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FINAL REPORT

ProWoodBuild

Promoting long-lived wood buildings for climate change mitigation and adaptation

Euroopan unionin rahoittama –
NextGenerationEU

Low-carbon built environment programme (VN/4823/2022)

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1. Summary

EN

Increasing the amount of wood in construction can reduce the climate change impact of buildings; however, to maintain ecosystems services along with wood production, it is important to lessen the pressure on forests by adopting measures that enhance resource efficiency. Such measures include the design of durable wood constructions and reusable wood elements and, importantly, extend the lifespan of buildings for as long as possible. In this way the storage of sequestered carbon in buildings can be promoted, whilst simultaneously reducing the demand for primary resources. The aim of ProWoodBuild was to increase the understanding of the lifecycle of wood buildings and the reasons for their demolition, to promote longevity and increase confidence in constructing in wood. A further aim was to communicate this in a practical way to practitioners and students. ProWoodBuild investigated the lifespan of wooden buildings by reviewing resent research, carrying out a series of semi-structured interviews, and analysing relevant statistical data on the topic. The semi-structured interviews covered experts representing the entire forest-wood construction value chain. The aim of these interviews was to better understand the reasons for building demolitions, with focus on wooden buildings, and to identify factors affecting their lifecycle. A variety of both technical and non-technical factors were identified from the interviews. To complement the interviews, an analysis of statistical data was conducted, finding that, in line with previous research, the average age of residential wooden buildings in Finland is around 50 years at the time of demolition. The main output will be a handbook communicating this knowledge in a practical way, about how to build and maintain durable wood buildings.

FI

Puurakentamisen osuuden lisääminen rakentamisessa voi vähentää rakennusalan ilmastovaikutuksia; jotta ekosysteemipalvelut säilyisivät puuntuotannon ohella, on kuitenkin tärkeää vähentää metsiin kohdistuvaa painetta resurssitehokkuutta tukevilla toimenpiteillä. Tällaisia toimenpiteitä ovat esimerkiksi kestävien puurakenteiden ja uudelleenkäytettävien puuelementtien suunnittelu sekä erittäin tärkeänä toimena rakennusten elinkaaren pidentäminen mahdollisimman pitkäksi. Tällä tavoin voidaan edistää rakennuksiin sitoutuneen hiilen varastointia ja samalla vähentää primaariresurssien, metsien, kysyntää. ProWoodBuildin tavoitteena oli lisätä ymmärrystä puurakennusten elinkaaresta ja niiden purkamisen syistä, edistää pitkäikäisyyttä ja lisätä luottamusta puurakentamiseen. Tavoitteena oli myös välittää tämä tietous käytännönläheisesti alan toimijoille ja opiskelijoille. ProWoodBuild tutki puurakennusten elinkaarta perehtymällä ajakohtaiseen tutkimustietoon, tekemällä laajan otoksen puoli strukturoituja haastatteluja sekä analysoimalla relevanttia tutkimustietoutta aiheesta. Puolistrukturoituihin haastatteluihin osallistui koko metsä- ja puurakentamisen arvoketjua edustavia asiantuntijoita. Haastattelujen tavoitteena oli ymmärtää paremmin rakennusten purkamisen syitä, erityisesti puurakennusten osalta, ja tunnistaa niiden elinkaareen vaikuttavia tekijöitä. Haastatteluista tunnistettiin useita sekä teknisiä että muunlaisia kuin teknisiä vaikuttavia tekijöitä. Haastatteluissa kerättyä aineistoa täydennettiin tilastotietojen analysoinnilla, ja havaittiin että aiempien tutkimusten mukaisesti Suomessa puurakennusten keski-ikä on purkamishetkellä noin 50 vuotta. Tärkein tuotos on käsikirja, joka välitttää käytännönläheisesti tietoutta siitä, miten kestäviä puurakennuksia voidaan rakentaa ja ylläpitää.

Our ProWoodBuild project has received support from the Ministry of Environment under the Low Carbon Built Environment Programme, funded by the EU's one-off Recovery Facility (RRF).

Hankkeemme ProWoodBuild on saanut tukea ympäristöministeriöltä Vähähiilisen rakennetun ympäristön ohjelmasta, jonka rahoitus tulee EU:n kertaluonteisesta elpymisvälineestä (RRF).

2. Background and objectives of the project

The ProWoodBuild project ('Promoting long-lived wood buildings for climate change mitigation and adaptation'; VN/4823/2022), began on 1.5.2022 and was initially scheduled to run until 30.4.2023, though was extended to end on 31.10.2023. This final report summarizes activities from the beginning of the project up to its completion. Additionally, plans for continuation are also included.

It is generally accepted that increasing the amount of wood in construction can reduce the climate change impact of buildings. It has even been postulated that the widespread adoption of engineered wood in the construction of mid-rise, multi-story buildings could help the transition of the sector from a carbon source to a carbon sink (Churkina et al. 2020). It has been shown that by increasing the use of wood in such typical mid-rise, multi-story constructions in Finland, an average of approximately 160 $kgCO_2\ m^{-2}$ emissions could be avoided by adopting wood construction instead of building in reinforced concrete, whilst a further 100 $kgCO_2\ m^{-2}$ could be stored in wooden buildings if they replaced reinforced concrete structures (Alam et al. 2023). By extrapolation, we have estimated that up to around 60 ktons CO_2 emissions could be saved annually in Helsinki alone if 50% of the predicted new residential floor area was to be constructed from wood (Alam et al. 2023). This would represent a saving of around 25% of current construction emissions in Helsinki.

Increasing the total amount of wood in construction can thus have a positive climate change mitigation impact so, clearly, *its use should be promoted* as a means of meeting carbon neutrality targets. Nevertheless, in a follow-up paper to the one written by Churkina et al. (2020), Mishra et al. (2022), concluded that 'forest plantations would need to expand by up to 149 Mha by 2100 and harvests from unprotected natural forests would increase', whilst Jonsson et al. (2021) pointed out that harvesting to meet the increasing needs for construction may well compromise the sink capacity of European forests. An increase in demand for biomass has already manifested itself, with the land use sector in Finland (LULUCF), for example, becoming for the first time, a net source of greenhouse gas emissions in 2021 (Official Statistics of Finland, 2021). So, whilst wood can be a powerful way to mitigate climate change, it's use needs to be viewed systemically, considering the role of forests, all stakeholders in the forest-industry value network, the construction sector and society. Churkina et al. (2020) recognized this dilemma and noted that, in terms of preserving forest sustainability, it would be important to adopt measures, such as the design of durable wood constructions and reusable wood elements, to improve resource efficiency. In this way the storage of sequestered carbon would be promoted, whilst simultaneously the pressure on primary resources would be reduced.

Thus, we should stimulate other actions to enhance the climate benefits of wood construction as much as possible, whilst alleviating the adverse effects associated with over-harvesting. These actions include i) increasing the longevity of wooden buildings as well as ii) promoting the cascade[1] use of wood materials recovered from renovation and demolition activities, which been shown to increase resource efficiency (Risse et al., 2017) and reduce the environmental impact of construction (Niu et al., 2021). Extending the longevity of wood buildings may present greater challenges in the future with climate change predicted to alter the interior environment of buildings (Lü et al., 2018) so adaptation measures will become increasingly important, though non-technical factors are still likely to play an important role in determining the lifespan of wooden buildings (Huuhka and Lahdensivu, 2016). So, how do we increase the level of wood construction and promote these other actions that will maximize climate change mitigation yet reduce the pressure on primary resources, as well as making wood construction resilient against a changing climate? These are the questions that ProWoodBuild set out to answer.

Wood construction and climate change mitigation

Atmospheric CO_2 captured during tree growth is stored in harvested wood products (HWP), such as sawnwood, cross laminated timber and glue laminated timber, until it is oxidized by burning or by biological degradation. Since every ton of dry wood can store around 1,8 tons of captured CO_2, long-lived wood products, such as those used in construction can potentially store CO_2 for considerable periods of time, perhaps even centuries. Consequently, there should be *strong incentive* to maintain these products *in service* for as long as possible to maximize their carbon storage potential, and avoid the embodied impacts associated with the manufacture of new materials. In this way not only is carbon stored for longer, but it also reduces the need to harvest primary resources, thus helping to promote the role of forests in climate change mitigation and the maintenance of other ecosystem services. The use of wood primarily in long-lived wood products has been highlighted by a pan-European group of scientists as an important way to enhance and promote the sustainability of forests in Europe (EASAC, 2017). In addition, if HWPs are reused in a materials cascade, then additional benefits, that come from substituting other functionally equivalent materials (e.g., concrete and steel), can be realized (Leskinen et al. 2018).

In the recently completed CircWood project, we modelled the effect of extending the lifetime of wood products on the storage of (atmospheric) carbon. Although eventually all the carbon contained in wood entering the built environment will leave, due to oxidation at end-of-life, we have shown that by increasing the lifespan of wood products the total amount of carbon stored in the built environment can be increased (Hill et al, 2021), and its return to the atmosphere delayed. Whilst increasing the longevity of wood buildings is the most effective way to extend carbon storage in wooden building products, their reuse and recycling in a material cascade can also be a valuable way to extend carbon storage. Although cascading wood materials from the renovation and demolition of buildings also results in an increase in stored carbon, CircWood demonstrated that, as a strategy, it is not as effective as extending building lifetimes.

[1] Cascading is the sequential use of wood products in material form, prior to burning for energy.

To maximize the potential of wood construction in climate change mitigation we therefore need to *simultaneously increase the level of wood construction as well as promote activities that prolong the lifetimes of building and enhance the cascade use of wood materials*. How do we do this?

Information about the lifespan and fate of wooden buildings in Finland and the factors that affect this is lacking. Without this kind of information, it is difficult to i) devise means to prolong building lifetimes and ii) predict when demolitions and renovations will take place, thereby making the development of effective strategies for waste wood cascading and solutions for increasing the durability and longevity of wood buildings challenging. Huuhka and Lahdensivu (2016), who conducted a study of demolished buildings in Finland, acknowledged that research in this area is sparse. Although their study was for all building types, and not specifically for wood, it is plausible that the situation would be similar for wooden constructions.

