World Conference on
Timber Engineering
Oslo 2023

TOWARDS ADAPTABILITY AND CIRCULARITY OF TIMBER BUILDINGS

Robert Jockwer[1], Vera Öberg[2], Lisa-Mareike Ottenhaus[3], Paola Leardini[4], Yutaka Goto[5]

ABSTRACT: The construction industry has been a major contributor to resource consumption and global greenhouse gas (GHG) emissions, owed to high demand for building construction and the rapid urbanization trend. Timber construction has gained traction globally due to environmental advantages, such as renewability and carbon sequestration. However, sustainably available wood resources are limited. Extension of service life of timber structures is key to prolong their carbon stock. This paper showcases research projects carried out in Australia and Sweden that aim to design adaptable timber buildings capable of accommodating functional and spatial changes over time, thereby extending the service life of buildings and their components, as well as optimising their life cycles through spatial variations and repair of local damages to structural elements. This approach, known as Design for Adaptation (DfA) is an important step of the roadmap towards circular design solutions for timber buildings, which provide many economic, social and environmental benefits to all stakeholders and key players related to the building process, including manufacturers, engineers, architects, end-users, municipalities, and others.

KEYWORDS: Timber Buildings, Circularity, Adaptability, Sustainability

1 INTRODUCTION

Urban population has dramatically increased since the 1950s, driving the need for more buildings in densely populated areas globally [1]. As the construction industry has been a major contributor to greenhouse gas (GHG) emissions and resource consumption [2], the recent global attempt to decarbonise the construction industry has boosted interest in timber buildings due to their inherent environmental benefits.

For example, the Swedish construction market has seen a rapid growth of multi-storey timber construction for both residential and commercial buildings. The share of wood in newly built multi-storey constructions grew to approx. 20% in 2020, while it was 0% until the legislative change in 1994 [3], which was made possible by advances in fire safety engineering and allows to build more than 2 storeys in timber. Likewise, the Australian government is encouraging timber buildings as a pathway to emission reduction through policies and incentives, which has led to a nationwide timber shortage [4]. Although Sweden currently has a sufficient supply of timber for the domestic market, the export of sawn timber may increase from 70% of the current production to a much higher share in the coming decades, as it is expected that the timber construction industry will continue to grow globally [3].

Wood shortage is aggravated by its use in other sectors; wood is an attractive alternative as a renewable energy source and has applications in the chemical industry and for packaging. It is obvious that there must be a more rational and efficient use of raw materials in the overall wood-consuming industry; therefore, it becomes crucial to maintain the value of wood-based products and building components for an extended time. The best way is to utilize larger elements made of solid timber or engineered wood products (EWPs) as long as possible before letting them be transformed (cascaded) into other less valuable products, such as wood chip, pellets or pulps, which are the most common options. By reusing timber building components, the material is kept at the highest levels of the value chain, also assuring the continued storage of carbon in wood products [5].

In practice, when damages and deterioration of timber elements occur in critical parts of a structure, the whole building might need to be demolished if local repairs are not feasible for technical and/or economic reasons. Often though, other reasons may lead to building demolition and replacement. Regardless of the construction material (wood, concrete etc.), buildings might face the end of their service life due to the functional changes and different user needs over time. According to Thormark [6], there is a tendency for buildings in Sweden to be demolished far too early in terms of their technical service life; approximately 25% of buildings which have been demolished after 1980 were 30 years old or younger. If the construction system of those buildings, had allowed for easy removal or replacement of structural elements and enclosure components, their service life could have been significantly extended.

---

[1] Robert Jockwer, Chalmers University of Technology, Gothenburg, Sweden, robert.jockwer@chalmers.se
[2] Vera Öberg, Chalmers University of Technology, Gothenburg, Sweden, vera.oberg@chalmers.se
[3] Lisa-Mareike Ottenhaus, The University of Queensland, Brisbane, Australia, l.ottenhaus@uq.edu.au
[4] Paola Leardini, The University of Queensland, Brisbane, Australia, p.leardini@uq.edu.au
[5] Yutaka Goto, Chalmers University of Technology, Gothenburg, Sweden, yutaka@chalmers.se

