Title	Adding value to timber components through consideration of demolition and disassembly
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Publication date	2021-08-12
Conference details	World Conference on Timber Engineering, WCTE, 9-12 August 2021, Santiago, Chile
Link to online version	https://wcte2021.com/
Item record/more information	http://hdl.handle.net/10197/12867

ADDING VALUE TO TIMBER COMPONENTS THROUGH CONSIDERATION OF DEMOLITION AND DISASSEMBLY

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ABSTRACT: Consideration of the life cycle of timber products within the traditional construction sector in Ireland has been extremely limited to date. Consequently, the majority of timber recovered following demolition is incinerated for energy, contributing to global warming.

Analysis of the current Irish housing stock has shown that it contains high volumes of quality timber components in good condition and of significant capital value. In making relatively minor adjustments to design, construction and demolition practices, opportunities exist to enable disassembly and reuse which would add timber components and completed constructions.

KEYWORDS: Timber, Timber Connections, Environmental Impact, Designing for Disassembly

1 INTRODUCTION

Within the context of growing environmental awareness and reduced resources, the circular economy and life cycle assessment (LCA) of construction materials now forms part of the European Commission's 'Level(s)' framework for Green Public Procurement [1]. The circular economy considers materials and products after-use value as important environmental and economic factors and a key tool to reduce global warming [2]. As such, buildings may be considered as material banks; as repositories for materials that could potentially be extracted for reuse or re purposing in the future [3]. As these building elements begin to replace primary resources extracted for construction, the need for primary resource use is reduced. Yet in Ireland, timber is largely considered a single use product in a linear economy (Figure 1), with almost all material incinerated for energy following demolition and thus increasing the emission of carbon into the atmosphere [4].

The aim of the study was to identify the impediments for this transition from the current wasteful linear economy to the circular economy within the context of timber construction. To establish the way in which timber is currently extracted from buildings and treated, an analysis of the the demolition sector and current waste practices has been undertaken. Following this, the quantity of timber currently encapsulated in the domestic building stock that could potentially be reused has been estimated. These factors of demolition, waste and available timber are used to frame the development of a design tool or matrix that could aid practitioners improve their design process to increase the potential for the recapture of timber from building stock in the future.

Though this study will focus primarily on the housing stock only, the design matrix will be applicable to other typologies.

Figure 1: *Mixed skip with significant timber content (source. author)*

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2 ANALYSIS OF DEMOLITION & WASTE PRACTICES IN IRELAND

The Irish Environmental Protection Agency (EPA) have noted in a *Design Out Waste* Factsheet [5], that '… the fundamental design decision to reuse an existing building or demolish it for a new building will determine, to a large extent, the level of waste prevention in a project. In accordance with the waste hierarchy, the design team should explore reuse, recovery and recycling opportunities …'. Demolition practices could play a key role in the recovery of quality reusable timber components, yet demolition is rarely considered in the design and construction of buildings.

Deconstruction practices over the last 50 years have changed, resulting in less salvage and reuse. Before the 1970s, Addis noted that a large proportion of demolition was undertaken by hand, apart from the very final stages when a 'ball and chain' method might have been used, and as a consequence items were more frequently salvaged undamaged [6]. He highlights some changes to the industry, with potentially contrasting implications, that suggest some reasons for this;

- Pressure to reduce demolition and disposal costs
- Pressure to reduce the timescales
- Impetus to improve Health & Safety
- Change of perception from 'Demolition' to Material recovery & disposal Activity'.
- Greater environmental concerns, including an awareness of materials 'whole life cycle'
- Global market for demolition

In conjunction with NUI Galway, our study took the form of several site visits to demolition sites and waste treatment facilities. It was found that demolition methods are very much project and task specific, with several factors influencing the chosen method such as programme, waste segregation, building construction and site constraints; however, most decisions are entirely driven by the economics of the process.

Figure 2: *Pre-Demolition Site Photo, Seagrave House, Dublin (source. Dr. Elizabeth Shotton)*

2.1 SURVEY OF CURRENT DEMOLITION PRACTICE

Across Europe, the legislative and regulatory context within which Demolition occurs has become more complex with a range of legal structures now impacting the process, including workplace and construction health & safety and waste treatment regulations. This growing legislative and economic pressure on demolition and waste companies is to ensure as little waste goes to landfill as possible, but also to work in a safe way can be contradictory.