Objectives

The main objectives of our project were thus, along with utilising the relevant topical research on the topic, to conduct semi-structured interviews with experts from the entire forest-wood value chain to collect comprehensive information about the technical, economic, and societal factors that affect the lifecycle and lifetime of wooden buildings and to identify key factors that might affect these. To complement this information, we conducted survival analysis of wooden buildings, based on statistical sources. This analysis, as well as knowledge about the underlying factors affecting demolitions and renovations, would then enable us to propose measures that would *extend the lifespan* of wood buildings, make the prediction of secondary wood resources arising more accurate and reliable, and provide educational material for students and practitioners alike. The main output of ProWoodBuild is to be a 'handbook' that will be published in physical form as well as in digital format.

The approach adopted in ProWoodBuild was to collect the information simultaneously through both qualitative sources e.g., expert interviews and prior research, and quantitative sources in the form of statistical analysis. The semi-structured interviews aimed to gather 'silent knowledge' of practitioners about the factors that affect building lifetimes and durability. We were especially interested in both the technical reasons for renovation and demolition activities (e.g., faults arising from moisture damage, due to design errors, or poor building practices) as well as non-technical, economic, and societal factors. Our aim was to understand how to facilitate, build and maintain long-lasting wood building and to determine what properties/factors are common in durable wooden buildings. We were also interested in knowing what mistakes are commonly seen in wooden buildings that result in the need for major renovations or that make renovation impracticable. Additionally, we aimed to retrieve and analyse statistical data about the lifetimes of wooden buildings and use this to conduct a *survival analysis* so that we could accurately predict building lifespans in future modelling.

As noted by Huuhka and Lahdensivu (2016), rather little is known about why buildings are demolished, so for this purpose we studied the reasons for renovation and demolition, using a combination of knowledge from interviews, statistical data sources and prior research. With this knowledge, our goal was to highlight how such errors occur and how they can be avoided. As a biogenic building material, wood has some unique properties that require careful consideration in the design, construction and use phases of the building lifecycle. Thus, wood buildings require specific knowledge: mistakes are commonplace whilst renovating buildings, and this can lead to a reduction in lifespan and might even make renovation impossible. Our objective was to gather this information from a diverse array of sources and communicate it in a clear and collected way, that will support building, use, and renovation decisions, as well as decisions made about the demolition and re-use phases of wooden buildings.

We intended to not only to catalogue the reasons for renovation and demolition activities, but also to use this information to create a handbook of '*what not to do'* for practitioners and users as well as highlighting good practices. It is expected that such a resource would be of great interest and relevance to practitioners (architects, building contractors, developers etc.) as well as students of architecture and building technology. Such a resource would be valuable in helping promote effective wood construction by highlighting the risks associated with wood buildings, but also by highlighting actions that could be taken to avoid problems in the first place. Moreover, with this information, the effective cascading of wood building products could be promoted through identifying existing buildings/building parts that are suitable for reuse and recycling.

3. Project partners and methodology

3.1 Parties involved

ProWoodBuild was led by Professor Mark Hughes, head of the Wood Materials Technology group at the Department of Bioproducts and Biosystems at Aalto University and the project was prepared and carried out in collaboration with Studio Kantele, represented by Architect and Designer Saara Kantele.

Over the course of the project, the personnel working on it were, from Aalto University, Professor Mark Hughes, doctoral student Bahareh Nasiri, staff scientist Kaarlo Nieminen, master's student Mikaela Kumlin, bachelor student Tinja Aromaa, bachelor student Michael Ostapenko and project worker Paul Bot. Mark Hughes assumed overall responsibility for the conduct of the project, working in close collaboration with Saara Kantele. He was involved in most of the interviews conducted as part of work package 2 (see below) and in work package 3 as a co-author. Hughes has devoted several months of his time directly to working as a researcher on the project in addition to his coordination role. Bahareh Nasiri is a doctoral student under the supervision of Hughes and is working on (wood) materials stock and flow analyses, and wood quality issues. For the final part of her doctoral degree (to be completed in 2025), Bahareh has developed a stock and flow model that will form the basis of a tool to predict the future availability of recovered wood from the building stock. Her model requires the accurate prediction of building lifetimes, so she has been mainly involved in the analytical work on building survival being carried out as part of work package 1 and she is the thesis supervisor of Mikaela Kumlin. To support the work in work package 1, Kaarlo Nieminen has also been involved. Kaarlo is a mathematician who has, for many years, been involved in different kinds of modelling work. He has given technical support and advice to Mikaela as well as more generally to the project.

Mikaela Kumlin is a master's student on the Creative Sustainability program. Her thesis involves analysing data obtained from Digi- ja väestötietovirasto (DVV) and Tilastokeskus, to determine the most appropriate mathematical functions to describe building survival. Tinja Aromaa is a student at the School of Chemical Engineering, who contributed to the project by gathering prior research for her bachelor thesis "Puurakennusten elinkaareen vaikuttavat tekniset tekijät Suomessa". Mark Hughes and Saara Kantele were her thesis advisors. Bachelor student Michael Ostapenko, also from the School of Chemical Engineering, worked as a part-time research assistant on the project for several months, under the direct supervision of Mark Hughes, carrying out an extensive literature survey of the factors affecting the demolition of buildings. Paul Bot was a project worker and is currently a student at Aalto University. In work package 2, the interviews carried out with experts were recorded and transcribed. Due to the large number of interviewees (>25) and the, often, lengthy interviews (>1 hour), transcription was very time consuming. Paul used his coding skills to speed up the automatic transcription process before the transcripts were read and checked by the project researchers. Paul was engaged on a part-time basis to speed up the transcription process. This was deemed vital as we wished to use both manual and AI-based approaches to analyse the transcripts. The intention is to use the results of the analysed interviews as the basis of a scientific article that is to be prepared (already in progress) and it is hoped will form the first article in Saara Kantele's doctoral thesis. Saara Kantele was engaged in the project during the preparation phase and subsequently as the main researcher responsible conducting interviews with the experts, overseeing the transcriptions and analysing their content. Moreover, Saara, in conjunction with Mark Hughes, is responsible for the future 'handbook' publication.

The project relied on a mixed methods approach to conduct the research. This included a quantitative component – the statistical data analysis in work package 1 – and a qualitative component, being the semi-structured interviews carried out in work package 2.

3.2 Methodology

ProWoodBuild was executed as a series of three interlinked work packages, each complementing one another. The work packages are described below:

Work package 1 comprised a statistical analysis of demolition and renovation data. Data was purchased from DVV and Tilastokeskus and has been analysed to understand historical trends in constructions, demolitions, and renovations for selected building types (residential buildings). The empirical data were compared with mathematical functions (e.g., normal distribution) that are frequently used in input-output stock and flow models. In this way, our aim was to assess not only the appropriateness of certain functions, but also to see how these might vary geographically (e.g., city vs rural milieu). Overall, we expect to be able to accurately predict the survival of certain building types and from this will be able to develop strategies to extend building lifetimes and predicts the flows of secondary materials.

Work package 2 analysed the underlying factors affecting building longevity and the reasons for demolition. This was carried out reviewing the relevant literature, and by interviewing experts and practitioners involved in the forest-wood construction value chain (forest specialists, architects, building contractors, legislation specialists, building economists and other relevant experts) to determine the underling factors affecting demolition and renovation activities both technical (e.g., the products failures, structural failure, poor indoor air quality, mould, decay) and non-technical (building obsolescence, attitudes, perceived risks) and link these to different life cycle stages. This data was to be combined with the analysis conducted in work package 1 to provide a comprehensive understanding of the factors affecting the longevity and demolition of wooden buildings.

Work package 3 includes publication, education, and recommendations. Using the information gathered in the preceding work packages, we will produce a handbook of best practices concerning wood building. This book will be published in both electronic and physical formats (following completion of the project). The information will be taken into the educational programs at Aalto University, directed at students of architecture, civil engineering, and wood materials technology, through the Aalto Wood cooperation program.

4. Results of the project

4.1 Achievement of project objectives and planned results

The objectives of ProWoodBuild, detailed in the project plan (see Appendix 1), were principally twofold. The first was to gain a holistic understanding of factors affecting the lifespan of wooden buildings and for their demolition, with the aim being to identify factors that could, ultimately, be leveraged to extend building lifetimes and, where possible, delay or eliminate demolitions. The second objective was to communicate these findings as widely as possible and to as large an audience as possible, in the hope and expectation of changing practices and mindsets.

The first objective constituted the main effort during the project period and consisted of both quantitative and qualitative components. Work package 1 comprised the quantitative component, with the idea being to understand current (wooden) building lifetimes, and particularly the distribution of lifetimes, from available statistics. The motivation for doing this was twofold: firstly, without understanding clearly what current building lifetimes are, it is impossible to assess whether any proposed actions might be successful in lengthening building lifetimes! Secondly, to predict the flow of wood exiting the building stock, it is necessary to know the expected lifetimes of buildings, and from this the flow of biogenic carbon into and out of the building stock. This is important if we are to model the effects of extending building lifetimes on climate change mitigation efforts. Current modelling approaches use various mathematical functions to predict building survival and it is known that the type of function chosen affects material flows, whilst the function chosen is also dependent upon location (Miatto et al. 2017). Thus, the quantitative analysis was also designed to assess which functions are most appropriate in a Finnish context, and possibly to propose others. Work package 2 comprised the qualitative component. The aim of this research was to gain deep insight into the factors affecting the lifetime of wooden buildings and the reasons for their demolition. Recognizing that the wood building value chain begins in the forest and involves a very large number of stakeholders, we adopted a holistic approach, as depicted in Fig. 1, and interviewed experts and practitioners representing various phases of a building's lifetime as well as the overall societal and environmental context which affects the longevity of wooden buildings.