https://doi.org/10.52202/069179-0203

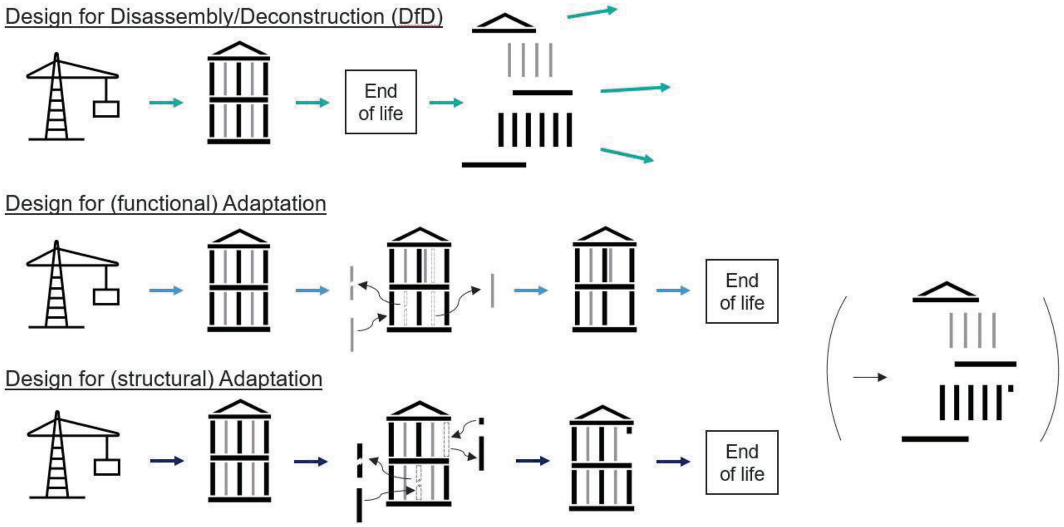

Figure 1: *Definitions and illustration of the concepts of DfD and DfA.*

To explore this potential, projects researching aspects related to adaptability and circular design of timber buildings have been initiated in parallel at Chalmers University of Technology (Chalmers) [7] in 2021 and at the University of Queensland (UQ) in 2022. They both focus on the numerous challenges still to be addressed in the circular design realm, such as a lack of adequate legal frameworks including standards, procurement requirements, regulations, and quality assurance, but also a lack of technical solutions for planners, engineers, and architects as well as a general lack of knowledge regarding the benefits of considering circularity and adaptability already in the design stage. Addressing these gaps requires the definition of a detailed and concrete roadmap towards the implementation of circularity and adaptability in timber buildings.

In this paper, we will critically present and discuss the concept and theory of design for adaptation (DfA), review the status of the timber and construction sector in Australia and propose the next steps to be taken for an effective implementation of DfA in timber construction.

2 CONCEPT AND THEORY

2.1 DfA and related concepts

Existing research on building adaptability has, to a large extent, focused on architectural and spatial changes. Definitions vary, but a common thread is the building's capacity to change in some way to meet new functional requirements or user demands, with the goal of extending its *useful life* [8]-[11] (for engineering aspects the term *service life* is used instead). DfA, in turn, has been described by Graham [12] as "a strategy used to avoid building obsolescence, and the associated environmental and cost impacts of resource consumption and material waste". While this could refer to the design for adaptability of both a building's structure and its non-load-bearing parts, this paper makes a distinction between the two, as designing adaptable non-load-bearing parts is dissimilar, both in execution and desired outcome, to doing the same for load-bearing parts. For example, designing non-load-bearing partition walls to be movable, removable, or replaceable enables the *functional* adaptation of indoor spaces without changing building structure and envelope, while designing parts of the structure, e.g., floors or load-bearing exterior walls, to be moveable, removable, or replaceable could instead defined as *structural* adaptation.

The concept Design for Disassembly or Deconstruction (DfD) is, in many ways, related to DfA, as it is a prerequisite for adaptability. DfD aims to limit waste production and raw material consumption by designing building elements (and the uncontaminated materials they are made of) to be disassembled and reused at the building's end of life [13],[14]. An important aspect of applying this concept to timber structures is the design of reversible connections [15], which are also crucial for designing timber structures for adaptation. It is indeed assumed that a timber structure designed for adaptation would also enable, or at least facilitate, deconstruction and reuse of its parts at its end of life. It should, however, be noted that the deconstruction and reuse of separate elements and materials at a building's end of life is not inherently a part of the DfA concept.

The concepts Design for Disassembly/Deconstruction, Design for (functional) Adaptation and Design for (structural) Adaptation are demonstrated in Figure 1.

2.2 Why do we demolish buildings?

If the purpose of implementing DfA is to prolong the service life of buildings, one should first consider why buildings are typically demolished. Any building, whether it is a single-family house or a multi-storey office building, is presumably at a low risk of demolition while it is considered useful and functional, i.e. if there is a need

