

ISSN 2759-7318 (Online)
ISSN 2760-327X (Print)

S B E

JOURNAL OF SUSTAINABLE CIVIL ENVIRONMENT

VOLUME 3
NUMBER 2
MARCH 2026



Issue

Volume 3, Number 2 (March 2026)

Publisher

株式会社間渡出版 (Jandoo Press Co., Ltd.)
Tokyo office: 1-53-13 Nishigahara, Kita City, Tokyo 114-0024, Japan
Tel: +81 3-6823-8813
Email: contact@press.jandoo.ac

Journal info

Portal: <https://jandoopress.com/journal/jsbe>
ISSN 2759-7318 (Online)
ISSN 2760-327X (Print)

Copyright

© 2026 by the Author(s).

Journal statement

1. The views, interpretations, and conclusions expressed in the articles published in the Journal of Sustainable Built Environment (JSBE) are solely those of the authors and do not necessarily represent those of the Editorial Board, the Editorial Office, or the publisher. Authors bear full responsibility for the accuracy, integrity, and legality of the content they submit and publish.
2. JSBE is an open access journal. Unless otherwise stated, all articles published in the journal are made available under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0) License (<https://creativecommons.org/licenses/by/4.0/>). Under this license, anyone may read, download, copy, distribute, reproduce, print, adapt, and reuse the published material in any medium or format, provided that appropriate credit is given to the original author(s) and source, a link to the license is provided, and any changes made are clearly indicated.
3. Authors retain copyright in their work. By submitting a manuscript to JSBE and agreeing to its publication upon acceptance, authors grant the journal the right of first publication and a non-exclusive license to publish, disseminate, archive, index, preserve, and display the work in electronic, online, and related formats for academic communication and public access.
4. Authors must ensure that their submissions are original, do not infringe any copyright or other legal rights of third parties, and are not under consideration elsewhere at the time of submission, unless clearly disclosed to the journal. Where images, tables, long quotations, or other third-party materials are included, authors are responsible for obtaining any necessary permissions prior to submission and for providing appropriate acknowledgements where required. Any dispute arising from copyright infringement, academic misconduct, or other legal deficiencies remains the responsibility of the author(s).
5. All submissions are subject to editorial review and peer review in accordance with the journal's policies. The journal reserves the right to make necessary editorial revisions to accepted manuscripts for clarity, consistency, language quality, formatting, referencing style, and house style, provided that such revisions do not alter the academic substance of the work. Substantive changes affecting content or interpretation will be made only in consultation with the author(s).
6. A DOI is assigned to each published article to support persistent identification, citation, dissemination, and long-term accessibility. Once an article is formally published, the digital version hosted on the journal's official website shall be regarded as the version of record.
7. Manuscripts must be submitted through the journal's official submission channel or website. Submitted materials are generally not returned. If no decision is communicated within three months of submission, authors may withdraw the manuscript and submit it elsewhere.
8. JSBE is committed to the principles of academic integrity and publication ethics. In cases of plagiarism, fabrication, falsification, duplicate submission, improper authorship, or other forms of academic misconduct, the journal reserves the right to reject, retract, correct, or otherwise address the publication in accordance with established editorial and ethical standards.

Official print edition notice

1. In addition to the digital edition published on the journal's official website, the journal may produce a limited number of official print copies primarily for submission, archiving, and review purposes. Official printed copies may also be provided to article authors upon request.
 2. The availability of official print copies does not alter the open-access status of the content. All published materials remain available under the Creative Commons Attribution 4.0 International License (CC BY 4.0), and may therefore be downloaded, reproduced, printed, and reused in accordance with the terms of that license.
 3. Where authors request official printed copies, the related production and delivery costs shall be borne by the requesting author(s). Charges are determined according to the length of the issue concerned. Please contact the Editorial Office for further details.
 4. For citation, indexing, and version-control purposes, the digital version published on the journal's official website shall be regarded as the version of record. Printouts made from downloaded PDF files do not constitute official print editions.
-

JOURNAL OF SUSTAINABLE BUILT ENVIRONMENT

JSBE is an open-access, peer-reviewed journal dedicated to publishing research on sustainability in urban and regional development. Covering topics such as climate adaptation, sustainable infrastructure, urban economics, and green building. JSBE serves as an interdisciplinary platform for academics, policy makers, and professionals focused on creating resilient and sustainable environments.

