasses preliminary sketches and finalized designs; whereas the verbal material consists of students' essays and discussions that took place during tutoring between the students and myself as their teacher.

Traditionally, close reading and content analysis are used in text analysis, but I applied the methods for graphical material, considering drawings and images as communicative and 'readable'. In the analysis, I followed the three phases of content analysis, i.e. reduction, clustering and abstraction of the material, with the purpose of producing a new classification from the material (Silius 2005). First, I listed the design solutions intended to facilitate reuse in each of the projects (reduction). Secondly, I grouped similar approaches together (clustering). Thirdly, I induced more general design principles from the applications (abstraction). After coming up with principles that covered all the applications, I carried out an iteration round to eliminate overlapping and associated the principles with the barriers from literature. Thus, the content analysis was theory guided, i.e. the classes arose from the material but the concepts originated from the theory (Silius 2005). Finally, I quantified the solutions in the light of the identified principles, as can be seen in Table 1 in the end of the paper.

Figure 7. Cross-sections of an antique trim (left) and a modern panel (right). The former is extremely dense, almost entirely made of durable heartwood and the heartwood is towards the exposed surface. The latter is coarse-grained and has no heartwood.

Results and discussion

Properties of salvaged timber

Wood species

International literature distinguishes a difference in the reclamation of hardwoods and softwoods. In the southern hemisphere, durable hardwoods become well separated from other woods and are considered valuable, whereas reuse of softwoods is less developed due to a lesser financial value (Forsythe 2011; Gravina da Rocha & Aloysio Sattler 2009; Storey et al. 2005).

Almost all Finnish construction wood is softwood, since Scots pine (Figure 6) and Norway spruce dominate in Finnish forests. Common endemic Finnish hardwoods, silver and white birches, do not endure weather and have therefore not been used in construction, apart for interiors. Although oak, a hardwood, occurs in doors and windows of prestigious urban buildings, it is so rare that focusing on hardwoods is not a feasible strategy in Finland. Thus, resolutions for softwood reuse can contribute to reclamation in other countries too.

Material properties

To safely use reclaimed timber in structural applications, designers must be able to trust its load-bearing capacity. In general, wood exhibits good strength properties in both compression and tension, and timber can, therefore, be used in massive or skeletal form. Mechanical properties are the most critical in applications facing tensile or bending stresses, such as beams and columns, and less critical in massive compressed structures, such as log walls.

It is generally believed that aged timber keeps its properties unless it is damaged biologically or physically, which is why I treat the mechanical properties of aged timber and the damage that has possibly occurred during its history separately. Over the years, a number of studies have examined both aged and deconstructed timber to provide evidence for the aforementioned belief. These studies have recently been evaluated in a review paper (Cavalli et al. 2016).

There is some evidence that strength properties of wood might either improve or degrade over time. The aforementioned review concludes, nevertheless, that most studies imply that ageing in itself does not reduce compressive and tensile strengths. Bending strength may remain unchanged or decrease slightly, but not in a decisive way; only the impact bending strength seems to decrease clearly due to ageing (Cavalli et al. 2016).

Wood quality

One difficulty with these studies is that the original properties of wood are rarely known. Density is an important factor for wood's strength, elasticity and durability, denser wood being better. Since slow growth produces dense wood, antique wood is believed to be denser than modern plantation-grown wood (Kaila 2008, 249). Moreover, the more heartwood in pine, the better its rot resistance. The amount of heartwood increases with the age of the tree. Since plantation-grown trunks are harvested at a young age, antique wood (Figure 7) is also considered more durable in this sense (Kaila 2008, 252).

Figure 8. Rot at the end of a salvaged floorboard. Damage in wood is easy to recognize visually.

One more factor influencing the quality of wood is the production process from a tree into a log and further into a construction component, including the selection, harvesting, drying and correct application of wood (e.g. heartwood for windows). These practices are regarded to have been better in past times (Obataya 2007; Kaila 2008, 393–404). The fact that historical wood has performed better than contemporary timber in some tests (Cavalli et al 2016; Obataya 2007) may support these views.

Damage

Not age but damage is considered to underlie major strength decreases in deconstructed timber (Cavalli et al. 2016; Nakajima & Murakami 2008). Defects in wood (natural or manmade) lower bending and shear strengths. Damage may occur during use or deconstruction. In-use phase damage originates from (over)loads, connectors (nail or screw holes) or biological attacks (rot, insects).

Figure 9. Painted members, traditional red ochre (left) and more modern paints (middle and right).

It has been suggested that nail holes can be considered equal to knots when timber is reused (Hradil 2014), because in testing, knots and nail holes have had the same effect on the tensile strength of deconstructed timbers (Nakajima & Nakagawa 2010). Excessively nailed timbers should, however, be deselected from structural applications, since dozens of nail holes may reduce the performance notably (Nakajima & Murakami 2008).

Permanent deflection from overloading and biological degradation are also easy to identify visually (Figure 8), enabling discrimination in the selection process. Many authors have brought up that official grading rules for secondary timber would facilitate reuse (Cavalli et al. 2016; Huuhka & Hakanen 2015; Teshnizi, 2015; Storey et al. 2005).