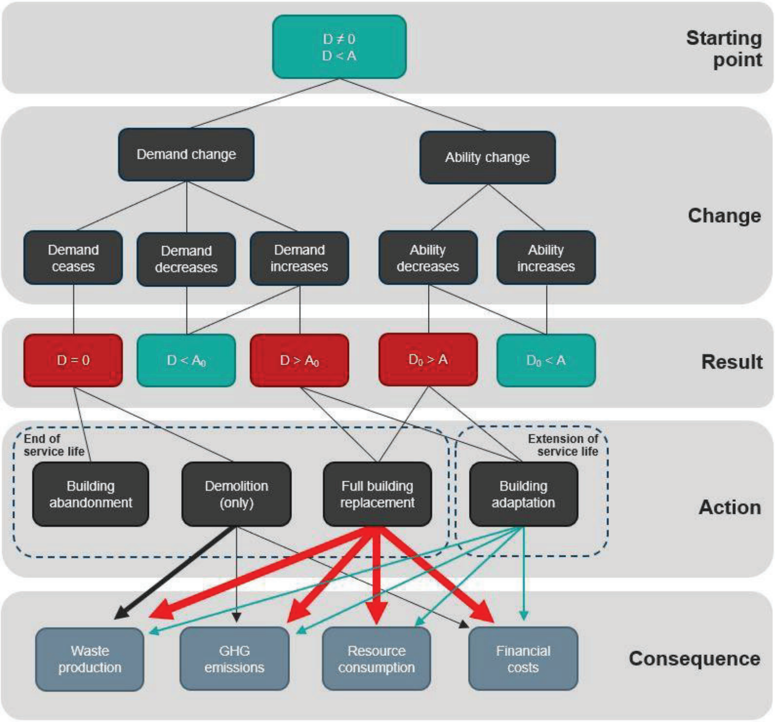

Figure 2: *Why do we demolish buildings?*

for the building in question and the building sufficiently fulfils specific functional and performance requirements. Consider the market **demand (D)** for a building type and its associated performance and functional requirements, versus its **ability (A)** to satisfy those requirements. This is illustrated in Figure 2. The demand is external; for example, the demand for office space at a given location and with its associated imposed structural loads. The ability, instead, is internal; for example, the building's ability to provide office space and carry certain loads. In a simplified model, one could set up two criteria for any given building. The first criterion is that there is a demand ($D \neq 0$), e.g., the demand for office space in the building's location. The second criterion is that the ability is greater than the demand ($D < A$); e.g., the building can sufficiently provide the demanded office space for its location.

If a building meets both criteria, it could be considered useful, which is normally the starting point for a newly constructed building. After some time, however, a change might occur – see Figure 2. In case of an external change, the demand could either cease, decrease, or increase. A complete cease of all demands would render the building in that specific location useless, and logically the owner could choose between abandoning the building or demolishing it. An example of this is a remote building connected to a mining operation, where a complete depletion of the mine might cease the operation and render the building useless. A decrease in demand, however, would still imply that both criteria are being met (economic implications of a significantly decreased demand could, however, still cause a decision to demolish or abandon the building). Lastly, when the demand increases, it might exceed the building's ability, in which case an action needs to be taken. Assuming no additional space is available on site for new construction, a whole building replacement or a building adaptation would be the relevant options. For example, a three-story multi-residential building in a city centre (where land value is high) might be replaced by a taller building as the area becomes more densely populated and the demand for housing is increased.

Regarding internal changes as defined above, the 'ability' of the building, as referred to its performance, typically decreases over time. An ability decrease could be caused by, for example, deterioration, long-term structural effects, or local damage. If the ability decrease falls below the demand, the relevant actions are yet again either fully replacing the building or adapting it to again meet the demand. In structural terms, a building's ability increase might be observed, e.g., if assessment is performed, and more beneficial member properties can be utilized through updated information; an example would be increased strength of concrete beams over time that exceeds 28-day strength used in design.

This model though, is clearly simplified; for example, a change might not be isolated, or a building might have a simultaneous demand and ability change. Furthermore, one demand could simply be replaced by another demand, e.g., a demand for office space being replaced by a demand for housing. In this case, the requirements for span length or floor height might decrease while those for

https://doi.org/10.52202/069179-0203

acoustics and fire safety might increase. Hence, the building might need to be adapted or even replaced to meet the demand for housing along with its associated performance and functional requirements. If some requirements exceed the building's ability, owners may need to consider building adaptation (retrofit) or replacement.

The detailed consequences of these four actions – building abandonment, demolition, replacement, and adaptation – vary on a case-by-case basis. Focusing on waste production, GHG emissions, resource consumption and financial costs, one could compare the assumed effect of each action to identify the most effective (overall or for specific targets). Building abandonment might be an option only if the economic loss of no longer using the building is negligible. Therefore, it is assumed to not cause any of the four consequences in a significant way. After some time and inevitable degradation, however, building abandonment could also lead to demolition. Demolition would presumably mainly cause waste production, along with related GHG emissions and financial costs for demolition and disposal. A whole building replacement, however, would cause all four of these consequences in a substantial way. Finally, a building adaptation would also cause all four consequences, but presumably to a much lesser extent than a building replacement, which must be evaluated on a case-by-case basis; different cases require different levels and intensities of adaptations in terms of cost and technical difficulty. When are the required alterations too complicated and costly, to justify building replacements as the more economical alternative? This is where design for adaptability and disassembly may shift owners' choices. Key to this approach is conceiving a building as an assembly of systems.

A popular way to illustrate a building's separate systems is Brand's [16] concept of 'shearing layers' of change. In this model, Brand identifies six building systems as layers, where the systems' varying lifespans causes shear between them. If relatively isolated, one system with a short lifespan can be changed without affecting the more 'permanent' layers [16]. The load-bearing structure, however, is the system layer with the longest planned lifespan; changes in the structure will likely affect some, or all, other building systems. Furthermore, altering a building's structure can be considered more technically complicated than altering its non-load-bearing parts. While lighter repairs are often favoured over demolition due to economic advantages, severe structural damages often cause a decision to demolish due to technical challenges and the repair costs exceeding the cost of a whole building replacement [17]. In the decision to demolish or rehabilitate a building, Bullen and Love [18] concluded that the leading determinant was the financial criterion, followed by asset condition and regulation. Economic, environmental, and social sustainability were all deemed important factors but given a lower priority in the decision [18],[19]. It is clear that, to make building adaptations a favourable alternative to demolition, it needs to be a cheaper and more technically feasible option, also supported by building regulations.