Editor-in-Chief

Eamonn Canniffe
University of Manchester, Manchester, UK

International Editorial Board

Colin Harwood
University of Manchester, Manchester, UK

Ke Xie
Hefei University of Technology, Hefei, China

Tao Hong
Anhui Jianzhu University, Hefei, China

Yan Li
Northwestern Polytechnical University, Xi'an, China

Chengcheng Yu
Tongji University, Shanghai, China

Yichao Shi
Georgia Institute of Technology, Atlanta, USA

Yuhao Gu
International Institute of Management and Business, Minsk, Belarus

Xiaoxiao Liao
Keio University, Tokyo, Japan

Mark Baker
University of Manchester, Manchester, UK

Zhenlin Xie
Hefei University of Technology, Hefei, China

Chang Xu
Sichuan University of Science & Engineering, Zigong, China

Mingdong Jiang
Southeast University, Nanjing, China

Yangling Li
National University of Singapore Wei Wang University of Washington, Seattle, USA

Yue Chen
Beijing University of Civil Engineering and Architecture, Beijing, China

Sokuncharia Srey
Waseda University, Tokyo, Japan

Peiyi Fan
Sapienza Università di Roma, Roma, Italy

Assistant Editors

Xilin Zhang
Shandong Huayu Institute of Technology, Dezhou, China

Liwei Yang
Yunnan University, Kunming, China

Yudong Wu
Dongshin University, Naju, South Korea

Contents

1

Research article

**A Physical Audit of DfD Performance in a Panelised - Modular
Construction System**

Patrick Daly, Paula Gallego

A Physical Audit of DfD Performance in a Panelised - Modular Construction System

Patrick Daly ^{1,*}, Paula Gallego ¹

Received 24 February 2026

Revised 20 April 2026

Accepted 27 April 2026

Published 8 May 2026

Abstract: Prefabricated, panelized over-cladding façade systems are promoted as a means of accelerating the decarbonization of existing building stock while enabling circular construction practices. Although pilot projects have demonstrated the technical feasibility of this approach, significant challenges remain in defining and measuring circularity - disassembly performance in practice. This study investigates the application of prefabricated and modular systems in deep energy retrofit projects, with particular emphasis on integrating circularity principles - advanced design for disassembly (DfD) within the design and construction process. The paper outlines the rationale, methodology, and findings from a detailed physical audit assessing DfD performance in a pilot mock-up of a modular circular wall panel developed for retrofit within an Irish social housing demonstrator under the Drive 0 project. A novel DfD audit method was employed to evaluate actual disassembly and reassembly performance. Results indicate that DfD principles were largely successful in practice, with substantial potential for reuse and reassembly of elements, components, and materials across multiple levels of the construction hierarchy. Only minor damage and limited material loss, primarily associated with jointing systems, were observed. The mock up and audit also identified opportunities for system refinement to enhance disassembly efficiency, alongside broader architectural and technical improvements. Furthermore, the findings correlate with and provide validation for an innovative design-stage assessment method for disassembly. Overall, the research contributes to the growing body of knowledge on circular construction, addressing key gaps related to empirical physical validation of design for disassembly in case practice, holistic and hierarchical design for disassembly methodology advancement and validation, empirical design and prototyping of modular circular retrofit application, benchmarking to standards and other demonstrators.

Keywords: Design for disassembly (DfD); Circularity; Prefabrication; Modular systems; Retrofit; Architectural technical design



ISSN 2759-7318 (Online)
ISSN 2760-327X (Print)

© 2026 The Author(s)
Published by Jandoo Press Co., Ltd.

This article is licensed under the terms and conditions of the Creative Commons Attribution (CC BY) license:
<http://creativecommons.org/licenses/by/4.0/>

Introduction

Overview

The built environment has been identified as having significant sustainability impacts, leading to increased policy, legislation, and practice initiatives toward sector transition. Circular economy principles present a pathway to delivering sustainability aims, including greater resource efficiency, waste and pollution reduction, and decarbonization. However, transitioning the construction industry toward greater circularity presents several challenges, including unclear concept

definitions, diverse assessment methods, limited case applications, and the specific complexity of the built environment itself. Design for disassembly (DfD), as a key enabler of both technical and biological cycles, is central to circularity and value retention yet remains a significant research and practice gap ([Daly & Barril, 2025](#); [Gasparri et al., 2023a](#); [Hossain & Ng, 2018](#)).