At present, demolition practices aim to segregate as much material as possible at the early stages, with the primary aim to reduce the number of expensive mixed skips i.e. construction waste bins. Timber skips cost approximately 50% of a mixed skip, while metal skips generate income for the demolition contractor. This results in an initial 'soft strip' by hand which allows for waste to be separated in a considered way and thereby reducing contamination, as this can lead to a skip being rejected by the waste company. Once the maximum amount has been removed by hand, what remains is typically removed mechanically.

At various site visits, large section timber roof structure were evident which had the potential for reuse (Figure 2) however, any timber is cut to the most economical length to fit into the skip, with no consideration of value or reuse potential. This timber was removed by either being cut into short sections with a sabre saw or a long reach mechanical grabber, which rendered much of the material unusable in an unsorted pile, with the timber cracked and splintered due to the force of demolition (Figure 3).

Figure 3: *Construction waste including Timber extracted by grabber from Building (source. author)*

When mixed skips leave site, they are typically brought to a sorting location, where they are further segregated. This process often involves the breaking down and separation of the waste with heavy machinery using density and magnetic force to separate the smaller elements of waste. Any waste which enters this second stage (collection by EPA accredited waste company) is considered waste and must be treated as such, therefore no opportunity currently exists for waste companies to reuse elements from construction. This suggests that either regulations should be changed or that the extraction for reuse or upcycling must occur prior to that stage.

Following this second stage of segregation, the timber waste is again distributed to a tertiary waste timber facility, where huge amounts of waste timber from numerous sources were evident (Figure 4). The timber is chipped into small particles so that it can be either incinerated, composted or reprocessed into pallet blocks (Figure 5). Over 102k tonnes of wood waste is produced every year in Ireland.

Figure 4: *Wood waste before process it in Thorntons facilities (source. author)*

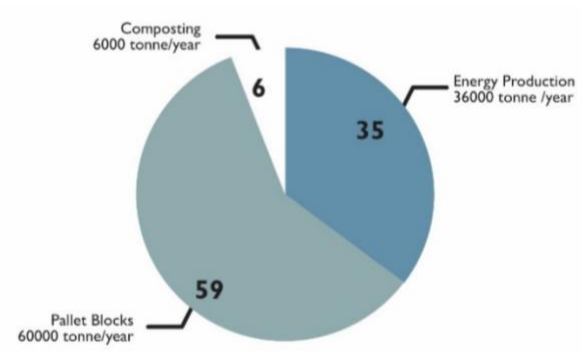

Figure 5: *Amount of Wood Waste in Ireland per Annum & End Use [4] (source. author)*

3 TIMBER IN IRISH DOMESTIC CONSTRUCTION

3.1 HOUSING; A GROWING NEED

By improving primary design to facilitate deconstruction rather than demolition, the primary objectives of the Infuturewood project are to increase the potential for reuse of timber products in the future circular economy. This will also involve the identification of potential new construction products using recovered timber or scenarios for the reuse of existing timber components.

Housing as a typology was chosen for the purpose of this study as it was the building type most likely to represent the greatest amount of timber per square metre, as well as being consistent and pervasive in nature. It would also provide a typology which could be easily compared between states.

In the forthcoming decades, there will be a focus on housing both nationally and internationally due to the global housing crisis [7]. Ireland is no exception, with an increasing number of households in Ireland experiencing some form of housing distress, and in particular the marked rise in homelessness [8].The government's action plan to counter the current housing crisis in Ireland sought to increase the supply of homes by 25,000 per annum by 2020, and a further 50,000 social housing units before 2021 [9]. The focus on housing as the typology of study will ensure that the most rapid and beneficial impact of the study is possible.

Though limited to housing, it should be noted that the principles and methodologies developed as part of the Infuturewood project will also be transferrable to non-domestic architecture and could potentially form a template for the recovery of other materials from construction.

3.2 IRISH DOMESTIC HOUSING STOCK

A study of the current Irish housing stock was undertaken to establish the predominant housing type; the volume, dimensions and quality of the timber used in residential structures; and the manner of its encapsulation. Data sources used in the study include Eurostat, Sustainable Energy Authority of Ireland (SEAI) and the Central Statistics Office (CSO) in Ireland, the latter providing data on the nature and era of the Irish housing stock used to establish the age profile of the houses analysed.