2.3 Expected benefits

So far, DfA has not been the prevalent concept neither for the design and conception of new buildings nor for the rehabilitation and adaption of existing buildings. It can be stated that the construction sector and building industry still follow a predominantly linear system, with a focus on the construction and development of new buildings. In previous years, the maintenance and rehabilitation of existing structures have contributed only minimally to the revenue of the actors involved in the construction process. Nevertheless, they are gaining importance (not least also in the infrastructure sector), and there is a clear trend to shift from a linear construction process to a more circular approach for the construction, use, and re-use of buildings and structures. In this process prefabrication is a natural way to implement DfA.

Amongst others, the following specific benefits are expected in the construction sector from a successful implementation of DfA for timber buildings:

- Contractors. Improved workflows on the construction site due to an increased use of standardized assemblies and the shift from on-site labour to offsite facilities, with associated benefits in terms of quality, cost, efficiency, and occupational health and safety.
- Manufacturers. Higher added value of building components will strengthen the producers' market position and create new business opportunities, e.g., leasing of components.
- Consultants, engineers, and architects. Best practice detailing and solutions that guarantee compatibility will allow to create more long-lasting solutions instead of individualized compromises.
- Developers. Buildings start to act as material banks, where the building retains a considerable material value. The value is retained after conventional 'end-of-life' through disassembly and reuse. At the same time benefits can be gained from the experience, repetition, and scaling effect of the successful circular concept and building system, hence, making the project development more cost-effective.
- Property owners. Long lasting, sustainable, and smart buildings that can react to changes in use and context conditions, thus maximising their value; this reduces maintenance costs and increases attractiveness of the property on the market.
- Users. Buildings that match user needs. For instance, tenants no longer need to adapt to the individual building; instead, the building adapts to their needs, requirements and wishes.
- Municipalities and society. Long lasting building stock that is able to adapt to changes in societal structure, such as demography or age distribution, to tackle new planning and building regulations, but also that can be used as a whole more effectively as buildings become material banks.

https://doi.org/10.52202/069179-0203

- Financers. Better estimation of economic risks and opportunities due to more sustainable buildings that can adapt to climate change; Thus, inherently lower risk in the light of an uncertain future, e.g., waterfront properties can be disassembled and relocated to respond to sea level rise.

3 REVIEW OF STAKEHOLDER STATUS AND DEMANDS

3.1 Overview

As part of the collaborative investigation carried out by UQ and Chalmers on DfA of timber buildings, the current stakeholder status, demands, and their development potential were evaluated in a study tour in Australia in October and November 2022. This tour was part of a project funded by the Swedish Research Council for Sustainable Development with the aim to establish a strong collaboration between the European and Australasian region with the focus on making timber buildings ever more sustainable by implementing the concepts of adaptability and circularity in their design.

The overall aim of the study tour comprised the following three objectives:

- Mapping the differences in use between new and reclaimed/reused wood-based building materials and elements from the perspectives of all stakeholders, such as producers, contractors, consultants, architects, engineers, and end-users.
- Analysing production, fabrication, design, use and re-use of timber building elements to identify opportunities and barriers to the transition to adaptability and circularity.
- Summarising barriers, challenges, and drivers, as well as possible means and technologies to overcome the differences between scales of applications, from construction products to building design.

By understanding the challenges and opportunities, it is possible to define the necessary steps for adaptability and circularity of timber buildings to be further developed, implemented, and utilised in Sweden and Australia, but also internationally. The following section presents the findings of the study tour, grouped by stakeholder type.

3.2 Stakeholder status, demands and development potential

3.2.1 Wood sector in Australia

Australia has a great diversity of wood species, however, only few softwood species are used to larger extent in the construction industry. In order to create sustainable development while maintaining and developing ecological diversity of forests, the utilisation of a more diverse range of wood species should be considered. Timber Queensland [20] is an association of wood industries in Queensland, which maintains an online tool to purchase Queensland timbers [21]. Finding a suitable application for each of the wood species in different applications will help enable a more sustainable utilisation of resources.

3.2.2 Forestry

Sustainable forestry is a prerequisite for achieving a thriving timber sector and implementing DfA. Timber plantations are a common solution for sustainable forestry and wood production in many parts of the world. For example, in Southern Queensland (Wide Bay Burnett, South East Queensland - SEQ, and Darling Downs South West) HQPlantations [22] manages 310,000 hectares of plantation forest in a 99-year lease contract; HQPlantations is both Forest Stewardship Council (FSC) and Responsible Wood (PEFC) certified, and their softwood supply is used to build 25,000 homes/year, covering most of the demand in the SEQ region.

Different wood species are grown in different locations, depending on the local climate and geographic conditions. For example, the hills around Imbil show great diversity in plantation and natural forests, with a variety of different hard- and softwood species. Natural hardwood forests cover the hilltops whereas diverse plantations stretch across the valleys. In contrast, the flat sandy landscape around Toolara provides soil conditions for large monocultural forests, from which the logs are directly transported to the nearby sawmills [23]. The different wood species at the various locations may offer different benefits for specific applications.

There are two important Southern Queensland wood species. Araucaria (Hoop Pine) is an endemic rainforest species mostly grown for visual grade veneers, baby cots (food grade timber) and musical instruments; its harvesting age is 50 years. The second one is Southern Pine, which is a hybrid of Slash and Caribbean Pine, harvested at 28 years, which supplies SEQ's structural timber demand, including engineered wood products.