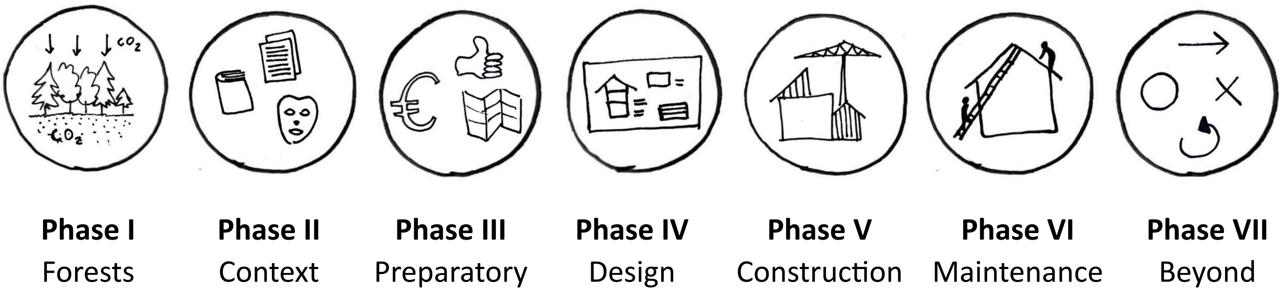


Fig. 1 Representation of the various phases in a wood building life

The second objective constituted engagement. Based on the findings from the first two work-packages, we will produce a book that will be finalized after the project period ends and will be jointly authored by Saara Kantele and Mark Hughes. The purpose of this book will be to communicate the findings of the project in a way that is accessible to a wide variety of practitioners and students. It will be written in Finnish and English and will be available in both electronic and hard copy formats. In addition to this book, there are other forms of engagement, including two peer-reviewed articles, one planned and the other in preparation at the time of writing, a master's thesis (ready in early 2024), conference and seminar presentations, exhibitions, and videos (see §6 for further details).

Concerning the first objective (work packages 1 and 2), statistical data was obtained from DVV, along with access to building production statistics produced by Tilastokeskus. The data from DVV included all residential buildings in Uusimaa. The data identifies building type (blocks of flats, detached houses etc.) and building construction material (e.g., concrete, wood), and includes data on buildings that currently exist and those that have been demolished. Analysis so far has established that there is a clear distribution of the age of buildings at demolition. The average age at demolition is around 50 years, which is in accordance with the findings of Huuhka and Lahdensivu (2016). Gaps in the data and differences in the way in which data has been collected and presented have provided some challenges. At the time of writing, further analysis work continues and will be reported in the master's thesis of Mikaela Kumlin in spring 2024. The results will also form the basis of a peer-reviewed scientific article, which will be submitted in late 2024.

A total of 28 semi-structured interviews were conducted during the project period. The majority were interviews with individuals, though in some instances groups of 2 or more individuals were interviewed. In total more than 30 individuals expressed their views and provided insights and recommendations to the project. The experts and practitioners represented the value chain from forest to buildings and beyond and they included experts in forests, the forest industry, architecture, wood construction, real estate management and economics, indoor air quality, as well as policy and regulation. The interviewees represented the different phases in a building life as outlined in Fig. 1. The group interviewed embodied a far broader spectrum of experts than originally envisaged in the project preparation phase. This resulted from the 'snowballing' effect of the early interviews and the recognition that a far greater number of factors and actors were involved in determining the longevity of wooden buildings and the reasons for their demolition. The main findings have been presented at the PLATE 2023 conference (see §6 and Appendix 2) and are summarised below. Further, more detailed analysis, is ongoing and will be reported in a peer-reviewed scientific article, currently under preparation.

1. In the **forest** phase, the following key findings arose from the interviews:

   - Forests and the resilience of the planet are strongly interlinked: biodiversity, climate stability and the carbon stored in the forest soil are all part of this system.
   - The multiple values and roles of forests need to be acknowledged and forestry decisions made in respect of these with a long-term broader benefit in mind.
   - The material taken from the forests should be used as efficiently and as holistically as possible for high-value, long-lifespan applications that allow for the materials to be cascaded into new high value applications following the first use.
   - Using wood to build is sensible, but the main emphasis should be on prolonging the life of the existing building stock and in designing new buildings for permanence and maintenance, or, ensuring that the materials can be recovered and reused with ease, in effect considering the material to be permanent, even if the building is not.
   - Slower growth and longer cycles produce better wood for wood construction and other high-value long-lifespan artefacts that can be subsequently cascaded.

2. The main findings concerning the **context** were:

   - Legislation and policy guidance have a significant impact on the longevity of buildings.
   - Both EU and national targets support the longevity of buildings and the ecological transition of the building sector. For example, the EU Circular Economy Strategies and Finland's new Building Act 2023 already address these issues. However, stronger guidance is needed.
   - In addition, cultural aspects, attitudes, and habitual practices influence longevity. These also act as a brake on change in construction patterns.

3. In the **preparatory** phase, the main findings were:

   - Urban design and urban structure influence longevity through the need for buildings. It is also important that the plan allows for flexibility and adaptability of building spaces and functions to changing needs.
   - From a building economics and financial point of view, factors that influence longevity or demolition are the need for the building, the possibility of higher profits and perceived risks. These factors influence regardless of the building material.
   - Wood construction is still perceived to be more expensive, although it appears to have a small premium in sales value due to demand. Insurance premiums do not have a significant impact in Finland.

- The market share of renovation is increasing whereas the share of new construction is declining. In the future, the main focus will be on maintaining the existing building stock.

4. In the **design** phase, the main findings were:

- Design intent, objectives and design solutions affect the longevity and resilience of buildings in a changing climate.
- In permanent construction, particular attention should be paid to the ease of maintenance and repair. Unexpected damage should be anticipated and considered in the design, as it will inevitably occur at some point during a long lifetime.
- Users should understand the structures and be able to notice any changes in them, for example by means of simplicity and accessibility.
- Known risk structures should be avoided, moisture management and air circulation in a wooden building should be ensured, and the building should be prepared in advance for changing weather conditions due to climate change.

5. In the **construction** phase, the following key points arose:

- Construction mindset, quality and materials influence the longevity of buildings.
- High-quality construction work that understands timber and the selection of construction and insulation materials suitable for the building in question contribute to the longevity of a timber building.
- Special attention must be paid to weather protection in timber construction.
- Building regulations are possibly hindering timber construction.
- A wide range of examples of durable and resilient timber construction are needed.

6. **Maintenance**:

- As the building stock grows and its nature becomes more permanent, the role of maintenance and repair will increase.
- All buildings need maintenance, and the main focus should be on continuous, light, preventive maintenance.
- Over-repairing and the use of building materials that are unsuitable for a wooden structure could cause problems and should be avoided.
- The importance of expertise and understanding of timber structures is emphasised in renovation, to ensure that the longevity of the structure is not compromised.
- There is a shortage of skilled experts in timber structures and their repair.
- Parts of the existing building stock are difficult to maintain and often require major renovation.
- Energy renovations are perceived as a potential risk to older timber buildings if they change the moisture balance or air circulation of the structure or affect demolition decisions.

7. The final phase – **beyond** – consider factors beyond the 'typical' life span of a building. The key finding here were:
   - When does the life cycle of a building end? Does it, in fact end at all?
   - Appreciation of existing buildings and their materials, historical layers and timeframe are important.
   - Sometimes the user also must adapt to the characteristics of an old building.

4.2 Deviations from plans

There were no deviations from the plans and, overall, the project proceeded as planned and all the intended objectives have been (or will be) achieved. Work package 1 proceeded slightly slower than planned due to the wish to gather a greater background to the topic through literature survey and interviews, before beginning the work, and due to the time taken to acquire the data. Whilst the work carried out for this work package came later in the project than anticipated, it has not materially affected the project outcomes. Work package 2 became more extensive than originally planned due to a 'snowballing' effect and due to the interests of the project researchers. We ended up interviewing a more extensive range of experts and practitioners, bringing more insights to the project. In work package 3, as detailed in §6, a good deal of communication has already been done. As originally planned, the 'handbook' will be finalized and published after the end of the project, and it is expected that it will be completed in the second half of 2024. A scientific article manuscript based on the results of work package 2 is in preparation and will be submitted in the first half of 2024. A scientific article manuscript based on the statistical analysis in work package 1 will be submitted in the second half of 2024. These actions are as envisaged and planned.

4.3 Causes of deviations

As mentioned earlier, once the project started and interviews with the experts began, it became clear that the potential scope of the project was far greater than initially thought and planned for. It is partly for this reason that the request to extend the duration of the project was made, to enable the project to explore new avenues and broaden the scope. It is believed that this greatly enhanced the project outcomes as it enabled us to interview a greater variety and number of experts and practitioners.