Treatment

Virgin timber is clean, but salvaged timber is often coated or impregnated. Since chemically treated wood is not used in house construction in Finland apart from external garden structures, the amount of such timber waste is not significant (Pirhonen et al. 2011, 36), unlike in New Zealand, where almost all modern framing wood is chemically treated (Storey et al. 2005). Nevertheless, exposed timber is almost always painted for surface protection indoors and especially outdoors (Figure 9).

Figure 10. Details of antique doors, crafted with skill.

Frame members are usually hidden inside the envelope and therefore remain untreated but may be contaminated with metal (nails, screws), concrete (former cast-mould timber) or insulation (mineral wool, polyurethane) after the deconstruction. At the moment, material recycling can only accept clean wood; therefore, reuse may be the only effective option to incineration for impregnated, coated and non-toxically contaminated timber.

Types of components

Available components depend on the local timber-building traditions. Typical to the UK and US, timber framing uses members with large cross-sections, enhancing the possibility for reuse and reprocessing into e.g. flooring (Pirhonen et al. 2011, 51; Storey et al. 2005). Although timber framing is not used in Finland, log buildings yield large cross-sections. The other conventional Finnish construction method is balloon framing with two-by-fours.

Although more wood would be available in frame members, crafted products such as antique doors and windows (Figure 10) are typically considered more valuable, in Finland as well as elsewhere (e.g. in Brazil, Gravina da Rocha & Aloysio Sattler 2009). Alas, the built-in frames of doors and windows are often discarded, and only door leaves and window casements get salvaged.

Figure 11. Contemporary doors of industrial manufacture.

Component quality

Salvaged components come in two categories: handcrafted and industrially produced. Antique doors and windows are artisanal products, whose artistic quality outweighs that of industrially serial-produced components (Figures 10 and 11). Not only the form-giving but also joinery and raw material are often more refined in handcrafting than in mass-production. The same applies to hand-carved logs in comparison to industrially planed or turned logs, not to mention glue-lam 'logs'.

On the other hand, historical components do not fulfil current energy norms. However, due to rapid developments in energy efficiency, only very recently produced components are able to meet today's standards. Nevertheless, Finnish energy norms incorporate a compensation principle that allows some components to have lower insulation values if heat losses are compensated elsewhere.

Figure 12. Reduction of length. Very few of the logs stored in this salvage yard span more than 2 m.

Dimensions

Dimensions of reclaimed timber differ from virgin timber in three ways: there is a reduction of length (Figure 12), a reduction of cross-section (Figure 13) and a lack of standardization (Figure 14). Timber sold in hardware stores typically spans 3.6–4.2m. Studs of older houses may be shorter than this in the first place, since room and floor height requirements have increased. In Japanese tests, however, lengths of salvaged two-by-fours averaged only 2.3m (Nakajima and Murakami 2008; Nakajima and Nakagawa 2010), clearly less than a room's height. In a study situated in Finland, length losses ranged from 1% to 69% in machine demolition, depending on the cross-section (Sakaguchi 2014).

Very large (4x4 beams) and very small (1x4 and 1x6 cladding) members kept their length best, whereas medium cross-sections of the frame performed clearly worse. Their original lengths were 3–4m, and after deconstruction they achieved average lengths around 2m only. (Sakaguchi 2014). Some losses could probably be mitigated with hand deconstruction. However, as members are usually nailed from their ends, the ends are prone to cracking (Figure 15). Weather may also contribute to the need to shorten exposed components.

Figure 13. Reduction of cross-section. A notch in a log.

The second dimensional anomaly, the reduction of cross-section, is supposedly a local phenomenon that is accidentally inflicted during deconstruction or that results from the nature of the previous use. In long members, reduced cross-sections will often contribute to their shortening, too: a member will easily be cut to two at the location of a notch. Design loads of beams have also been raised, denoting that members in older houses may originally exhibit smaller cross-sections than current houses. However, due to the intensification of energy regulation, widths of studs and heights of beams are often not defined by loads but the space needed for thermal insulation, up to tens of centimetres.

Unlike before, construction today is modular-coordinated, following multiples of 10, 30 or 60 cm, depending on the building part. The interfaces and tolerances between parts have also been designed to serve this coordination. Historical components do not, however, follow these rules. Therefore, missing door or window frames cannot be replaced by serially-produced substitutes. Norms have also established particular dimensions for certain components; e.g. doors come in given sizes due to accessibility regulation. Thus, few decades old salvaged doors might be modular-coordinated but no longer wide enough.

Figure 14. Lack of standardiza-tion. None of these windows are exactly the same.

Summary of properties

In some cases, reclaimed timber can be considered the same material as virgin timber (e.g. salvaged nearly-full-length logs end notches cut off and with no peg holes or middle notches). Chances are, however, that in most cases, salvaged wood is a different material, although it is the same (softwood) species as virgin timber. It will differ from virgin timber by its supply, mechanical properties, available dimensions and surface treatment. It will be more variable, slightly weaker in bending, shorter and thinner, possibly painted, not quite up to the latest energy norms, more often handmade than industrial, and already made into a component, such as a stud, log, door or window.