Fire management is a crucial part of HQPlantations' activities: fire observation towers are installed in different locations to detect smoke plumes, all vehicles are equipped with firefighting equipment, and the staff consists of trained fire fighters. The active fire management of the forest, through prescribed burning and controlled burns in collaboration with adjacent landowners, is an effective means to control the fuel load.

The direct connection and vertical integration between the forest and the further processing steps in the wood value chain are important to create a more resource efficient wood value chain. An example of this efficiency is linking the growth data from the forest, including stem dimensions and qualities, to the production demands and capabilities of the sawmills, in order to manufacture higher value products and avoid unnecessary waste during production. Such an integration provides benefits both for forest and plantation owners, supplying higher value-added products to sawmills, which can then meet their customers' demands more efficiently. An important first step in this process is, for example, the delivery of full size (untrimmed) logs of Southern Pine from the Toolara plantations by HQPlantations to the Hyne sawmill in Tuan, Queensland [24]. For the plantation owners, this vertical integration includes selecting the most appropriate genetic resources and breeding seedlings in nurseries.

https://doi.org/10.52202/069179-0203

3.2.3 Producers and Sawmills

A variety of structural products are manufactured in different sawmills and production plants across Australia. As part of the study tour, a total of 6 sawmill, glulam, and CLT plants were visited. Depending on the location and the local raw material supply, the sawmills are specialized in different raw materials, timber products, production processes. Despite their individual differences, some commonalities and challenges can be identified:

- Grading and strength classes. The strength class system of machine graded pine (MGP) is rather strict and allows only for a limited range of adaptation to the feedstock. Almost all sawmills use machine grading to produce MGP10 lumber and partly higher qualities. Lower qualities than MGP10 result in F-grade timber, which is assessed based on bending strength rather than stiffness. Over the time, the market demand has adapted to these qualities. However, this strict and limited system of strength classes does not allow for a better and more efficient utilisation of the raw resources in the future. Vertical integration between the sawmill and the users in the construction industry can provide a solution here.
- Timber treatment against termite attack. Most of the timber products used in Australia require chemical treatment against termite attack. The effective and sustainable use of chemicals is a general challenge for the re-use of timber elements and circularisation of resources. Reliable and long-term specification of the treatment type is important. At the same time (private) users are familiar with certain colour codes for different applications and demand these colours without further questioning the performance.
- Optimisation of sawing patterns. The yield of the sawmill depends, to a large extent, on an optimal choice of the sawing pattern for the feedstock. Depending on locations and species of the feedstock, the log's cross-section, length, and straightness can vary quite considerably. E.g., Radiata and Southern Pine used by Associated Kiln Driers Pty Ltd (AKD) Softwood Mill Caboolture, Queensland [25] have a considerably smaller diameter compared to Radiata Pine used by TimberLink, Bell Bay, Tasmania [26]. Good interaction and communication between the forest owners, harvesters, sawmills, and consumers are crucial to achieve an efficient utilisation of resources. The vertical integration enables also to track the product Chain of Custody.
- Hardwood species are used to a much smaller extent in the construction industry compared to softwood. Several manufacturers work with hardwood in Australia and produce glulam or CLT. However, hardwood has not yet fully penetrated the market; some of the challenges of working with hardwoods are the different gluing requirements compared to softwoods and the more careful and slower drying processes to avoid wood matrix damages.
- Automation can help to upscale the production volume compared to elaborate production by hand. Automated glulam production from softwood of standardized sizes in the Hyne timber Glulam factory [24] (Maryborough, Queensland) is a good example. However, individual and customised timber members of other dimensions or bespoke shapes still require manual production.

  The trimming of full size CLT panels on CNC machines at XLam Australia, Wodonga [27][26], offers the possibility to prefabricate entire wall and floor elements and integrate the connection details in factory. This enables to integrate DfA solutions as standardized detailing solutions in the process.

Excellent examples of small innovative producers are CLTP and CUSP Building Solutions [28], in Wynyard, Tasmania, which have developed hardwood CLT and glulam for a better utilisation of local resources: they produce Eucalyptus Nitens and Eucalyptus Grandis composite Glulam beams and Eucalyptus Nitens CLT panels. At the same time, they utilise the finger jointing lines to re-use MGP10 cut-offs to produce structural finger jointed lumber of a similar quality. This is an excellent example of efficient resource utilisation and reuse, well aligned with circularity principles.

3.2.4 Architecture and Engineering

Common challenges for engineers and architects for the development of the mass timber industry where discussed with NexTimber [29], which is the Melbourne-based mass timber (Glulam and CLT) division of Timberlink [30]. These are the reuse of CLT panels, lack of a standardised connection details, repairability of structures, and classified material properties. These gaps impact the ability of engineers and architects to design for deconstruction, reuse, and recertification of timber components, as well as the carbon credits system, as it cannot be assured that timber remains in use and is well maintained.

Advancing education around the use of timber in architecture is in the focus of the Centre for Future Timber Structures at the University of Queensland's St Lucia campus, as well as the Centre for Sustainable Architecture (CSAW) at the University of Tasmania's Newnham campus. UQ projects include, amongst others, research on adaptable timber structures and innovative reversible connections [31][32], and hygrothermal performance of CLT in hot and humid climates [33]. UTas projects include, amongst others, the use of salvaged timber materials for innovative structures, and research on local hardwoods [34]-[36].