This research examines the integration and performance of circularity principles, specifically advanced DfD, in the design and realization of a panelized-modular wall system applied in social housing energy retrofit in Ireland. The paper

¹School of Architecture Building and Environment, Technological University of Dublin, Dublin D01 K822, Ireland.

* Corresponding author. Email: patrick.daly@tudublin.ie

presents a comprehensive physical audit assessing the DfD performance of a prototype prefabricated circular wall panel system developed for the EU Drive 0 project, which aims to accelerate housing decarbonization through modular construction retrofit solutions across European demonstration sites ([Drive 0, 2023](#)).

The principal innovation centered on designing, developing, testing, and deploying a modular wall construction guided by circular design principles. This included prototype mock-ups that facilitated detailed auditing of actual DfD performance, examining whether design intent was achieved in practice, at what performance level, and with what implications for research and practice.

Research questions

This research addresses critical questions in modular construction and circularity assessment:

- RQ1.** How can advanced design for disassembly be determined, implemented, and assessed in real-world modular retrofit practice?
- RQ2.** Can DfD design principles be effectively implemented across all construction hierarchy levels (element, component, material)?
- RQ3.** Can design-stage DfD assessment methods predict actual disassembly performance?
- RQ4.** What material impacts and reuse potentials are achieved through hierarchical DfD strategies?
- RQ5.** How does modular DfD performance compare to conventional retrofit systems and international benchmarks?

Research overview

The paper summarizes research methods, contextualizes the work within existing literature, introduces the Irish Drive 0 case study and modular over-cladding solution, describes the prototype design, and reports on the planning and execution of a detailed DfD performance audit. The STaMPD (Systems, Technical, Materials, Process, Data) DfD framework ([Daly & Gallego Barril, 2025](#)) serves as both the design guidance structure and audit reporting framework, leading to critical discussion, conclusions, and validation support for the STaMPD method.

[Figure 1](#) presents a schematic overview of the project scope and research presented in this paper, including the Drive 0 case dwelling context, the modular wall system, design development of the mock-up, and the DfD auditing method and its implementation across mock-up stages, with reporting on results, findings, and analysis.

Research contributions

This research contributes to emerging knowledge in circular construction by addressing several identified gaps:

1. Empirical validation of DfD design intent through comprehensive physical auditing across construction hierarchy levels;
2. Methodological advancement through validation of a design-stage assessment tool (STaMPD) against real-world disassembly outcomes;
3. Practical evidence of modular system application in retrofit contexts with integrated circularity principles;
4. Comparative benchmarking against international DfD standards and other leading validated research projects demonstrating reversibility of modular systems for secondary validation.

The research relates to knowledge gaps in modular systems application in retrofit, achieving and assessing DfD at all construction levels, and real-life case validation ([Hossain et al., 2020](#); [Ahn et al., 2022](#); [Khadim et al., 2022](#); [Tokazhanov et al., 2022](#); [Munaro & Tavares, 2021](#)).

Methods

Research approach

This innovative research arises from several knowledge gaps, notably contributing to circularity/DfD assessment and practice within the context of designing, developing, prototyping, testing, and realizing a prefabricated over-clad wall system applied in a housing retrofit project.

The research combines qualitative and quantitative methods in a mixed-method approach framed as an inductive, grounded, bottom-up detailed case study ([Yin, 2018](#); [Stake, 1995](#)). It utilizes various research methods and data sources (both hard and soft data) and explicates practitioner-researcher empirical perspectives on the novel design and testing of a prototype mock-up modular wall system focused on DfD performance ([Daly, 2023a](#); [Daly & Gallego Barril, 2025](#); [Johansson, 2003](#); [Groat & Wang, 2004](#)).

Methods overview

The DfD performance audit comprised a range of integrated research methods:

- Design Research and Case Study Framework: Performance-based design theory incorporating mixed methods within a case study research framework, including iterative design research with both quantitative and qualitative approaches.
- Literature Review: Detailed review on modular systems in retrofit and circularity to contextualize the work and identify knowledge gaps. A secondary review on DfD assessment methods informed the development of the STaMPD framework.
- DfD Assessment Method: Drawing from literature critique and the Drive 0 method ([Daly, 2023a](#)), the STaMPD DfD assessment method was designed and piloted ([Daly & Gallego Barril, 2025](#)) and is used as the framework for reporting and recording DfD performance in the physical audit.