Tectonic use of salvaged timber

Apparently, the tectonic use of reclaimed timber must be, in most cases, also different from that of virgin timber in conventional wood architecture. Analyzing student projects helped me to identify strategies that enable the use of reclaimed timber better. I derived the following ten design principles from the students' architectural applications.

Figure 15. Cracking and nail holes at the end of a floorboard.

The principles are fusions of several applications that share common features addressing certain properties of reclaimed timber. They are, by and large, as intertwined as the design-related barriers of reuse, and also partially contradictory, because they are intended for a variety of different circumstances (e.g. one strategy suggest to use multiple lengths, while another suggest to use short stubs). I mention possible applications of the principles, originating from the student projects as well as literature. Designers' brief comments on the task accompany the principles.

Principle 1: Divide the spatial program into smaller units

Shortness of beams and other horizontal components such as logs is a typical challenge. When a spatial program is divided into several rooms or volumes instead of one large space (Figure 16), the utilization of shorter and thinner beams is enhanced, with the proviso that load-bearing interior walls are used. When long timber is available, using continuous beams instead of simply supported beams enhances the use of smaller cross-sections.

"Reuse must include a smart and strategic approach to designing from the very beginning."

- Martins Ostanevics

Figure 16. Divide the spatial program into smaller units. The plan of this café pavilion consists of multiple freestanding volumes (design and image by Paula Tiainen).

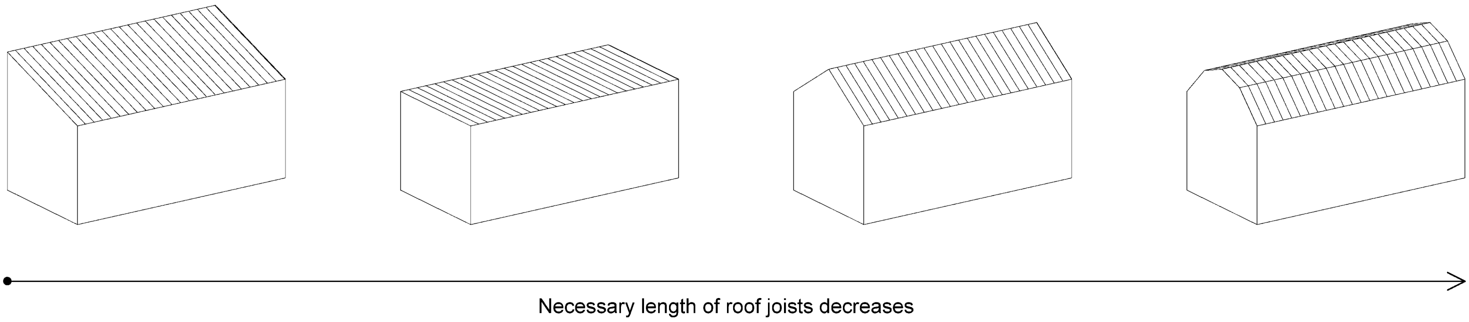
"Reuse gives an impression of moderation, of necessity, and engaged the design with efficiency."

- Paul Texereau

Principle 2: Divide elements into smaller units

Shortening in deconstruction applies often to vertical members, such as frame studs. This challenge can be overcome by dividing the structure into smaller units. The most obvious example is using the platform frame instead of the balloon frame. Whereas studs extend all the way from the foundation to the roof in the balloon frame, in the platform frame, walls are constructed floor-by-floor, reducing the necessary length of studs in multi-storey constructions (Knaack et al. 2012, 38). When the available stud length does not measure the room height, studs can be lengthened with nailed halved scarf joints. In fact, vernacular construct ion withholds several solutions for lengthening both compressed and tensioned members with traditional carpenter joints (Zwerger 2012, 233–237), which have become forgotten due to the contemporary unlimited availability of long timber.

Figure 17. Divide the structural elements into smaller units. The figure illustrates the relation of the roof shape and the roof joist length.



"Do more with less."

- Marta Prikule

In horizontal direction, one wall frame can be divided into several narrower (prefabricated) wall panels to shorten the lengths of sole and base plates and head binders. Respectively, a gable roof or a split-level roof consisting of two sets of joists facilitates using shorter members than a shed roof or a flat roof that requires one set of long joists; a gambrel roof consists of four sets of even shorter joists (Figure 17).