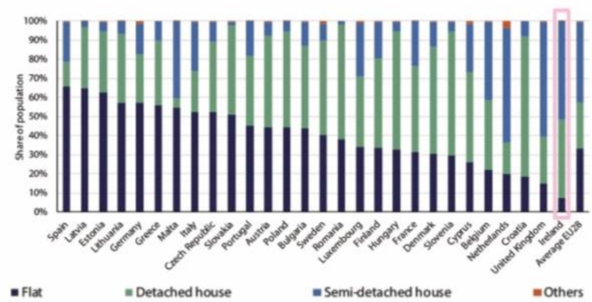

Figure 6: *Distribution of population by dwelling type in EU member states, 2015 (source. SEAI, 2018 [10])*

Only 12% of Irish households reside in apartments (Figure 6), out of the approximately 1,700,000 housing units in Ireland [11]. This is the lowest proportion of apartment use in the EU (average 46 %) and in stark contrast to other states such as Spain and Greece with above 60% residential occupancy in apartments [11]. As a consequence, the housing stock is predominately made up of terraced, detached, and semi-detached houses [12], accounting for approximately 87% of the housing stock (Figure 7). As a result, the study focused on these housing types for further analysis [11, 13].

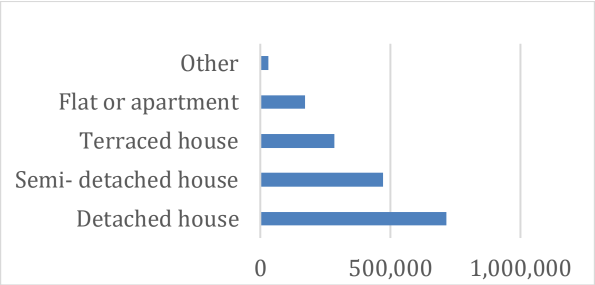

***Figure 7:** Irish Housing Stock (source. CSO)*

Of the existing housing stock in Ireland, 42% was constructed before 1981 and almost 25%, has been built between 2001 and 2010 [14]. The significant amount of housing constructed post-2000 is important as changing building regulations and shifts in construction technology could influence the amount and type of timber encapsulated in these house types. The number of residential units represented in the analysis which followed was just short of 1.5 million units.

3.3 ENCAPULATED TIMBER IN IRISH DWELLINGS

To establish the volume, dimensions and quality of structural timber encapsulated in domestic construction several case studies were examined. These studies represent the range of construction periods covered in the census and are therefore considered to be representative of the overall housing stock.

By understanding the current context, the aim was to provide an insight into how existing timber extracted from demolition might potentially be reused as is or reprocessed into timber products while also revealing how the connections might be improved. The study also highlighted where timber has weathered badly, either due to failure of weathering products, inadequate maintenance, or poor detailing, and how this might be detrimental to the potential reuse of the elements.

The data was gathered via desk analysis, using as sources material from the Irish Architectural Archive, recent examples of work provided by an engineering practice, and several houses forming part of the author's professional architectural practice and experience. Analysis of these sources found that despite the range in era of construction, the earliest dating from 1890 to the most recent from 2010, the building technology used in these low-density single-family dwellings has remained remarkedly consistent, with only minor deviations in dimension and technology.

***Figure 8:** Case Study photos (source. Donaghy + Dimond)*

A masonry outer leaf construction is typical in Ireland, either of brickwork or rendered blockwork. It typically consists of external and sometimes internal load bearing masonry walls, with timber use limited to ground, first floor and roof joists, non-loadbearing internal timber stud walls and a timber-cut truss roof structure (Figure 8). The most significant change observed from pre-2000 construction was the increased use of engineered timber products, such as I-joists and engineered trusses in the more recent developments.

This common Irish domestic typology has resulted in large footprints, with surprisingly significant and consistent amounts of quality timber components. Based on an analysis of 8 case studies, using building plans and sections (Figures 9 & 10), the amount of timber encapsulated in these housing types vary between 0.027 and 0.034 cubic meters per square meter of floor area, with an average of 0.031 cubic meters per square meter. Most of this timber has been protected from the elements, due to the use of a masonry outer leaf, and therefore remains in a good condition This points to a considerable amount of timber available for reuse currently stored in this 'material bank', suggesting that upwards of 46,000 cubic meters (25,300 tonnes) of timber could be recaptured in future if demolition practice evolved.