Innovative construction concepts are offered by ArKit, Sunshine, Victoria [37]. ArKit's projects range from bespoke architectural designs using volumetric and panelised offsite construction, to Passivhaus standard projects, and volumetric social housing. The use of modular, panelised, and volumetric prefabrication in their factory enables high-performance and quality solutions also for low budget social housing funded by the Australian government. The modularity enables the

https://doi.org/10.52202/069179-0203

refurbishment of existing modules in the factory after their initial lifetime for a second cycle.

3.2.5 Exemplar timber buildings

Structural timber is a common building material used in residential buildings and there are many historic examples of mid-rise timber buildings in Australia, such as the oldest surviving building in Albert Street, Brisbane [38]. The development of modern structural engineered wood products (EWP), namely glued laminated timber (GLT), laminated veneer lumber (LVL), and cross laminated timber (CLT) enabled to build also larger high-performance structures in timber instead of the other prevailing building materials steel and concrete.

One of the most celebrated modern, multi-storey buildings made of EWPs in Australia is the office building at 25 King Street in Brisbane [39]. Lendlease is the developer, Aurecon is the engineering consultant and Bates Smart the architecture firm who designed the building of the 9-storey mass timber office building using Stora Enso CLT. Despite attracting a 'timber premium', the lease worked out much cheaper than Aurecon's previous offices in the CBD. Furthermore, employees enjoy the timber feel of the building with the building winning design and wellbeing awards.

The following structural design features of this showcase building can be highlighted:

- Slotted in steel plates, concealed with timber covers, and timber plugs for bolts and screws to enhance fire performance also enable potential deconstruction.
- 5-layer CLT in the staircase, with the first two layers running vertically to improve load bearing resistance - the staircase has no lateral bracing function. This solution also improves fire resistance rating.
- Hardwood LVL banded Glulam beams to reinforce the beam around services penetrations.
- Large open floor plans offer functional and spatial flexibility.
- Durability and repairability of exposed timber elements improved by adequate protection from wetting and weathering; UV protection is crucial to avoid colour variations in different exposed members.

The timber building at 25 King Street is exemplar towards implementing DfA as, in principle, much of the building is deconstructable due to the fasteners and brackets chosen, and due to a clear and open member design, which applies circular design principles for.

Another exemplar building is the recently opened extension of the Maryborough Fire Station [40], designed by Baber Studio (architecture) [41] and Bligh Tanner (structural engineering), and realised by Hutchinson Builders. While the old brick façade of the existing fire station building was preserved, the whole new extension is made from Glulam and CLT supplied by Hyne Timber and XLam - manufactured from local softwoods from their Tuan mill. Design features of the fire station extension include CLT band beams and concrete ring beams in the fire engine area, to kept timber off the ground while fire engines are being washed down or when leaking water. This building is particularly relevant as it shows the potential of timber also in non-conventional applications.

Finally, the Inveresk UTas Library, in Tasmania, is an exemplar hardwood structure made of local Tasmanian Oak. Tasmanian oak is the name used for three eucalypt hardwoods: Eucalyptus delegatensis (alpine ash) can be found at higher altitudes, while E. regnans (mountain ash) is found in wetter sites; and Eucalyptus obliqua (messmate) has a wide distribution, growing in wet forests but also extending into drier areas. The timber members are used in bespoke roof trusses offering large open spaces and appealing architectural design, which is an excellent example for the use of local resources in a performant structure. The efficient large span truss structure offers a flexible usage of the building.

3.2.6 Research

Circularity of wood products

The circular use of wood requires strategies to maintain wood products at their highest value and then provide efficient solutions for a cascading application, at a lower value. This is one of the focus areas of the Advance Timber Hub, an Industrial Transformation Hub funded by the Australian Research Council (ARC) to advance timber in Australia's future built environment. Furthermore, researchers at Queensland's Department of Agriculture and Fisheries (QDAF) facilities at Salisbury are looking at engineered wood-based composites, kiln drying and sawmilling technology, timber grading,

wood product design, and performance testing, which all enhance timber recovery and durability throughout the value chain. Particularly significant towards the implementation of a circular timber construction sector is research led by A/Prof Benoit Gilbert, which addresses: high quality products from the raw material in form of sawn boards or veneers from different wood species [42] to be used in LVL, glulam, or CLT; recycling and reuse of different waste materials in value-added products, such as tyres and wood fibres in composite particle boards; and product durability to ensure a long and safe service life. Durability of EWPs is also at the centre of a collaborative research project by PhD candidate Marcus Strang, under the supervision of Dr Paola Leardini (UQ) and Dr Maryam Shirmohammadi (QDAF); the study investigates the hygrothermal performance of high-performance CLT construction in hot and humid climates, providing design guidance that, ultimately, also ensures structural durability across different Australian climates [43].

Construction strategies and solutions

Technical solutions for the application of DfA in construction are investigated by the research group of A/Prof Hamid Valipour at the University of New South Wales (UNSW), Sydney. Hybrid steel timber elements are being developed that offer a variety of benefits [44]; the combination of low-grade timber elements with steel rods in hybrid elements can provide high quality usage for low quality timber in standardized components, such as columns or beams. Standardisation facilitates the use and

https://doi.org/10.52202/069179-0203

re-use of these components in different applications. Constructing with standardized components instead of members with individualized geometry is common already e.g., in the steel or prefab-concrete industry and offers high circularity potential also in the timber field. The combination of these hybrid elements with conventional structural solutions in steel or concrete offers the easy implementation of more resource efficient components in the construction sector. Further implementation of specialized connections will facilitate construction and deconstruction, and it enables the implementation of fuse elements to achieve ductility for robustness or seismic purposes.