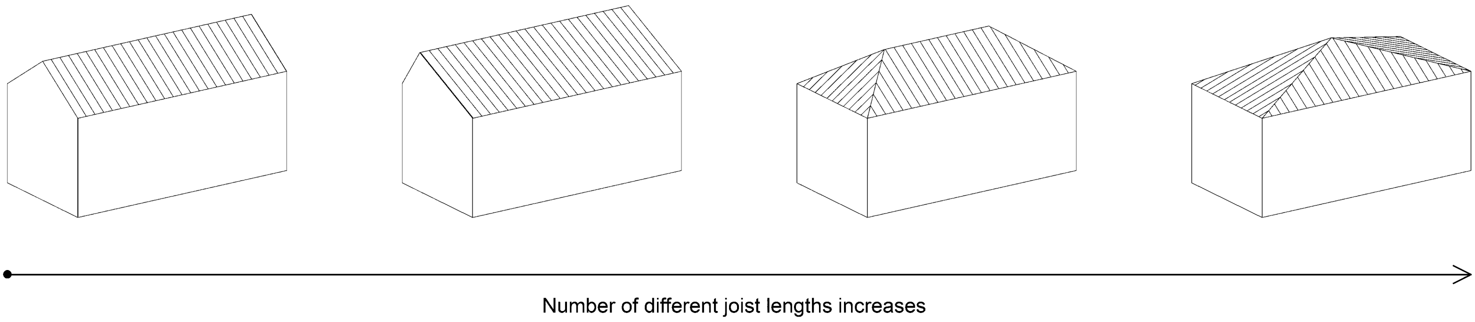


Figure 18. Avoid equal spans and dimensions. The figure illustrates the relation of the roof shape and the number of different roof joist lengths.

Principle 3: Avoid equal spans and dimensions

Salvaged timbers typically come in varying lengths; to avoid leftover cuttings, a design should accommodate many lengths. Oblong room shape is therefore superior to a square in log construction. Oblique layouts, on the other hand, provide opportunities for using several beam lengths. Similarly, an asymmetrical catslide roof is better than a symmetrical gable roof; furthermore, a pavilion roof consists of many joist lengths that are mostly repeated for only eight times (Figure 18).

In addition, multiple-span girders can accommodate different beam lengths by employing sleeved beams or suspended span beams. If beams are organized diagonally in relation to a rectangular room plan, the use of unequally spanning beams is also enhanced.

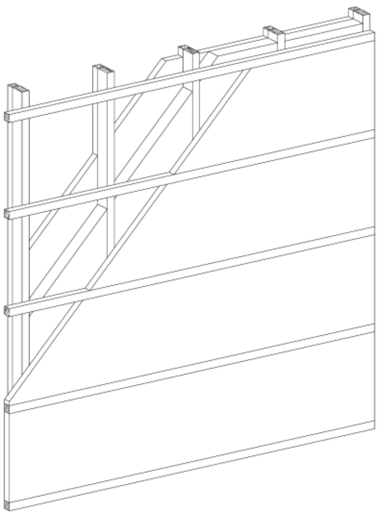


Figure 4. Distribute functions for different structural members. A wall structure with high U-value (0.17) made of thin studs: two-by-fours bear loads, inner and outer battening provide space for thermal insulation.

Principle 4: Distribute functions for different members

Traditional balloon frames were compiled from two-by-fours, which provided 100mm of space for thermal insulation. Nowadays, studs normally range 150–200mm because of energy efficiency requirements; for passive houses, laminated veneer timber studs up to 350mm are used. Studs this wide are oversized from the viewpoint of loads and they may be difficult to encounter in older buildings. However, if the load-bearing function and the function to provide space for thermal insulation are divided for different members, the necessary insulation space can be achieved by combining thinner studs. Load-bearing two-by-fours can be coupled with inner and outer battening made of two-by-twos (Figure 19). Even more thermal insulation space can be achieved with ladder-like structures familiar from straw-bale construction; using blow-in insulation mitigates the inconvenience for insulation work.

Beside walls, this principle can be applied to floors and to roof beams for providing the air gap between insulation and roofing. As for vernacular techniques, post and plank construction enables the use of short logs, laid between slotted posts. The posts bear the loads while the planks act as thermal insulation. These functions can be separated for different members in modern construction, too: if a facade only bears its own weight and wind stresses (and the load-bearing frame consists of posts and beams), the requirements for its load-bearing capacity are lesser. This enhances the use of lengthened or low-quality studs.

Principle 5: Use efficient forms for long spans from short pieces

Some structures are more efficient than others thanks to their geometry (Salvadori 2002, 179–205). For example, arches, vaults and domes can bridge extensive spans and bear immense loads although they are put together from small bricks. They represent the type of structures where only compressive stresses are present (Salvadori 2002, 144–149; 225–230). Using short sections of two-by-fours as 'timber bricks' would allow the construction of forms reproducible with actual bricks. Nails, screws, wedges and wooden pegs could replace the mortar in 'timber masonry'. In fact, a type of timber masonry wall is known in vernacular construction (Zwerger 2012, 231–232). In this technique, called stackwood building in the US and known Europe, too, the timber sections, perpendicular to the wall itself, are joined with clay mortar. In addition to real arches and vaults, corbelled forms can also be constructed with simple timber blocks (Figure 20).

"Being used to think that everything is available can cause a gap between the architectural concept and the salvaged components."