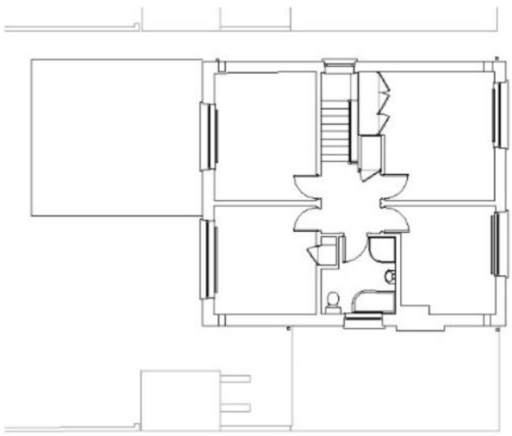

***Figure 9:** Case Study Floor Plan (Source. Donaghy + Dimond)*

Figure 10: *Case Study Sections (Source. Donaghy + Dimond)*

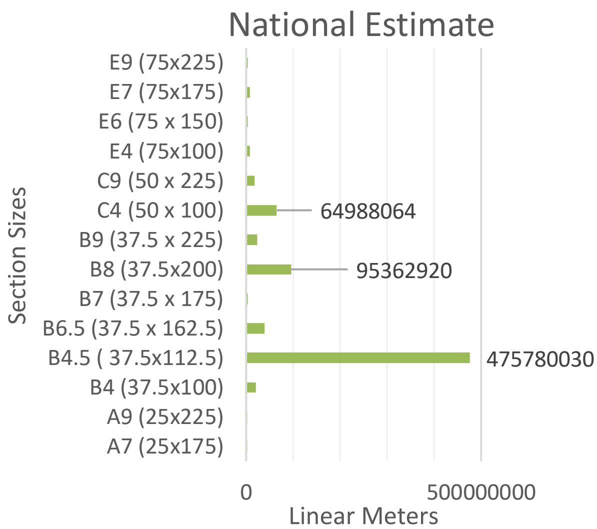

Figure 11: *Analysis model; Timber in Typical Irish house (source. author)*

The section sizes of encapsulated timber are also crucial to estimate, as it impacts its reuse or reprocessing potential in future scenarios. The volume of each of the common section sizes found in each type of house studied was cross referenced to the CSO data on house type by construction date [14] to obtain a national estimate of the inventory of timber encapsulated in current housing stock in Ireland (Figure 11). Based on this analysis, by far the most common section size used in Irish dwelling construction is 37.5mm x 112.5mm (1.5" x 4.5"). This section size accounts for approximately 60% of all linear meterage, for a total of an estimated 475 million linear meters. It is a section size that has considerable potential for reuse in its current form and a high potential for use in the fabrication of engineered wood products such as in Cross Laminated Timber (CLT) panels, the latter under study in the Infuturewood project by our partners at the National University of Ireland Galway, Universidad Politécnica de Madrid and the University of Ljubljana.

In some cases, site observations were possible in addition to the desk-based study of drawings. This revealed that damage due to dampness had largely occurred at wall plates for joists and eaves level for rafters, extending between 25mm and 150mm along the length of the element. This would reduce the useable linear meter of these elements as these damaged ends would be required to be removed. If found to be a common situation this could conceivably reduce the national estimate of available timber, of the 37.5mm x 112.5mm size, from 475 million linear meters to 425 million linear meters.

The manner in which elements are fixed in place or to other elements is equally important, as it may influence how easy or difficult it is to salvage these timber elements. On-site investigations revealed that a mixture of large truss nails and clout nails were used, with gang nail plates used on the more recent engineered truss roofs. Nails are considerably more difficult to remove than screws or bolts, influencing recovering time in demolition, while gang nail plates, used to connect two or more timber members together and typically seen in truss assemblies, are particularly difficult to remove without damage to the timber elements.

The analysis of the housing stock has highlighted the high amounts of potentially reusable material in the Irish 'material bank' but more importantly, the potential to allow for the reuse of material in future design.

3.4 LIMITATIONS

As mentioned above, the analysis of the housing stock has been limited to terraced, semi-detached, and detached houses, while omitting multi-unit dwellings. These studies have either been sourced from the author's architectural practice or from the Irish Architectural Archive on the Dublin Artisan Dwelling Company. Consequently, it was not possible to visit all the case studies to ascertain the current amount or condition of timber elements, which may have altered significantly due to renovation activity in the intervening years since its construction.