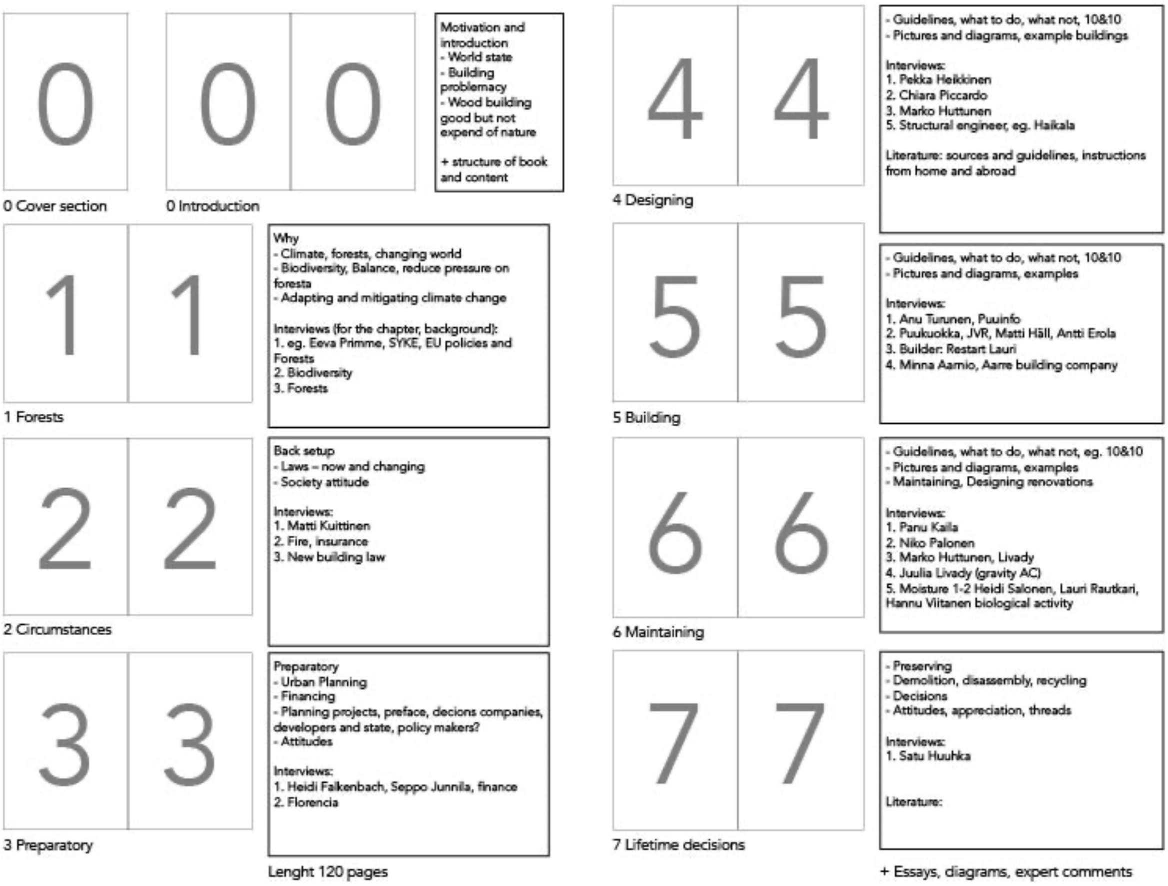
5. Project impact

5.1 Positive and negative impact of the project

The principal impact from the project will come though the increased understanding of factors that affect the longevity and lifespan of wooden buildings. The carbon and other benefits of wood construction are reasonably well understood, though these can be enhanced by prolonging the lifespan of wooden buildings and by cascading the materials contained in them. Importantly, these actions are necessary to reduce the pressure on forests and maintain and enhance biodiversity. It is expected that the main impact will come following completion of the project through the publishing of a book (see below) in 2024, though it is also expected that the various engagement activities that have already taken place will have had a positive impact. The planned scientific articles will help underpin the basic research relating to the lifespans of wooden building and the reasons for their demolition.

Book (to be published 2024)

- *Target group: public audience, professionals, and non-professionals. The book aims to reach larger audience and communicate the study results in an easily accessible means.*
- *Preliminary cover and content plan for the book are shown below:*



5.2 Other impacts

The project has helped to develop the core expertise about wood construction in the Wood Materials Technology group at Aalto University. It has also helped strengthen the career of Saara Kantele and, it is hoped, to launch her career as a doctoral student. The project will help the advancement of doctoral student Bahareh Nasiri and master's student Mikaela Kumlin, as well as adding a new dimension to the career of Kaarlo Nieminen.

6. Implementation and results of communication

6.1 Communication channels

ProWoodBuild has already been widely communicated. Multiple and diverse channels have been used to communicate the project to different target groups and to engage with various audiences. Audiences have been both national and international and have comprised groups ranging from academic audiences to wider public audiences and alternative professional groups.

The results will continue to be communicated through the preparation and publication of the abovementioned scientific articles and the publication of the handbook. Hughes and Kantele envision a Vlog series and a future exhibition exploring the notion of longevity at the Designs for a Cooler Planet exhibition.

6.2 Communication activities

A brief description of the main communication activities is given below.

6.2.1 Plate 2023 conference 31.5-2.6.2023

https://www.plateconference.org/plate-2021-conference-3/

- *Target group: academic community*

The ProWoodBuild -project took part in the PLATE 2023, an international conference focusing on product lifetimes and the environment. In the conference Saara Kantele presented the principles and findings of the ProWoodBuild project and engaged with the academic community. As part of the conference a long paper with the title "*Thoughtful: towards the longevity of wooden buildings for climate change mitigation and adaptation*" was written by Saara Kantele and Mark Hughes, and later published as part of the conference proceedings book: "PROCEEDINGS 5th PLATE Conference" (available at https://aaltodoc.aalto.fi/handle/123456789/122687).

A! Aalto University School of Arts, Design and Architecture

PLATE Product Lifetimes And The Environment

5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

Thoughtful: Towards the longevity of wooden buildings for climate change mitigation and adaptation - Plate Conference Proceedings Template 2023

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Keywords: Forests; Wood construction; Building life cycle; Demolition; Building obsolescence.

Abstract: The building sector is no longer functional; if we wish to maintain a livable planet a major shift in mindset and practice is urgently needed. Wood construction has been identified as an important way to decarbonise the built environment. However, sourcing wood *must* consider *all* the values of the forests; so to avoid overharvesting, biodiversity loss and other damage to ecosystem services, we should use wood thoughtfully. New wood buildings should be designed for adaptation and disassembly and built to last, and the lives of old ones should be extended. Currently, little is known about the factors affecting the lifetime of wooden buildings and holistic comprehension is

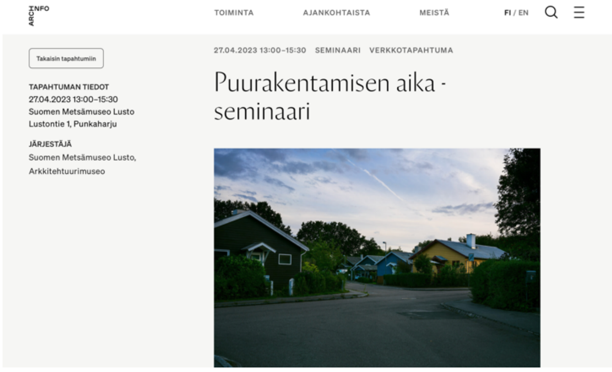
The plate-conference paper (Appendix 2)

6.2.2 Puurakentamisen aika -seminaari 27.4.2023

https://www.archinfo.fi/tapahtumat/puurakentamisen-aika-seminaari

- *Target group: wider public audience and alternative professional group related to wood material and forests*

The ProWoodBuild project's themes and findings were presented at Puurakentamisen aika -seminar in Punkaharju in April 2023, when Saara Kantele gave a presentation to the public audience and professionals interested in building, wood, and forests at the Finland's forest museum Lusto.

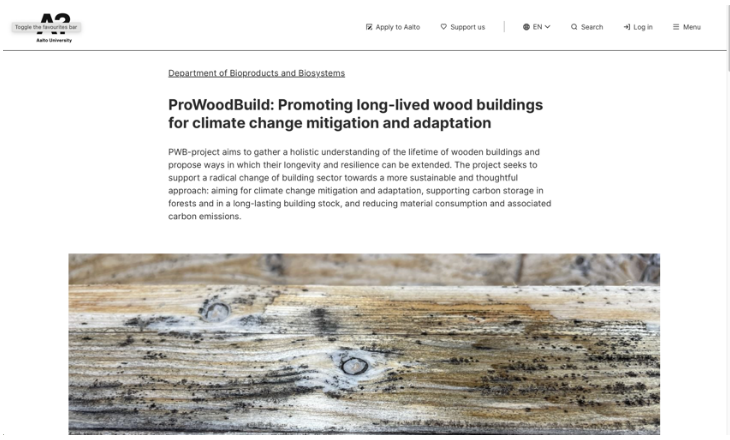


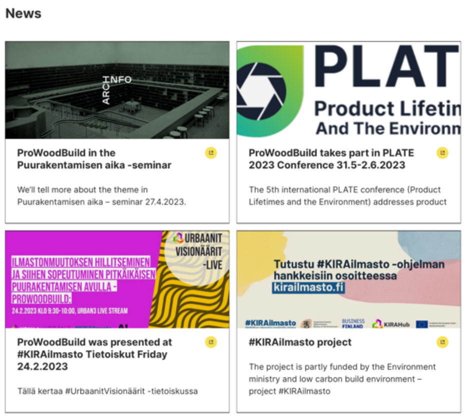
6.2.3. Website

www.aalto.fi/en/longevityofwoodenbuildings

- *Target group: wider public audience*

The project website was initialised to communicate the project's goals and findings to wider public audience. The project's news and events were shared in the News-section of the website. The website continues to be active also after the project.