- Karianne Fonn Jårvik

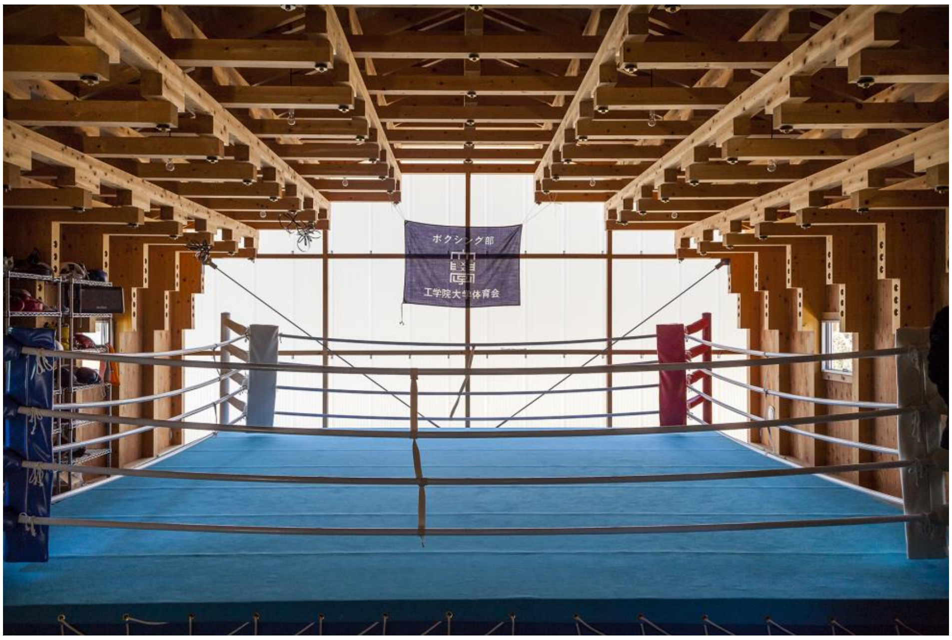


Figure 20. Use efficient forms for long spans from short pieces. Although not made of reclaimed timber, this figure illustrates the 5th principle with the corbelled roof structure of Kogakuin University Boxing Club in Tokyo, designed to be built from short low-quality wood (designed by FT Architects, photo in the courtersy of Jonas Aarre Sommarset).

"We must identify the constraints of reclaimed parts and transpose them into possibilities."

- Razvan Iov

Space grids and grid shells are more modern sources of inspiration for utilizing short timber pieces. For example, the geodesic dome is made of equilateral triangles; the high bearing capacity of the structure is based on the space-grid action of its members (Knaack et al. 2012, 62–64). CAD and BIM tools offer new possibilities for designing complex structures, although traditional hanging chain models also allow developing pure compression shells. More conventional examples of structurally efficient components are roof trusses, flat trusses, I-beams, I-posts and box beams. Although industrially manufactured timber I-joists and I-posts are today constructed with plywood webs, similar structures (traditional braced beams) can also be nailed together from diagonal boards. Three-hinged arches and folded slabs can be constructed with this method from short boards.

Principle 6: Define ranges instead of fixed properties

This principle manifests replacing designer control with tolerance towards the material. In a normal project, the architect's task is to define the dimensions and visual properties of a building and its parts unambiguously. This serves the building permit application as well as the contract and working drawings. To be able to do this with salvaged components, the parts would have to be acquired before the design begins. However, storing components from early on has notable cash flow and management consequences for the developer, and when pre-purchase is not a viable option, redesign rounds are needed when suitable components are eventually found and purchased (Gorgolewski 2008; Gorgolewski et al. 2008).

To avoid redesigning, defining prefixed properties should be replaced by giving ranges. For example, the same room area can be acquired with multiple wall widths that enable different beam spans or log lengths. Flexible ranges are especially beneficial for reusing logs because the laborious task of re-carving notches can be avoided by employing entire rooms. Respectively, the dimensions for windows and doors can be given as ranges. The principle can even be applied to the colors of cladding by allowing multiple hues of a color or combinations of hues or colors (Figure 21).

"It was clear from the beginning that some flexibility should be maintained regarding the appearance and availability of the material."

- Marta Prikule

Figure 21. Define ranges instead of fixed properties. A facade cladding with ranges of red and grey colours; the window layout can also tolerate windows of varying dimensions (design and image by Szymon Galecki).

Principle 7: Rotate and repurpose

Reuse does not have to obey the original construction too faithfully: horizontal buildings can make vertical constructions by turning beams into columns, or vice versa. Very large glued laminated beams and columns from industrial buildings or warehouses can be utilized as wall panels or floor slabs in the same way as cross-laminated timber (Figure 22). Of course, components can always be sawn to sections if the new application is smaller or has smaller loads than the original. Furthermore, a permanently deflected beam could, in theory, make a pre-cambered beam when turned over. Solid timber beams and columns as well as planks and boards may be piled as if they were logs. In terms of vernacular techniques, stave construction was often employed with salvaged logs, because log rooms are typically wider than what their height is. With stave technique, the logs suffice better for new construction even though damaged notches are cut off.

"What first was an obligation became an aid and an inspiration."

- Valentin Szymoniak

"It is up to us architects to make use of the advantages of reused materials and to make sure our designs allow materials of any origin to be used."

- Paula Tiainen

Figure 22. Rotate and repurpose. The use of glue-lam beams as walls and a slab (design and image by Lassi Viitanen).