The information on construction of any buildings which were not visited was ascertained through archive drawings or drawings provided by practitioners involved on the projects. In cases where site visits were possible, and where material build-ups precluded a visual examination and measurement of a timber element, the depths of coverings (plasterboard, floorboards etc.) were estimated. Additionally, approximately two-thirds of the case studies were located in Dublin; however, it is not envisaged that there are significant differences in construction techniques elsewhere in the country.

The timber included as part of the assessment was limited to the structural timber in the buildings, primarily due to the research aims of the Infuturewood project, which is focused on structural engineering solutions. Thus the national estimates developed for encapsulated timber in Irish housing stock fails to account for a considerable amount of other timber elements, including floor boards, stairs, windows, doors and skirting boards, all of which could be successfully recaptured under an improved demolition practice, to be reused or repurposed for other uses. Thus, the national inventory developed for this project should be understood as an underestimate of all encapsulated timber in the existing Irish housing stock.

3.5 REVIEW OF CURRENT LITERATURE & DESIGN PHILOSOPHY

In a survey of 100 leading UK architectural practices by Osmani & Glass, it was found that only about 2% of practices designed for disassembly as a common practice [15]. This analysis suggests that information and tools for designing for disassembly and reuse must be developed and made more accessible if it is to become part of the everyday design in architectural practice. While many authors have discussed the main strategies and tactics for design for disassembly and reuse in isolation [16-19], there have been limited attempts to link the theoretical work to practical case studies.

Chisholm has attempted to address this lack of practical guidance through a study and discussion of more specific aspects of detailing. In this case study, a timber frame multistorey dwelling was examined and in particular, a typical floor-wall junction, to investigate potential for disassembly. Though the study represents an interesting examination of a detail through the lens of design for disassembly & reuse, it is limited to one junction which would have been developed in the detail design phase, while to achieve true circularity strategies would be required for each work phase of the design process. Additionally, the matrix mentioned by Chisholm largely refers to life cycle assessment, which though important, does not aid a designer in the practical aspects of the design process [20].

The Royal Institute of British Architects (RIBA), in their role of governing the practice of architecture in the UK, have developed guidance on the stages of design, similar in structure to many other national architectural accrediting bodies, such as the Royal Institute of Architects of Ireland (RIAI). In an effort to develop more practical guidance for the architectural profession, the Scottish Ecological Design Association (SEDA) have mapped strategies to these RIBA stages in their guidance document on *Design and detailing for deconstruction* [21]. However, the strategies outlined are broad and the document is reliant on designers and architects seeking out further information, rather than simply using this modified RIBA work stage document. The RIBA published a *Sustainability Guide to the Plan of Work 2013* [22], prepared by the GAIA Group, an interdisciplinary practice of architects, planners and researchers focused on sustainable design strategies, processes and technologies for the built environment. Though it makes reference to designing for disassembly, similar to the SEDA publication, it fails to offer sufficient detailed guidance to practitioners.

The literature review has highlighted that there is a lack of specific, detailed and accessible design guidance or tools to enable architects and engineers to successfully design for disassembly and reuse. The lack of specificity in these well-meaning guidance documents may be a result of attempting to provide guidance to any form of building and all types of construction. As the scale and type of construction used on a project will have significant implications for how to design for disassembly at each work stage, guidance has been reduced to generalisations that can be easily, though not effectively, applied to any project. It appears clear from this review that a more tailored approach, specific to either the scale of construction or the primary structural system used, or both, could provide substantially better guidance to architects and engineers. To this end the Infuturewood project has focused on buildings where timber is the primary structural unit, which will have implications for the direction and specificity of design guidance documents or tools, based on a variety of structural timber construction types (Figure 12).