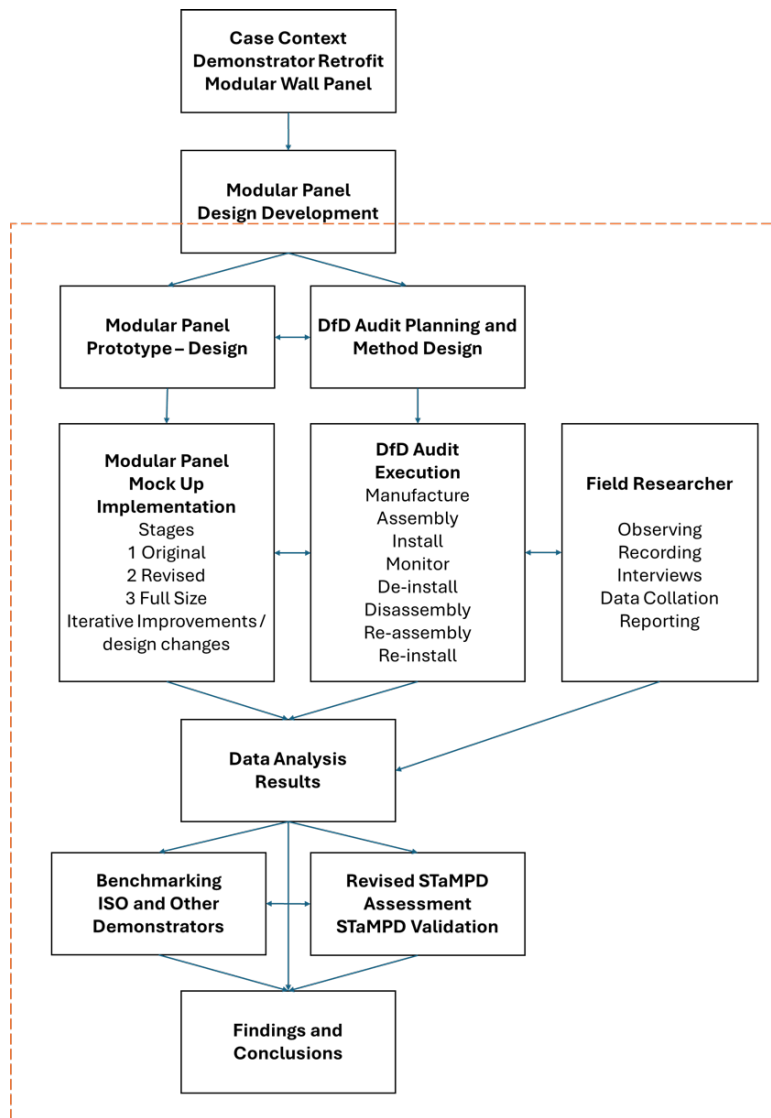


Figure 1 | Schematic showing research scope and actions in context of case demonstration and design and execution of prototype modular wall solution with integral DfD Audit, STaMPD assessment and benchmarking

- **DfD Audit Design and Implementation:** A detailed DfD auditing plan was developed incorporating three main stages assessing assembly, installation, de-installation, disassembly, re-assembly, and re-installation. Data collection utilized observation, semi-structured interviews, material and product impact assessment, and documentation analysis. The physical audit was conducted across all mock-up stages with observations and data recorded according to the audit plan.
- **DfD Audit Analysis and Reporting:** Data and results were collated and reported using the STaMPD DfD framework, providing structured performance auditing and facilitating comparison to design-stage assessments.

DfD audit plan

A high-level plan for physical DfD audit was developed comprising three main stages, each with auditing/recording

activities for analysis at each construction hierarchy level, comprising observation, recording (using photos, video, and notes), collation of documents for analysis, and interviewing manufacture, engineering, and installation staff.

Key stages

Stage 1: Manufacture, Transport, Installation, and In-situ Observation. Covered manufacture, transport, installation, and a period observing in-situ performance while exposed to external weather conditions.