Principle 8: Select the application according to the properties

Sometimes shortness or damage of members may prevent using salvaged timber in load-bearing functions. Luckily, a timber building encompasses a number of components for non-load-bearing purposes: stairs; exterior and interior claddings (weatherboarding, lining, flooring, ceiling, trim, screens and grilles); and rough grounds (battening, furring, sarking and pugging boards). These uses tolerate short and variable timbers, and the lastly mentioned category does not even pose any requirements for their appearance.

Traditional shingle wall and roof coverings utilize overlapping short planks, but even non-overlapping weatherboarding can withstand discontinuity if the detailing effectively prevents rainwater from stagnating. However, the shorter the cladding boards, the more battens are needed to provide fixing points. Indoors, where rain is not an issue, claddings can be executed in an unrestricted manner (Figure 23): timbers of different widths and depths can be utilized to produce relief surfaces. Even the shortest pieces can make wood mosaic or end grain woodblock flooring.

"A limited supply enhances creativity. If an architect would have all the materials in the world, the result would be less exciting because one tends to reach for standardized solutions."

- Erlend Espenæs

Figure 23. Select the application according to the properties. Interior cladding made of short boards that would otherwise be practically useless (design and image by Razvan Iov).

Principle 9: Combine creatively

A designer's creativity can fight the incompatibility of salvaged components. Even conventional timber construction hosts solutions that suit well for putting together cladding boards from varied sources. For example, clapboarding, staggered siding or board and batten cladding facilitate using weatherboards of different widths. Clapboarding also enables combining boards with different profiles or damaged tongues and grooves. Short sections of sidings with different profiles or colors can be combined in an orderly manner by arranging them into fields separated by cover fillets. The combining strategy can be applied to windows and doors in order to create larger surfaces (Figure 24).

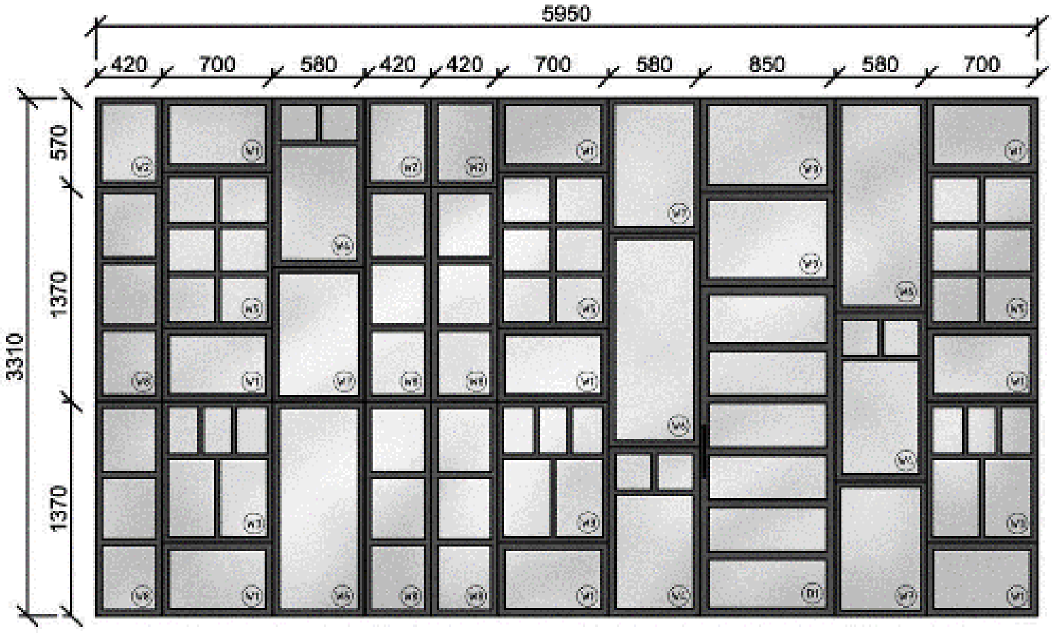


Figure 24. Combine creatively. A schema for a glass wall made of salvaged windows (design and image by Michala Konarikova).

"Sustainability can only be gained when the building conveys the message of reuse to its users.

- Hai Hoang Le Nam

Principle 10: Let the patina speak

The appearance of aged surfaces is called 'patina'. Kalakoski (2016) associates patina with the psychological experience of comfort and continuity by referring to the writings of such renowned theorists as Georg Simmel, Juhani Pallasmaa, and David Lowenthal. The students who created the research material found this aspect of reclaimed timber as especially meaningful. There is, indeed, an undeniable appeal to the old, for the decoration market boasts with products imitating cracked paint or corroded steel. The phenomenon extends to the building sector in the form of rusting cor-ten steel, mechanically produced 'hand-molded' bricks reminiscent of antique bricks and fiberboard doors pressed in the shape of handmade old-age panel doors, although reuse would be more environmentally friendly and architecturally more honest.

In the case of timber, weathered natural grey (Figure 25) as well as faded or layered and chipped paint are aesthetic features that are difficult to reproduce plausibly in new material. Although repainting is always an option for salvaged timber, stripping paints can be laborious (and thus, expensive) or harmful to the environment (if stripping chemicals are used). The patina should rather be seen as an indigenous feature of reclaimed wood and beside color, it includes many kinds of minor damage. In design, it should, however, be noted that due to its nature, patina is irreparable. When patinated components are combined to one oeuvre from multiple sources with artistic intentions, the effect cannot be retained when maintenance (e.g. repainting) becomes unavoidable. Relocating patinated

Figure 25. Let the patina speak. Weathered barn siding in an otherwise contemporary design (design and image by Paula Tiainen).

components to the interior, on the other hand, halts the decaying process whose nature is to evolve.