3.3 Necessary steps towards DfA

While significant research is currently carried out, further steps are necessary to ensure the transition of timber construction to circularity and the implementation of DfA, including:

- Vertical integration of processes, from the forest to the end-user.
- Utilisation of a wider range of wood resources.
- Effective use of all by- and side products of the wood value chain (e.g. structural finger jointed timber, scrimber)
- Production of standardized components instead of materials.
- Design and construction of flexible structures in terms of both floor plans and re-use and deconstruction.
- Use of offsite prefabrication and modularisation as mainstream practice.
- Mapping of differences in use between new and reclaimed/reused wood-based building materials and elements, from the perspective of all relevant stakeholders, such as manufacturers, contractors, consultants, architects, engineers, and end-users.
- Development of business concepts including the re-use of material, members, components, and entire structures for transitioning to adaptability and circularity.
- Translation and commercialisation of circularity and adaptability research in collaboration with industry stakeholders and research providers.
- Education of architecture, engineering and building professionals with respect to durable and circular design, better interdisciplinary networking, and collaboration between industry stakeholder to achieve common goals.

4 CONCLUSIONS

The results of the research and built projects described in this paper provide a greater understanding of the challenges and opportunities of DfA and, more broadly, circularity of timber buildings, with a special focus on the Australian and Swedish market. The concept and general benefits of DfA were explained. Then the current status and ongoing development of the stakeholders in the Australian timber construction industry and research environment were analysed. Following this evidence-based analysis of the Australian timber sector, the paper proposes some first but necessary steps for adaptability and circularity in the timber sector to be further developed, implemented, and utilised. This paper leverages results of government funded research projects on DfA currently being conducted at UQ and Chalmers, thus significant findings are expected in the future.

ACKNOWLEDGEMENT

The paper is based on the following research projects: “Roadmap towards adaptability of timber buildings” (project number 2021-02711) and “Design for adaption for resource efficient timber structures” (project number 2021-02499), both funded by FORMAS, the Swedish research council for sustainable development; and Linkage Project “Offsite manufacture reimagined for high-performance adaptable housing” (LP200301402), funded by the Australian Research Council. The researchers would like to thank Timber Queensland, HQPlantations, AKD, Hyne timber and XLam Australia, Timberlink and NexTimber, CLTP and CUSP, UTas, UNSW, QDAF, Baber Studio, ArKit and Aurecon for their input.

REFERENCES

[1] European Environmental Agency. (2006). Urban sprawl in Europe: The ignored challenge. Office for Official Publications of the European Communities, Luxembourg.

[2] Directorate-general Environment. (2014). Resource efficiency in the building sector – final report.

[3] Svensk Trä: www.svenskttra.se

[4] Building Design Association of Australia. (2021) Timber Shortage Hits Australia. https://bdaa.com.au/timber-shortage-hits-australia/ 12 Dec 2021. Viewed 25 March 2022

[5] Churkina, G. et al. (2020). Buildings as a Global Carbon Sink. Nature Sustainability 3, no. 4, 269–76.

[6] Thormark, C. (2008). Projektera för demontering & återvinning. Svensk byggtjänst, Stockholm.

[7] Jockwer R, and Goto Y. (2021) Design for Adaption - Making Timber Buildings Ready for Circular Use and Extended Service Life. Proceedings of the World Conference on Timber Engineering (WCTE 2021).

[8] Douglas, J. (2006). Building Adaption. 2nd ed. Butterworth-Heinemann, Oxford.

[9] Bullen, P.A. (2007). Adaptive reuse and sustainability of commercial buildings. Facilities, 25(1/2), 20–31.

[10] Schmidt, R., Associate, R., Eguchi, T., Austin, S., & Gibb, A. (2010). What is the meaning of adaptability in the building industry? Paper presented at the 16th International Conference O&SB20210 “Open and Sustainable Building”. Bilbao, Spain.

[11] Wilkinson, S. J., Remøy, H. & Langston, C. (2014). Sustainable Building Adaptation – Innovations in Decision-making. John Wiley & Sons Ltd, West Sussex.

[12] Graham, P. (2005). DESIGN FOR ADAPTABILITY — AN INTRODUCTION TO THE PRINCIPLES AND BASIC STRATEGIES. Environment Design Guide, GEN 66, 1-9.

https://doi.org/10.52202/069179-0203

[13] Durmisevic E. (2006). Transformable building structures – Design for dissassembly as a way to introduce sustainable engineering to building design & construction (Doctoral dissertation, TU Delft, Delft, the Netherlands).

[14] Rios, F.C., Chong, W.K. and Grau, D. (2015). Design for Disassembly and Deconstruction - Challenges and Opportunities. Procedia Engineering, no. 118, 1296–1304.

[15] Sandin, Y. et al. (2022). Design of Timber Buildings for Deconstruction and Reuse —Three methods and five case studies. RISE report 2022:52.