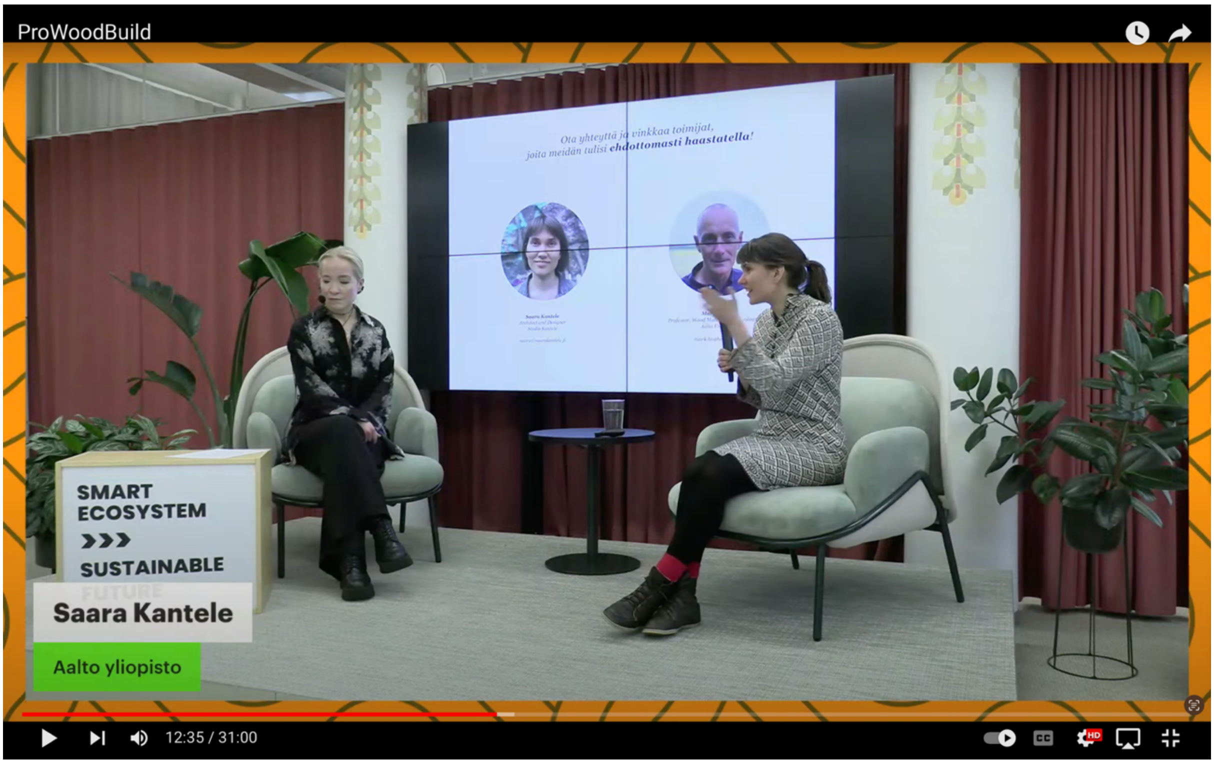


6.2.4. KIRAHub morning talk 23.2.2023

https://www.youtube.com/watch?v=mC2eyTI6o1Y

- *Target group: professionals*

The ProWoodBuild-project was taking part in KIRAhub morning talks to communicate the project findings, to arouse conversation on the longevity and resilience of buildings, and to engage the professionals of the built environment.



6.2.5. Designs for the Cooler Planet, Helsinki design week 2022 7.9.-12.10. 2022

https://www.aalto.fi/en/events/re-valuing-wood-another-look-at-wood-and-the-forest

- *Target group: public audience and non-professionals*

Connected to the ProWoodBuild -project and thematically adjacent Nordic Waste Wood for Good -project a Designs for a Cooler Planet exhibition "*Re-valuing wood – another look at wood and the forest*" took place as a part of Helsinki Design Week 2022 program.

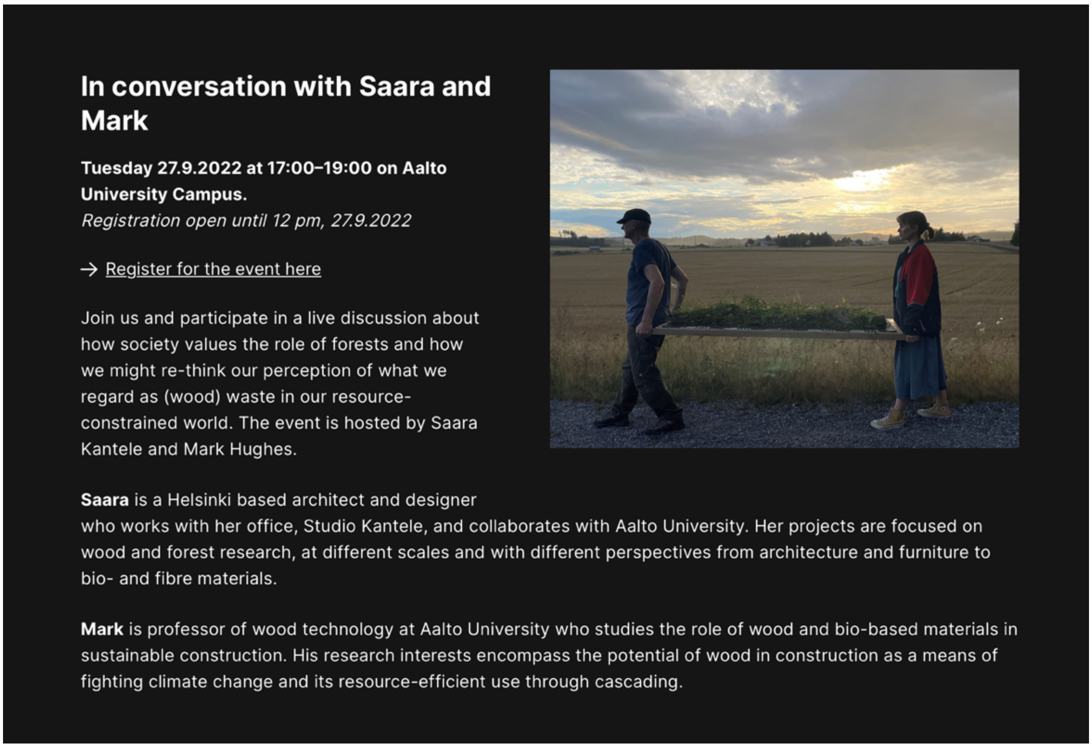
The exhibition tackled the circularity of wood materials and highlighted its value and potential thorough all the cascading phases. A student work from course held by the project team, reuse of recycled construction waste, was also showcased. As part of the exhibition introduction, presentations of the theme were held by Mark Hughes and Saara Kantele, considering the perspective of forests and the thoughtful use of wood material for building, and the audience was engaged to conversations. To deepen the conversation, a small-group conversation was organised.

“We need to ensure long-term forest sustainability and one good way to do this is to reduce the demand for primary wood by being as resource efficient as possible through re-use and cascading of wood products.” – The exhibition website

Photos: Top left - Anne Kinnunen, Top right - Saara Kantele, Lower left - Saara Kantele, Lower right - Hector Grønborg and Saara Kantele

The perspective of forests and the thoughtful use of wood material for building was presented during the exhibition

Photo: Mikko Raskinen



A small-group conversation was organised to deeper discuss the themes

6.2.6. New European Bauhaus goes Into the Woods 24.11.2022

The launch of the Nordic New European Bauhaus was attended by Mark Hughes who participated in the panel discussion “Architecture inspired by nature”. https://www.nordicbauhaus.eu/into-the-woods#/page=1.

Discussion about the longevity of building and the reuse and recycling of materials contained in them.

6.3 Success of the communication

The communication was based on the original communication plan made at the start of the project, although new content was added. All-in-all, the communication seems to be successful: the themes and results of the project were successfully distributed to wide and diverse audience, and conversation was aroused. The communication work of the results should be further continued to keep up, to increase the impact.

7. Sustainability and exploitation of results

The project highlighted that the current paradigm in the building sector is flawed. Nearly all persons canvassed during the course of the project believed that the way in which we currently build should change. We should build to last and avoid demolitions where possible - we should regard the materials contained in buildings as ‘practically permanent’. In this way we not only maximise the carbon storage potential of wood, but we also reduce the need to extract primary resources so helping preserve, or even enhance, other ecosystem services. In the face of a changing climate, buildings need to be adaptable and maintainable to extend their lifespans, requiring new approaches.

To support these changes, we need to assess sustainability and the tangibility of the results and associated factors (political support, institutional/legislative support, economic and financial opportunities, technological feasibility, stakeholder interest and commitment). To effect change proposals should be made to exploit the results of the project, including business and regulatory aspects, whilst official guidelines addressing the longevity of wood buildings could be produced and introduced to industry and private users. Additionally, the results should be utilised in follow-up studies and projects (see §9).

8. Financial report

Please see separate financial report.

Most of the original planned budget was related to the hire of personnel to carry out the project. This is included a budget of € 25 000 for Saara Kantele, who led work package 2 and is responsible along with Mark Hughes for the communication activities of work package 3. The remaining personnel budget was used, as planned, for the hire of a master's student in connection with work package 1, and for the time of Bahareh Nasiri and Kaarlo Nieminen who have both also worked mainly in connection with work package 1. The salary costs of Michael Ostapenko and Paul Bot are also included in the Aalto cost. Due to some small underspend, the project budget was slightly amended and agreed. The revised budget is as shown:

Cost category	'Old' (EUR)	'New' (EUR)
Personnel costs	120564	127564
Costs of instruments and equipment	10000	8500
Procurement of specialist services	25000	25000
General costs	2500	2000
Other costs	8000	3000
Eligible costs in total	166064	166064

9. Recommendations for future projects and programmes

Within the limited timespan of this study, the topic of the longevity of wooden buildings and the factors contributing this were studied in a holistic manner thorough the whole forest-wood value chain. Research into the theme of building longevity is vitally important and should be further investigated, diving much deeper into each focus phase of the wood building process to understand how the lifespan and utility of wooden buildings can be extended to promote long-term carbon storage and enhance resource efficiency. The results of these studies should be further communicated to decision makers.

When perfectly serviceable buildings are unoccupied, the paradigm of demolishing buildings and constructing new ones is, quite rightly, being questioned. The reasons for demolition in Finland should be further investigated to obtain more information on how to influence this and keep well-maintained buildings in use for longer.
To better quantify the theoretical aspects explored ProWoodBuild, this project should be followed-up by a practical phase, in which the results and guidelines for renovating and building long-lasting wooden houses could be further studied in real-life on tangible pilot projects involving real buildings.

10. Summary of the main results of the project

EN

Throughout the wood-building value chain it seems crucial to change the mindset and alter the emphasis of the wood building process. Currently, ‘temporary’, albeit a few decades, wooden buildings or the materials contained in them could be seen as ‘practically permanent’. We should plan and understand the life span of the buildings accordingly. Our findings suggest that factors relevant to the longevity of wooden buildings can be broadly divided into two categories; firstly, those factors that are relevant before the building process begins and factors that come into play after the start of the building process.