Appraisal of principles and applications

The principles I have presented touch upon aspects of architectural design ranging from more general design (massing and plan design – Principles 1–3, 5, 6) to structures of architectural elements (walls, roofs, floors – Principles 2–8) and, eventually, surfaces and secondary components (Principles 6–10). They do not discriminate between massive and skeletal construction, but are equally applicable to both. Since the room height is fairly standard in buildings, apart for certain building types, more opportunities seem to arise for enabling reuse in horizontal structures. Most principles (2–7) are, nevertheless, applicable to both vertical and horizontal structures, but for some, it is easier to recognize horizontal applications (3, 6). Based on the occurrence of the principles in the research material (Table 1), it seems easier to find applications for reclaimed timber on the facades than within the structure.

Some principles (1, 8) do not denote significant changes to conventional architectural design or construction methods. For instance, massing into several volumes (Principle 1) is a decision often made on solely architectural grounds, as it creates in-between spaces resulting in a richer spatial experience. Some applications of other principles (2–4) are also fully conventional, whereas their other applications and some other principles (5, 7, 9) may easily result in nonconventional forms and structures. These require more structural design skills but may produce impressive structures able to adopt aesthetic roles, an aspect characteristic to tectonics.

The downsides of nonconventional designs (Figure 26), while they indisputably promote material efficiency by enabling reuse, are the increased laboriousness in both design and erection, which may have unwanted cost implications, as well as challenges in moisture behaviour/long-term durability, which may make them

Table 1. Occurrence of the applications of the principles in the research material. P=principle.

Principles	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Design 1								■		■
Design 2										
Design 3	■		■						■	■
Design 4								■		■
Design 5							■			
Design 6						■			■	■
Design 7						■		■		■
Design 8	■			■			■		■	
Design 9							■	■		
Design 10							■	■		■
Design 11								■		■
Design 12							■			
Design 13										
Design 14									■	■
Design 15				■				■		■
Design 16			■	■			■			
Design 17								■		■
Design 18						■		■	■	
Design 19				■					■	
Design 20	■						■			
Design 21								■		
Design 22				■		■				■
Design 23	■			■		■				■
Design 24		■					■			
Design 25	■						■			
Design 26					■	■				
Design 27									■	
Design 28	■			■				■		■
Design 29				■			■	■		
Design 30							■	■		
Design 31			■			■	■			■
Design 32						■				
Design 33						■			■	■
Design 34			■					■		
Design 35					■		■			
Design 36			■				■			■
Total	6	1	5	8	2	9	14	14	8	16

more suitable for temporary pavilions than for permanent buildings. These notions, however, are characteristic of architecturally ambitious projects in general. In some cases, the opportunity for prefabrication may help to mitigate the assumed cost increase and enable to activity to be scaled up to a more industrial level (e.g. Principle 1 – spatial modules; Principle 2 – pre-lengthened studs; etc). Some applications (e.g. timber masonry suggested under Principle 5) will, however, remain artisanal and as such, exceptional.

Nevertheless, other principles may also help to reduce costs. Principle 6, for instance, is aimed at evading excessive pre-purchase and redesign, and Principle 10 for obviating laborious and costly stripping. Principle 7 may also ease procurement, as it helps to identify the affordances of components.

To understand the full environmental implications of the principles, the relation between material efficiency and energy efficiency would need to be studied further. Whereas some applications of the principles may even help to decrease the necessary amount of (reclaimed) material (Principles 5 and 7), others may result in its increased use (e.g. Principles 4–5, 8). Even more importantly, some principles (1, 2) may require more foundations to be used, and these are made of carbon intensive mineral materials. Therefore, column foundations should be favoured, and the overall carbon balance should be studied carefully. Principle 1 may also increase the area of exterior walls, which implies greater heat losses than in compact buildings.

As the principles are aimed at mitigating the variability of the reclaimed material, they also call for tolerance towards variability of appearance (6, 9, 10). Whereas architectural unity might then be risked, playfulness and organicity may also be gained. Designers must, however, be willing to relinquish a part of their authority, resulting in a co-creation between the designer, the builder and the material – an idea possibly difficult to accept by the architect, trained and yearning to design. Moreover, similar flexibility is required from the building permit process, built into the Finnish legislation (Maankäyttö- ja rakennuslaki 1999, 134§; Maankäyttö- ja rakennusasetus 1999, 79§) but assumingly rarely employed in practice.

Lastly, these principles also tap into the ontological aspects of buildings, essential to tectonics. Reuse of reclaimed materials withholds cognitive risks, related to the recognition of time layers in the built environment. These risks are influenced by informedness of the viewers as well as the communicative nature of the design. Exposing the weathered substance for observation is one of the focal aspects for the symbolic dimension of tectonics in salvaged materials.