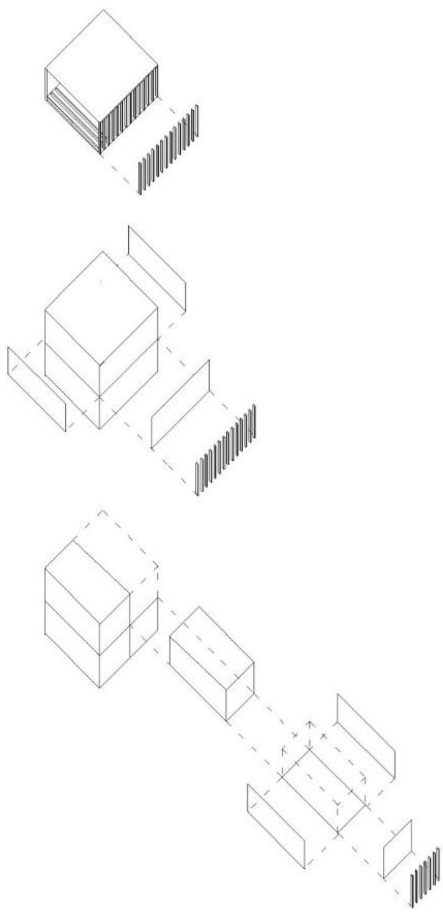

Figure 12: *Analysis model; Different levels of Timber construction (top: timber frame; middle: panel system; bottom: volumetric system) (source. author)*

3.6 DESIGN MATRIX; PRACTICAL IMPLEMENTATION OF DfDR PRINCIPLES

Due to economic and time constraints on professionals such as engineers and architects, it is important that any guidance document or a design tool intended to support Design for Disassembly & Reuse (DfDR) is both accessible and easily implementable. Any tool developed also needs to consider the costs of such a strategy as, for this approach to be successful, the client must be supportive of such innovations. From a client's perspective it should be as cost neutral as possible given the potential lack of return. Equally, any tool should also cover not only the design for future disassembly but also how salvaged materials might be incorporated into a design with the aim of reducing the construction budget and / or improving a sustainability rating.

A Design Matrix is proposed to address the limitations identified in the previous guidance documents, using the work stage template as an underlying structure, as this was the most valuable attribute to both the SEDA and RIBA documents. Several project work plans were considered, from a variety of national professional institutes, however the 2020 RIBA Workplan was chosen as this represents a widely accepted international standard and provides for modern procurement methods such as design and build.

A review of Design for Disassembly & Reuse (DfDR) literature was undertaken to identify principles and strategies for the different RIBA work stages. In conjunction with discussions with craftsmen and demolition contractors these principles and strategies were assessed from the perspective of timber construction to establish what methods might easily enable disassembly and future reuse of timber. This assessment has highlighted that simple traditional techniques, such as pre-forming holes (Figure 13), might ensure fixings can be removed easily following use with limited damage to the material, while not increasing the cost of construction prohibitively.

The common elements of the work stages (outcomes) coupled with the guidance from research on DfDR, classified as principles, strategies and tactics, have been interrogated regarding their applicability for timber construction and collated into a matrix (Figure 14). The intention is to provide clearer guidance for implementation of DfDR principles in practice at each stage of the design process. Thus, the matrix incorporates a different range of strategies and tactics appropriate to consider in each respective RIBA work stage. DfDR principles are also integrated into information exchanges defined at each stage by the RIBA, and specific design strategies and tactics combined with complimentary design tasks. The aim of the matrix is to enable a design team easily to assess what decisions to take at what stage, to enable the recapture and reuse of timber at demolition, to add value to timber components and structures.