[16] Brand, S. (1995). How buildings learn: What happens after they're built. 2nd ed. Viking, New York.

[17] Alba-Rodríguez, M.D. et al. (2017). Building rehabilitation versus demolition and new construction: Economic and environmental assessment. Environmental Impact Assessment Review, no. 66, 115–126.

[18] Bullen, P. and Love, P. (2011). A new future for the past: a model for adaptive reuse decision-making. Built Environment Project and Asset Management, 1(1), 32–44.

[19] Bullen, P.A. and Love, P.E.D. (2010). The rhetoric of adaptive reuse or reality of demolition: Views from the field. Cities, 27(4), 215–224.

[20] Timber Queensland http://www.timberqueensland.com.au/ , accessed 11/03/2023.

[21] The Accredited Queensland Timber Merchant Network (AQTMN) http://www.buyqldtimber.com.au/ , accessed 11/03/2023.

[22] HQPlantations: https://www.hqplantations.com.au/ , accessed 11/03/2023.

[23] https://gympietoday.com.au/news/2021/12/05/hq-managing-timber-in-region/ , accessed 11/03/2023.

[24] Hyne Timber https://www.hyne.com.au/ , acc. 11/03/2023.

[25] AKD: https://www.akd.com.au/ , accessed 11/03/2023.

[26] Timberlink: https://timberlinkaustralia.com.au/ , accessed 11/03/2023.

[27] XLAM: https://xlam.co/ , accessed 11/03/2023.

[28] CLTP https://www.cltptasmania.com/ , acc. 11/03/2023.

[29] NexTimber: https://nextimber.com.au/ , acc. 11/03/2023.

[30] https://architectureau.com/articles/timberlink-announces-new-clt-and-glt-brand-nextimber/ , accessed 11/03/2023.

[31] Yan, Z., Ottenhaus, L.-M., Leardini, P., & Jockwer, R. (2022). Performance of reversible timber connections in Australian light timber framed panelised construction. Journal of Building Engineering, 61(September), 105244. https://doi.org/10.1016/J.JOBE.2022.105244

[32] Kuiri, L., & Leardini, P. (2022). Design for Adaptability and Disassembly: Towards Zero Construction Waste in the Australian Housing Sector. 1ST International E-Conference on Green & Safe Cities (IeGRESAFE).

[33] Strang, M.; Leardini, P.; Brambilla, A.; Gasparri, E. (2021). Mass Timber Envelopes in Passivhaus Buildings: Designing for Moisture Safety in Hot and Humid Australian Climates. Buildings, 11, 478. https://doi.org/10.3390/buildings11100478

[34] Wood, K., Morrell, J., and Leggate, W. "Enhancing the Durability of Low Durability Eucalyptus Plantation Species: A Review of Strategies." In Proceedings IRG Annual Meeting (ISSN 2000-8953), IRG/WP 20-40910. online: The International Research Group on Wood Protection, 2020.

[35] Chen, Xudong, Yingyao Cheng, Andrew Chan, Damien Holloway, and Gregory Nolan. "Aniso-tropic Tensile Characterisation of Eucalyptus Nitens Timber above Its Fibre Saturation Point, and Its Application." Polymers 14, no. 12 (January 2022): 2390. https://doi.org/10.3390/polym14122390.

[36] Liang, Yingwei, Assaad Taoum, Nathan Kotlarewski, Andrew Chan, and Damien Holloway. "Behavior of Cross-Laminated Timber Panels Made from Fibre-Managed Eucalyptus Nitens under Short-Term Serviceability Loads." Buildings 13, no. 1 (January 2023): 245. https://doi.org/10.3390/buildings13010245.

[37] ARKit: https://arkit.com.au/ , accessed 11/03/2023.

[38] https://heritage.brisbane.qld.gov.au/heritage-places/1987#:~:text=This%20building%2C%20constructed%20circa%201865,Brisbane%20between%201861%20and%201884 , accessed 11/03/2023.

[39] Aurecon: https://www.aurecongroup.com/projects/property/25-king , accessed 11/03/2023.

[40] https://www.abc.net.au/news/2022-11-22/mass-engineered-timber-fire-station-officially-operational-qld/101683446 , accessed 11/03/2023.

[41] Baber Studio: http://www.baberstudio.com.au/maryborough-fire-and-rescue-station/ , accessed 11/03/2023.

[42] Leggate, W., McGavin, R., Outhwaite, A., Gilbert, B., and Gunalan, S. "Barriers to the Effective Adhesion of High-Density Hardwood Timbers for Glue-Laminated Beams in Australia." Forests 13, no. 7 (2022): 1038. https://doi.org/10.3390/f13071038.

[43] Strang, M., Leardini, P., Brambilla, A., and Gasparri, E. "Mass Timber Envelopes in Passivhaus Buildings: Designing for Moisture Safety in Hot and Humid Australian Cli-mates." Buildings 11, no. 10 (2021): 478. https://doi.org/10.3390/buildings11100478 .

[44] Kia, L., and Valipour, H. R. "Radiata Pine and Douglas Fir Timber Steel Encased Columns Subjected to Concentric and Eccentric Loading." Journal of Structural Engineering 148, no. 2 (2022): 04021272. https://doi.org/10.1061/(ASCE)ST.1943-541X.0003266.

https://doi.org/10.52202/069179-0203