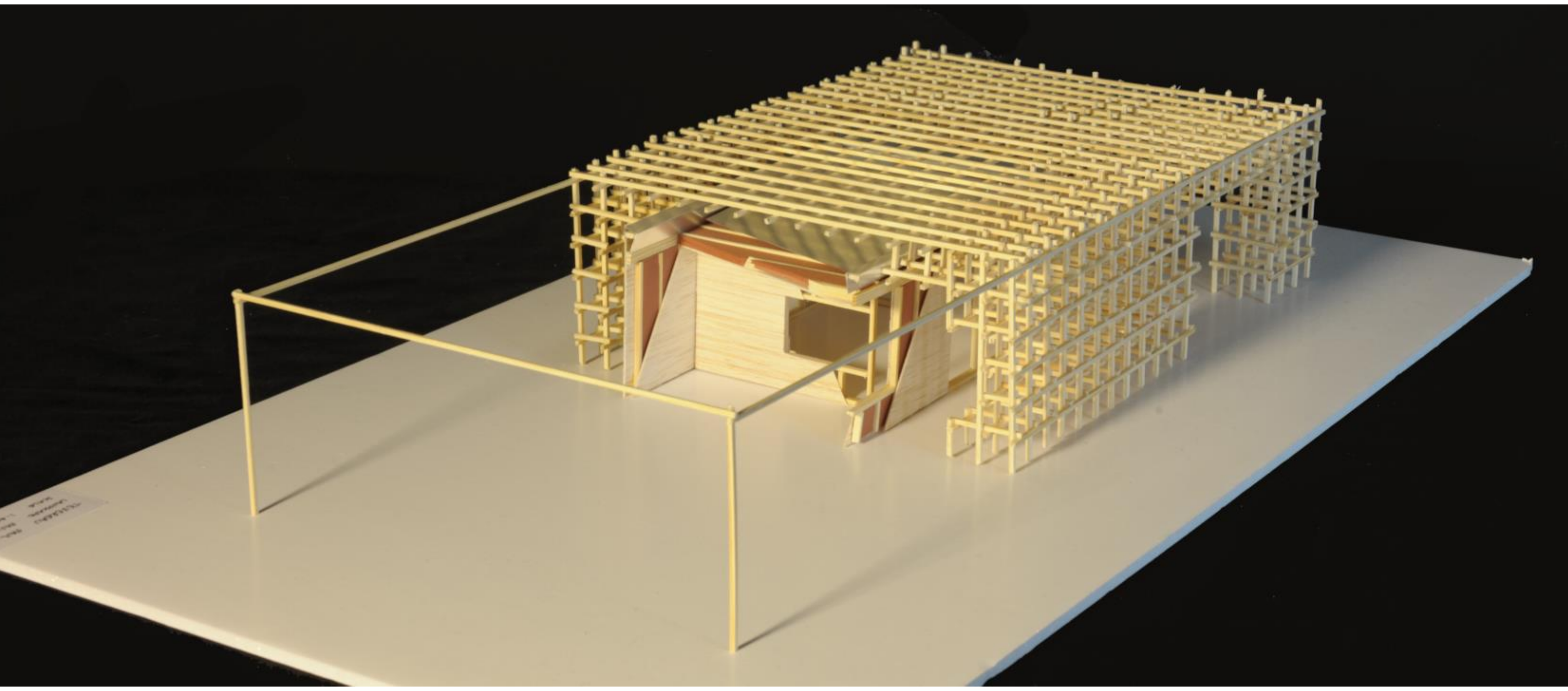


Figure 26. A non-conventional structure, with positive implications for architecture but challenges with long-term durability (design and model by Paul Texereau, photo by Arto Jalonen).

Conclusion

My purpose in this paper was to discuss the significance of architectural design for the reuse of a reclaimed material – timber – and to provide practical guidelines for architects working with the topic. I started off with the viewpoint of tectonic (crafting-based) architecture, and made an effort to expand the understanding on the barriers of reuse by elaborating on the material-specific aspects of timber reuse. I conducted a literature review that suggested that in comparison to new timber, the salvaged material will likely be more variable, slightly weaker in bending, shorter and thinner, possibly painted, not quite up to the latest energy norms, more often handmade than industrial, and already made into a component.

Then, due to the lack of realized projects that could act as research material, I engaged my students to work with reclaimed timber in order to find design solutions appropriate for the material, i.e. to relieve, if not overcome, the material-specific barriers. In their projects, I found the inherent properties of the material to affect massing, plan design, facade design, roof design, structural design, interior design as well as building specification: basically, the whole spectrum of architectural design. My content analysis also revealed a vast number of applications that helped them to manage the variation of properties in salvaged timber. I was able to synthesize ten more universal design principles for facilitating the use of reclaimed timber from these applications, and to associate further applications with the principles. The principles, thus, surpass the case-specificity of the applications and can help architects to cater for reuse in their own way from the very beginning of the design process.

Methods-wise, the experiences I gained during the research suggest that design simulation followed by a content analysis can be a feasible method for the systematic exploration of solutions for unconventional architectural problems, such as design from reclaimed components, at an early stage.

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