In the former category, it is important to understanding the role of **the forests** and the origin of the material. Finland has a growing domestic market for wood building and so the emphasis on wood production should be shifted towards quality rather than quantity. By harvesting less and creating more value from what we take from the forests, we could generate new employment in the more labour-intensive wood building products sector. This has economic potential and may favourably influence the future know-how of Finland. All this contributes to the resilience of the forests and the planetary system**. The context**, with societal, cultural, and legislative aspects has an impact. Legislation and policy guidelines appear to have a significant impact on the longevity of buildings. Additionally, attitudes and cultural aspects, like habits and customs, seem to have an influence. Existing habits and practices seem to hinder changes to building practices. The influence of building decisions: in the building **preparatory** phase, urban planning and building economics are the two main factors investigated, it seems that a clear economic plan to transition to a carbon neutral society is needed. It seems that urban planning as well as the city structure and density can affect obsolescence and the flexibility of the building stock, which can affect the demolition decision. Key building economic issues affecting longevity include redundancy – the need for the building, the profit motive, spatial obsolescence, and perceived risks.

After the building process starts, factors include the **design, construction, maintenance** and **beyond** phases. In general, it seems that we need to start to design and build for permanence or ‘thoughtful temporality’. We should emphasise design and building for resilience, adaptability, and a changing climate, preparing for unexpected situations, extreme conditions, and increased moisture, or heat related issues. According to a number of interviewees, more specialised professionals, greater knowledge and expertise, as well as more examples of resilient wooden buildings are needed.

FI

Koko puurakentamisen arvoketjussa näyttää olevan ratkaisevaa muuttaa ajattelutapaa ja puurakentamisen painopistettä. Nykyisin "väliaikaiset", vaikkakin muutaman vuosikymmenen kestävät puurakennukset tai niissä käytetyt materiaalit voitaisiin nähdä käytännössä pysyvinä. Rakennusten elinkaari olisi suunniteltava ja ymmärrettävä sen mukaisesti. Tulosten mukaan puurakennusten pitkäikäisyyteen vaikuttavat tekijät voidaan jakaa karkeasti kahteen luokkaan: ennen rakennusprosessin aloittamista vaikuttaviin tekijöihin ja rakennusprosessin aloittamisen jälkeen vaikuttaviin tekijöihin. Ensimmäiset näistä tekijäistä alkavat metsien roolin ja materiaalin alkuperän ymmärtämisestä. Suomessa on kasvavat puurakentamisen kotimarkkinat, joten puuntuotannon painopistettä tulisi siirtää määrän sijasta laatuun. Jos hakkuita tehtäisiin vähemmän ja metsästä otetusta materiaalista tuotettaisiin enemmän arvoa, voitaisiin luoda uusia työpaikkoja työvoimavaltaisemmalle puurakennustuotesektorille. Tässä on taloudellista potentiaalia ja se voisi vaikuttaa suotuisasti Suomen tulevaan osaamiseen. Tämä olisi tapa edistää metsien ja planeettamme kestokykyä eli resilienssiä. Yhteiskunnalliseen kontekstiin vaikuttavat mm. kulttuuriset ja lainsäädännölliset näkökulmat. Lainsäädännöllä ja poliittisilla linjauksilla näyttää olevan merkittävä vaikutus rakennusten pitkäikäisyyteen. Lisäksi asenteilla ja kulttuurisilla näkökohdilla, kuten tavoilla ja tottumuksilla, näyttää olevan vaikutusta. Nykyiset tavat ja käytännöt näyttävät estävän rakennuskäytäntöjen muuttamista. Valmistelu – rakennuspäätösten vaikutus: Kaupunkisuunnittelu ja rakennusekonomia ovat kaksi tärkeintä tutkittua tekijää. Nämä viittaavat siihen, että tarvitaan selkeä taloussuunnitelma hiilineutraaliin yhteiskuntaan siirtymiseksi. Vaikuttaa siltä, että kaupunkisuunnittelulla sekä kaupunkirakenteella ja -tiheydellä on rooli rakennuskannan tarpeettomaksi tulemiseen ja muuntojoustavuuteen, joilla on vaikutusta purkamispäätöksiin. Keskeisiä pitkäikäisyyteen vaikuttavia rakennustaloudellisia kysymyksiä ovat muun muassa rakennuksen tarpeellisuus, voitontavoittelu, alueellinen tarpeellisuus ja koetut riskit. Rakentamisprosessin aikaisiin tekijöihin kuuluvat suunnittelu, rakentaminen, ylläpito ja ”jälkeen” vaihe. Yleisesti ottaen näyttää siltä, että meidän on alettava suunnitella ja rakentaa pysyvyyttä tai "harkittua väliaikaisuutta" varten. Meidän tulisi korostaa rakenteiden ja toimintojen joustavuutta, relissiensä ongelmatilanteita ja muuttuvaa ilmastoa varten, sekä varautua odottamattomiin tilanteisiin, ääriolosuhteisiin ja lisääntyneeseen kosteuteen tai lämpöön liittyviin ongelmiin. Useiden haastateltavien mukaan tarvitaan enemmän erikoistuneita ammattilaisia, enemmän tietoa ja asiantuntemusta sekä enemmän esimerkkejä joustavista puurakennuksista.

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APPENDIX 1

ProWoodBuild: Promoting long-lived wood buildings for climate change mitigation and adaptation

Background and motivation: It is widely accepted that increasing wood construction can help mitigate climate change and it has been postulated that the widespread adoption of engineered wood in mid-rise, multi-story buildings, could even turn the sector into a carbon sink[2]. In the SMARTA Wood project, we have shown that in Finland by constructing multi-story buildings from wood instead of concrete, an average of approximately 160 $kgCO_2\ m^{-2}$ emissions could be avoided and a further 100 $kgCO_2\ m^{-2}$ could be stored in wooden buildings. We have estimated around 60 ktons CO_2 emissions could be saved annually in Helsinki alone, if 50% of the predicted new residential floor area was to be constructed of wood[3]. This represents a saving of around 25% of current construction emissions. Increasing the total amount of wood in construction can thus have a positive climate change mitigation impact, making it important to rapidly increase wood building. Simultaneously, we should adopt other actions to enhance the climate benefits. These actions include increasing the durability and lifespan of wood buildings and emphasizing sustainable forestry in material sourcing, as well as promoting cascading[4] which has been shown to increase resource efficiency[5] and lower the environmental impact of construction[6]. Increasing durability will become ever more important as we need to adapt our buildings to a changing climate.

Wood construction and climate change mitigation: Carbon is stored in wood products until it is oxidized, by burning or by biological degradation. Since wood building products can store (atmospheric) carbon for decades or more, there should be strong incentive to maintain these products in service for as long as possible. This also reduces the need to harvest primary resources (trees), helping to promote carbon sequestration in forests and the maintenance of other ecosystem services. In addition, if wood products are cascaded, then additional substitution benefits can be realized[7]. In the CircWood project, we showed that by extending the lifetime of wood products, the total amount of carbon stored can be increased[8], and its return to the atmosphere delayed; this would help 'buy time' to develop other low carbon technologies. Increasing the lifespan of wood buildings is the most effective way to extend carbon storage in wooden building products/construction materials, and cascading can also be another valuable way to extend carbon storage. Therefore, to maximize the potential of wood construction in climate change mitigation we should simultaneously i) increase the level of wood construction, ii) promote activities that prolong the building lifespan and iii) increase cascading.

Our approach: Currently, information about the lifespan of wooden buildings in Finland and the factors that affect this is lacking and, without this, it is difficult to i) know how to prolong building lifetimes and ii) predict when demolitions and renovations will take place, making cascading challenging. Huuhka and Lahdensivu[9] studied demolished buildings in Finland and acknowledged that research this area is sparse. We will use statistical data about the lifetimes of wooden buildings to conduct a *survival analysis*, so that we can accurately predict building lifespans. Equally important is to study the reasons for renovation and demolition since many factors are largely unknown. To do this, we will use statistics, prior research and scientific studies and will

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[2] Churkina, G. et al. Buildings as a global carbon sink. Nat Sustain 3, 269–276 (2020). doi: 10.1038/s41893-019-0462-4
[3] Alam, A. et al. Sustainability assessment of a wooden multi-story building with an equivalent reinforced concrete alternative using ToSIA: A case study in Finland. *In preparation*.
[4] Cascading is the sequential use of wood products in material form, prior to burning for energy.
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complement this with the 'silent' knowledge of practitioners about the factors that affect building lifetimes and durability. We are especially interested in the **technical** reasons for renovation and demolition activities (e.g., faults arising from moisture damage, due to design errors, or poor building practices etc.) as well as **economic** and **societal** factors. We aim to understand how to build long-lasting wood buildings and to determine what factors are common in durable wood buildings. We are also interested in knowing what the mistakes are that are commonly seen in wood buildings that result in the need for major renovations or that make renovation impracticable. With this knowledge, we aim to highlight how such errors can be avoided. As a 'natural' building material, wood requires careful consideration in the design, construction and use phases and so wood building requires specific knowledge: mistakes are commonplace when renovating buildings and this can lead to a reduction in lifespan and might even make renovation impossible. We will gather information from diverse sources and will use this to create a handbook of "*what not to do*" (and what to do instead!) for practitioners and users and to highlight good practices. This resource will help promote wood building and support wood construction, use, and renovation decisions, and decisions about demolition and the re-use phases; it will help reduce the uncertainty and risks associated with wood building. The main output of ProWoodBuild will be an easily accessible resource in the form of a handbook in both digital and physical formats that should be of great interest and relevance to architects, builders, and owners, as well as students of architecture and building technology.

Project aims: The main aim of our project is to study and analyse the durability and longevity of wooden buildings, based on statistical sources, complemented with comprehensive information about the technical, economic, and societal factors that affect durability and lifespan and identify key factors that lie behind the life cycle of wooden buildings. This analysis, as well as knowledge about the underlying factors affecting demolitions and renovations, will enable us to propose measures that will extend the lifespan of wood buildings, make the prediction of secondary wood resources arising more accurate and reliable, and provide educational materials, thus increasing capacity for durable wood construction.