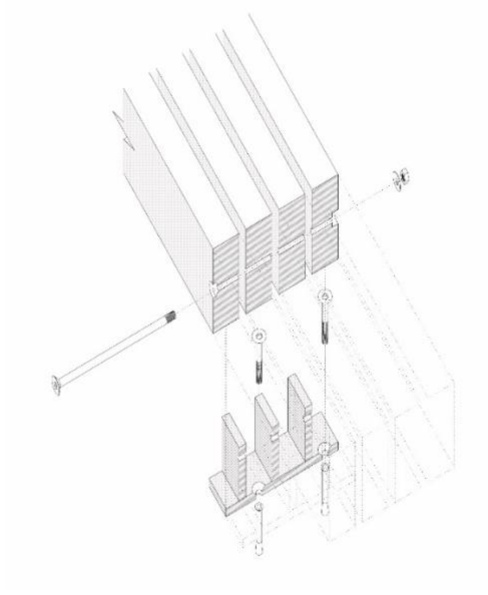

Figure 13: *Example of Design for Disassembly (source. AY Architects)*

	Typical Project Description (Source; RIBA Work Plan 2020)				DfDR Principle or Outcome			
4 TECHNICAL DESIGN	Stage Outcome	Core Tasks	Core Statutory Process	Information Exchange	DfDR Principle or Outcome	DfDR Strategy	Ref.	DfDR Design Tactics
	All design information required to manufacture and construct the project completed *Stage 4 will overlap with Stage 5 on most projects*	Develop architectural and engineering technical design Prepare and coordinate design team **Building Systems** information Prepare and integrate specialist subcontractor **Building Systems** information Prepare stage **Design Programme** *Specialist subcontractor designs are prepared and reviewed during Stage 4*	Submit Building Regulations Application Discharge precommencement Planning Conditions Prepare Construction Phase Plan Submit form F10 / AF2 to HSE if applicable	**Manufacturing Information** **Construction Information** **Final Specifications** **Residual Project Strategies** **Building Regulations Application**	Minimize resource consumption (Conserve)	*Stakeholder Engagement* *Planning in Advance* *Flexibility* *Layering* *Adaptability*		*Provide adequate tolerances for disassembly*
					Prevention (Building Reused)	*Whole design team, client and contractor need to be on board*	4,5,7	*Develop a deconstruction plan during the design phase*
					Maximize resource reuse (Reuse)	*Develop a deconstruction plan during the design phase*	3,4,5,7	*Design for maximum flexibility – to preserve the building as a whole*
					Material Reprocessed	*Allow for safe deconstruction*	2,3,4,5, 6,7	· *Use lightweight materials to facilitate easy handling of components.*
					Material Recycling	*Allow for disassembly at* **all scales** from materials to **whole buildings**.	2,3,4,5, 6,7	

Figure 14: *Draft Design for Disassembly Matrix (Source, Author)*

3.7 FURTHER STEPS

Through consultation with practitioners, craftsmen and demolition contractors, the matrix will be refined further to ensure it performs as intended. It will be complimented by and developed to work with a reusability indicator system, which will enable designers to assess the final impact of their design, similar to building sustainability assessment methods such as Breeam or Leed.

The Design Matrix will be further tested on prototypical designs developed using DfDR principles and tactics as outlined in the matrix, using various structural systems. The ambition is to increase the reversibility of traditional construction to maximise the quantity of timber components recovered for reuse. Following this prototype testing stage, the potential for a practical universal 'material passport' or 'marker' which will aid in the identification and tracking of the timber component or product will be developed.

4 CONCLUSIONS

Our analysis highlighted that a huge amount of waste timber, which is potentially suitable for reuse or remanufacture, is disposed of every year in Ireland. This fact, along with the significant quantities of potentially reusable structural timber in the Irish housing stock, highlights an opportunity and need for the development of accessible, practical guidance on the principles and strategies for DfDR that could be easily implementable in the design process and on site.

Despite the largely solid masonry construction, the low-density single-family housing typical to Ireland (and Western Europe) contains high volumes of quality timber components which can be found in good condition. However, due to the design of these dwellings, it is currently uneconomic for demolition contractors to extract the timber components intact, even when they could easily be reused or repurposed.

By understanding the consistency and nature of the existing housing stock as well as how we currently deconstruct buildings, relatively minor adjustments can be made to design, construction and demolition practices to generate significant opportunities for disassembly and reuse of timber components which would add value to timber products, buildings and reduce demand on virgin timber stocks from forestry.

However even minor adjustments can incur cost and delay in a design and therefore the incorporation of DfDR in a project must be as seamless as possible for it to be adopted in everyday practice. The Design Matrix, built on the foundation of the RIBA work stages, could address this need for an informative, accessible guidance tool for professionals.

5 ACKNOWLEDGEMENT

This work has been undertaken under the supervision of Dr Elizabeth Shotton, Associate Professor, School of Architecture, Planning and Environmental Policy, University College Dublin as part of a research Masters degree.

This research is part of the InFutUReWood Project, Innovative Design for the Future – Use and Reuse of Wood (Building) Components Project. InFutUReWood is supported under the umbrella of ERA-NET Cofund ForestValue and the Department of Agriculture, Food and the Marine in Ireland. The research is being undertaken in conjunction with Research Institutes of Sweden, Edinburgh Napier University, National University of Ireland Galway, Polytechnical University of Madrid, University of Ljubljana, Aalto University, and the Technical University of Munich.

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