Work plan: The project will be implemented as a series of three interlinked work packages (WPs):

WP 1. Statistical analysis of demolition and renovation data. In this WP we will obtain data from e.g., Digital and Population Data Services Agency (DVV) and will analyse the data to understand historical trends of demolition and / or renovations for selected building types (e.g., residential attached and detached houses). We will compare this empirical data with functions (e.g., normal distribution) that are frequently used in input-output stock and flow models[10]. In this way, we expect to be able to accurately predict the survival of certain building types and from this will be able to develop strategies to extend building lifetimes and predicts the flows of secondary materials

WP 2. Analysis of underlying factors. We will survey practitioners (architects, building contractors, building owners, demolition companies) to determine the underling factors affecting demolition and renovation activities (e.g., the product failures, design failure, poor indoor air quality, mould, decay, or other factors) and link this to different life cycle stages. This data will be combined with the analysis conducted in WP 1 to provide a comprehensive understanding of the factors affecting the survival of buildings.

WP 3. Publication, education, and recommendations. Using the information gathered in WPs 1 and 2, we will develop a handbook of best practices concerning wood building. The book will be published (following completion of the project) in both physical and electronic formats and will have light and informative visuals with reference images and infographics to efficiently transmit information from theory to practice.

Competence and project constellation: ProWoodBuild is built on over a decade of research into wood cascading and the use of wood in sustainable construction in the Wood Material Technology group, led by

[10] Miatto, A. et al. (2017). Resources, Conservation, Recycling 122, 143-154. https://doi.org/10.1016/j.resconrec.2017.01.015

Professor Mark Hughes, who is also engaged in multidisciplinary teaching, particularly about wood properties, to students of architecture and design. He has led and participated in numerous international and national research projects and has published over 100 peer-reviewed scientific articles. He will take the overall responsibility for the project and will contribute a significant amount of his own time directly to the project. Bahareh Nasiri, doctoral candidate, and an architectural engineer by training, will take part in the project, focusing on the survival analysis in WP1. Her work is focused on materials flow analysis, so the outputs from the ProWoodBuild project will be directly applicable to her own research. Bahareh's work will be supplemented by a master's thesis worker who will focus on the survival analysis. Saara Kantele is a Helsinki based architect and designer who works with her office Studio Kantele and collaborates with Aalto University. Her projects are focused on wood and forest research, at different scales and with different perspectives from architecture and furniture to bio- and fibre materials. Saara will study, observe, and document real buildings and will uncover the 'silent' knowledge of architects, builders, and building owners by conducting semi-structured interviews (WP2) and will be responsible for producing the handbook in WP3 along with Mark Hughes. Saara has practical experience of working as an architect and of producing visual graphical materials, as well as working in a research environment at Aalto University. Mark Hughes and Saara Kantele have recently collaborated in the frame of the Nordic Waste Wood for Good project.

How the project supports the aims of a Low-Carbon Built Environment: ProWoodBuild directly addresses the need to develop a 'low-carbon built environment' by promoting not just wood construction but also, importantly, the need to extend the lifespans of buildings to prevent unnecessary constructions and make the most of existing resources. Wood construction can mitigate climate change and by understanding the factors that affect durability and longevity, we can develop strategies to adapt our buildings to climate change. We will make use of 'digital solutions', to accurately predict the lifespans of building and will use this knowledge to propose ways to lengthen the lives of wood construction. The main aim of ProWoodBuild is to acquire a new 'knowledge base' and evaluation tools that support 'climate-friendly and low-carbon solutions in the built environment' which will be widely disseminated and will contribute to capacity building in the wood construction sector through 'education and training'.

Links to other projects and activities: ProWoodBuild integrates into an ongoing program of work in the Wood Materials Technology group at the Department of Bioproducts and Biosystems, Aalto University that is focusing on the sustainable use of wood in construction for climate change mitigation and adaptation as well as how circular economy principles can be adopted in connection with wood construction, to lower the environmental impact of wood construction and improve resource efficiency. In the SMARTA Wood project we have demonstrated that replacing reinforced concrete construction with wood construction can contribute meaningfully to the carbon neutrality targets of Finland. In the Forest Value ERA.net InFutUReWood project, partly financed by the Ministry of Environment, we are investigating the availability of waste wood from demolition as a source of secondary material for new constructions. It has been shown that using these secondary resources in a cascade can enhance the environmental sustainability of construction. To improve the accuracy of predictions about the flows of waste wood we need better data about the lifespans of wooden buildings, which is not in the scope of InFutUReWood but would enhance the outcomes of that project. The Ministry of Environment funded project CircWood established that extending the lifespan of wooden buildings would provide the best opportunity to build up the store of carbon in the building stock. ProWoodBuild would add to these findings, by identifying how the lifespan of wooden buildings could be extended, which is probably the most effective way of reducing the impact of building construction.

Management and budget: Mark Hughes will be responsible for implementation of the project and its coordination as well as communication with the Ministry of Environment. He will contribute 3 months of his time, mainly to WP2 and WP3. Bahareh Nasiri will lead the work in WP1 and contribute 4 months of her time and will instruct the master's thesis student, who's work will focus on analysing statistical data about the demolition of wooden buildings. The statistical work will be supported by staff scientist Kaarlo Nieminen, a mathematician. Saara Kantele's work will focus on WP2 and WP3. The budget mainly covers the costs associated with the project workers (including €25000 for Studio Kantele), however, a sum of €10000 is included to cover the cost of a data set on demolitions, €5000 to cover printing costs and €3000 to cover audit costs. In addition, €2500 is requested to cover travel in Finland. VAT remains Aalto's cost. The project duration is for 12 months, and the three WPs will run concurrently.

APPENDIX II

Aalto University School of Arts, Design and Architecture

PLATE Product Lifetimes And The Environment

5th PLATE 2023 Conference
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Thoughtful: Towards the longevity of wooden buildings for climate change mitigation and adaptation - Plate Conference Proceedings Template 2023

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Keywords: Forests; Wood construction; Building life cycle; Demolition; Building obsolescence.

Abstract: The building sector is no longer functional; if we wish to maintain a livable planet a major shift in mindset and practice is urgently needed. Wood construction has been identified as an important way to decarbonise the built environment. However, sourcing wood *must* consider *all* the values of the forests; so to avoid overharvesting, biodiversity loss and other damage to ecosystem services, we should use wood thoughtfully. New wood buildings should be designed for adaptation and disassembly and built to last, and the lives of old ones should be extended. Currently, little is known about the factors affecting the lifetime of wooden buildings and holistic comprehension is needed to support the transition towards long-lived and resilient building stock. In this paper we aim to better understand the lifespan of wooden building, the key factors affecting it, and propose means to extend the building lives; this can also support and promote new, durable, wood construction. Using a combination of literature study and semi-structured interviews, we explore factors affecting the longevity of wooden buildings and the reasons for major renovation or demolition. We adopt a process approach that takes the different events in the life cycle of a wooden building as the primary units of analysis and map the underlying reasons affecting building longevity within these units. Preliminary results suggest that the lifespan and sustainability of wooden buildings is a multi-layered complex matter that is already affected long before the actual building process starts, with forestry choices, planning, cultural aspects, investment, and legislation having an impact; and after the start of the building process by design, craftmanship and material choices, local attitudes, the understanding and knowledge of wood buildings and their aesthetics, as well as geopolitical trends, maintenance and renovation.

Introduction

Accounting for over a third of final energy use and nearly 40% of global CO_2 emissions (UN Environment Programme, 2020), the building sector is also responsible for around half of the 100 billion tons of raw materials extracted annually by humankind (Circle Economy, 2020; European Commission, 2004). Moreover, construction and demolition waste accounts for almost half of the total annual wastes in the EU (Eurostat, 2018). With an increasing urban global population needing good-quality dwellings, the demand for buildings is unlikely to diminish; yet if we continue to construct in the way that we do, 35–60% of the remaining carbon budget will be consumed by 2050, even if we are to limit climate heating to 2 ºC (Müller et al., 2013). Clearly, the building sector is no longer functional if we are to keep the planet liveable, and a major shift in both mindset and practices is needed. Change is at hand, so we need to ensure that this transition does not create new problems, and for this we require a holistic understanding of the whole building process.

Wood construction has been proposed as a means of facilitating this transition and it has been suggested that the widespread adoption of engineered wood in multi-story buildings could make the sector a carbon sink (Churkina et al 2021). Wood-based products store carbon and substitute functionally equivalent materials (Leskinen et al., 2018). The sequestered carbon stored in wood is only released back to the atmosphere when it is burned or decays, so long-lived wood building products are effective carbon stores.

Why not simply increase the amount of wood construction? Mishra et al (2022) recognized that to increase global wood construction to the level required, the harvesting of unprotected natural forest and an increase in tree plantations would be needed. In Europe, another study concluded that should wide-scale wood construction be adopted, the net effect on the sink capacity of the forest-harvested wood products sector would be negative (Jonsson et al, 2021) and in an open letter, a group of Finnish researchers stated that increasing the harvesting and use of wood in line with the bioeconomy strategy would decrease biodiversity and accelerate climate change (Researchers' Statement, 2017). Worryingly, these predictions appear to be coming true, since the Finnish land use sector became a source of emissions in 2021, partly because of over harvesting (Official Statistics of Finland, 2022).

To reduce the ever-increasing pressure on forests, we should use wood more thoughtfully and sparingly by extracting as much utility as possible from existing wood products. From a circular economy hierarchy perspective, reducing the consumption of resources, by extending the lifetimes of buildings and the materials that they contain, is preferable to recycling building products after demolition. This also has clear implications for climate change mitigation since, in terms of carbon storage, extending building lifetimes is more beneficial than recycling the wood products they contain (Hill et al. 2020).

Whilst the average lifespan of buildings in Finland is known, the factors affecting this are less well understood. Moreover, holistic knowledge of the means and capacity of extending the longevity of the buildings is insufficient. The aim of the ongoing study reported in this paper is, therefore, to generate a better understanding of, and new knowledge about, the lifespan of wood buildings and to propose ways in which their longevity can be extended. Moreover, this can support and promote new, durable, wood construction. These actions will help extend the carbon storage of wood-based building products, reduce the need for primary resources, and so help mitigate climate change. We report preliminary results from this study.

Methodology

To investigate the factors that affect both the longevity of wooden buildings and the reasons for their demolition, we utilised a qualitative approach comprising desk research tasks and interviews, collecting data through a literature search and semi-structured interviews with relevant actors. A snowballing approach was used to identify additional interviewees from the initial interviews. Interviews are still ongoing and have included discussion with experts and researchers from the following disciplines: Forest management and politics, forest bioeconomy, legislation, business and society, building economics, wood architecture, vernacular architecture, wood construction, wood science and technology, indoor air quality, and building inspection and conservation. Additionally, participatory observation in events, seminars and meetings was used to complement our understanding.
To undertake the analysis, we adopted a process approach, shown schematically in Fig.1, that creates analytical constructs from the different events in the lifetime of a wooden building as the primary units of analysis, and maps the underlying factors affecting building longevity within these units. The phases included in the process are Forests, Circumstances, Preparatory, Design, Construction, Maintenance and Beyond. This approach was complemented using an iterative research process and systems thinking to ensure a holistic viewpoint.

Results and discussion

The results suggest that factors relevant to the longevity of wooden buildings can be broadly divided into two categories; The first comprises factors that are relevant before the building process begins and the second are factors that are relevant after the start of the building process. The first category includes phases 1-3 in Fig. 1 (*Forests, Circumstances & Preparatory*) and the second, phases 4-7 (*Design, Construction, Maintenance,* and *Beyond*).

Phases 1-3: Before the building process begins

Throughout all phases, it seems crucial to change the mindset and alter the emphasis of the wood building process. Currently, wood buildings are mainly thought of as 'temporary' (albeit some decades), whereas we could consider them to be 'practically permanent' (some centuries) or, in some cases temporary with the permanent use of the material through cascading supported by e.g., design for disassembly. We should plan and understand the life span of the buildings accordingly.

Phase 1: Forests – global resilience and the origin of materials

From our interviews and background research, clearly wood should be used for buildings to help mitigate climate change (e.g., Churkina et al 2020) and reduce resource extraction, yet at the same time, forests should be preserved for the resilience of the planet. To achieve this, we should make efficient use of the wood extracted from the forest, and the wood that is harvested should be directed towards longer-lasting, higher-value products. This finding is not new; EASAC (2017), for instance, stated that since "*using wood in durable commodities and construction allows carbon to be stored over long periods, these uses should be stimulated*". Forestry practices should be developed; accordingly, longer rotations and more continuous cover, with focus on quality.

Finland has a growing domestic market for wood building and so the emphasis on wood production should be shifted towards quality rather than quantity. By harvesting less and creating more value from what we take from the forests, we could generate new employment in the more labour-intensive wood building products sector. This has economic potential and may favourably influence the future know-how of Finland.

Our findings suggest that a shift in the product line is the first part of the change, and the second is the efficient, holistic use of the materials harvested. By using the whole tree and side streams more efficiently and directing them to higher value products, ensuring the longevity and maintainability of these 'products' and cascading the material multiple times, we can reduce the pressure on primary resources and create a healthier wood life cycle chain. This will also help maintain a livable planet by protecting the forest carbon store, most of which is in the ground (Pan et al, 2011), maintaining active carbon sinks now, when we most need them, and help recover and save the remaining biodiversity. All this contributes to resilience of the forests and the planetary system.

Phase 2: Circumstances – cultural and legislation impact

Legislation and policy guidelines appear to have a significant impact on the longevity of buildings. Additionally, attitudes and cultural aspects, like habits and customs, seem to have an influence.

Both in the EU and at national level there are strong incentives to prolong building lives in connection with sustainable building practices, the green transition and climate change mitigation. Laws and guidelines have already addressed this issue, and both the EU circular economy strategies (European Commission 2020) and the Finnish Building Act 2023 (YmVM 27/2022) address building durability and longevity. Within the legislation some of the main factors having an influence are: supporting the different roles of the forest and material use, supporting adaptability and resilience within the city structure, setting and supervising goals for longevity, and requiring reasoning and possible compensation for demolition.

Whilst wood has long been the main building material for detached houses (Nasiri et al. 2021), attitudes towards constructing apartment blocks and public buildings from wood have changed and are now more positive. Circumstances also seem to now be more positive towards continuous cover forestry that could emphasise quality over quantity and the production of building scale wood instead of smaller scale wood for fibre. Nevertheless, there also seems to be doubt about using wood for new purposes e.g., wood building, because of threats related to the forest carbon store, carbon sink and biodiversity – issues that would need to be tackled to ease this doubt.

Existing habits and practices seem to hinder changes to building practices.

Phase 3: Preparatory – influence of building decisions

Considering preparing for building, urban planning and building economics are the two main factors investigated so far. The green transition connects both these categories, and it seems that a clear economic plan to transition to a carbon neutral society is needed.

It has been noted by interviewees that urban planning as well as the city structure and density can affect obsolescence and, moreover, flexibility i.e., the adaptability of the buildings and spatial functions, can affect the decision to demolish or not.

Regarding building economics, it seems that key issues affecting longevity include redundancy – the need for the building, the profit motive, e.g., constructing more floor area on a given plot, spatial obsolescence, and perceived risks. These issues were raised by several interviewees and seemed to apply irrespective of the building material, and be closely connected to political decisions, the location of the building, and banking practices. Wood buildings are still perceived to be more expensive, although it seems that they can command a small premium due to demand. Insurance costs do not seem to have a significant influence. Further, the share of renovation practices in the building market is growing (37% in 2021), whilst the share of new building is decreasing (45% in 2021), renovation having larger housing share in housing in 2021. The RT (The Finnish Building Industry) estimates that to achieve green transition, a huge possibility for the country according to them, the renovation construction should double. The shift towards renovation and maintenance would contribute directly to the longevity of buildings and is necessary to prolong building lives (RT 2023).

Phases 4–7: After starting the building process

In general, it seems that we need to start to design and build permanence or 'thoughtful temporality', with repurposing of building materials in mind. We should emphasise design and building for resilience, adaptability, and a changing climate, preparing for unexpected situations, extreme conditions, and increased moisture, or heat related issues (Lü et al., 2018). For this, according to a number of interviewees, more specialised professionals, greater knowledge and expertise and more examples of resilient wooden buildings are needed.

Phase 4: Design – contemplating impact

The design mindset and design decisions affect longevity. When designing for permanence, all structures should be easy to maintain and designs should be resilient considering unanticipated faults, some of which will eventually arise. The structures and maintenance of the building should also be understandable for users, with simplicity and accessibility of the structure being one means to achieve this. Moreover, known risks to structures should be avoided, by e.g., ensuring that they can dry readily, and that future risks, such as coping with changing weather conditions, are carefully considered.

To avoid obsolescence design for flexibility, repurposing, disassembly, and relocation or reuse are important tools.

Phase 5: Construction – building to last

The building construction mindset can also affect the permanence of a building or building elements. High quality work and building for ease of maintenance and the replacement of materials, are important. Additionally, it is important to avoid moisture damage at the construction stage. In the worst case, building guidelines or instructions risk hindering the wood building process. As noted earlier, more examples of resilient long-lasting wood construction are needed.

Phase 6: Maintenance – sustaining the longevity

By increasing longevity and growing the (wooden) building stock, the role of maintenance and renovation will become more important. All buildings need maintenance, and the focus should be on 'lighter' continual maintenance instead of neglect and major renovations; over-renovating should be avoided. However, some building typologies not well designed for maintenance, may present challenges in maintaining them, and may need larger renovations instead. When renovating, adequate expertise and professionals educated and specialised in wood building maintenance are crucial; a lack of both, according to several interviewees, exists.

Understanding buildings is important to avoid the risk that renovation might even compromise building longevity. In wood building it is important to use materials that are suitable for the building, and to understand e.g., the role of the attic and cellar on airflow in current building structures. According to some interviewees, creating living spaces in these spaces may present risks. Forthcoming energy renovation requirements were regarded by several interviewees to be possible risk factors, both for the structures of wooden buildings, if overdone, and affecting the decision to demolish if it was deemed uneconomic to renovate an older building. Additionally, regular condition examination of buildings is recommended.

Phase 7: Beyond – permanence, reuse and demolition choices

When does a building come to the end of its life? Does it? To promote longevity, we need to see the value in existing buildings and have the motivation to preserve them; to value the historical layers, the time and materials contained in the building. Sometimes *we* also need to adapt to the buildings.

The most important lifetime decision of a building is avoiding uselessness. If the building has no function the motivation to maintain it decreases. Thus, proper maintenance and keeping the building in use, healthy and functional is essential. Understanding the building and its maintenance needs are, therefore, extremely important. Additionally, the adaptability of the building and that of the city plan directly affects building longevity.

Conclusions

We present the preliminary results of an ongoing investigation into the factors affecting the longevity of wooden buildings. Employing a systemic approach and considering all the phases in the lifetime of a wooden building, we identify some of the main issues that affect this. Well before building construction begins, the quality and availability of the raw material, the legislative and regulatory environment, all have an effect. Design decisions and the current mindset, along with the construction itself, and subsequent maintenance also dictate longevity. Perhaps the biggest question of all is what does building longevity mean? This is a question we aim to address in our future work.

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Figures and Tables

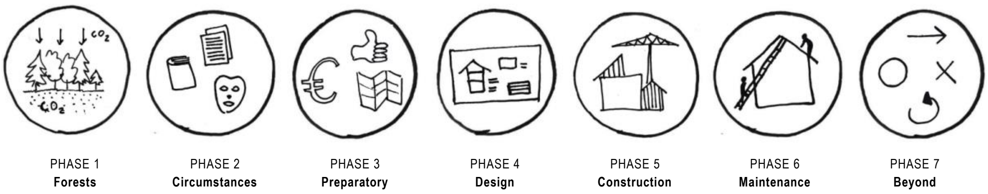

Figure 1. The phases of the wood building process that are being investigated