Stage 2: De-installation, Disassembly, and Re-assembly. Involved first actual disassembly across multiple construction levels:

- Level 1 (Element): De-installation of upper panels intact from host wall
- Level 2 (Component): Disassembly of wall-to-window components

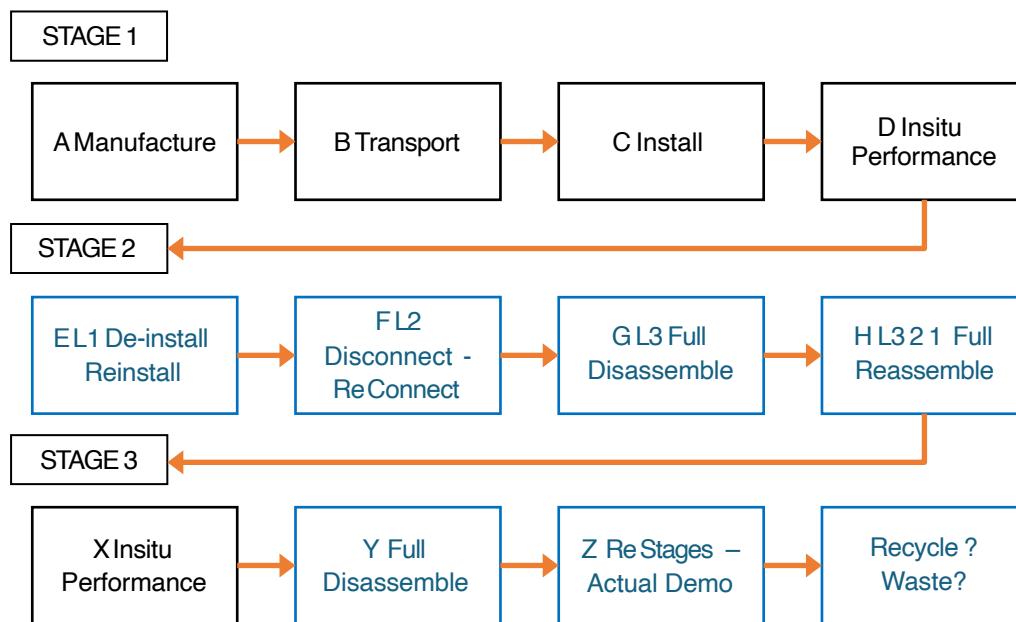


Figure 2 | Schematic of physical DfD auditing plan showing proposed stages of manufacture, installation in situ assessment and partial and full disassembly and re-assembly and re-installation, with specific DfD audit stages in blue

- Level 3 (Product/Material): Full disassembly of entire panel back to base materials and products, followed by full re-assembly

Stage 3: Re-installation and Supplemental Testing. Involved re-installation of panels and observation of another period of in-situ performance in external conditions prior to final full disassembly, including supplemental under-eaves installation trial (See [Figure 2](#)).

Impact assessment and re-application framework

A key focus of the physical DfD audit was assessing the impact of disassembly on elements, parts, products, and materials and their re-assembly and re-application potential. A simple reporting and scoring framework based on Likert type scale was developed comprising five levels of impact ranging from none to severe (score 1 to 5) with lower scores meaning poorer performance and visa versa. Framework included definition, description, and example of each, with corresponding re-application potential identified, which also had five levels ranging from highest re-use to lowest recycled levels.

See [Appendix 1](#) for complete Impact and Re-application Assessment and Scoring Guide.

Fieldwork and data collation

Given the extent of information required to undertake the DfD Audit, it was proposed that a researcher should be on site during all stages to undertake the required observational study with key data recording and collation as follows.

1. Observation: Observe all aspects of the works and record by various means, requiring safe access.
2. Recording: Record all relevant aspects of the work via notation, sketches and photo / video.

3. Interviews: Undertake a combination of informal (during works) and semi structured interviews (on completion).
4. Documents Review: Collate all relevant documents, drawings, schedules, specifications etc., for review and analysis.
5. Data Collation: Several templates and guides were developed to assist research, reporting and collation of data including use of material impact and re-application scoring, general reporting via STaMPD framework and interview questionnaires.

Researcher Context: The research team comprised design professionals involved in the modular panel design, Drive 0 circularity assessments, and research/development of the STaMPD assessment method itself, providing essential knowledge and insight into design circularity principles, DfD assessment, and auditing intent and method.

Limitations: Some modification and adaptation to planned researcher observation and recording during works was required, notably for transport and revised supplemental Stage 3b full scale panel install test, where non-researcher presence required reliance on manufacturer reporting and interviews- as noted in Section 6. However all key DfD activity was undertaken in presence of technical researcher.

Reporting framework

Collated data from fieldwork study was documented and reported using the STaMPD category framework, facilitating comparison to design-stage STaMPD assessment and validation support of the method. The reporting framework comprised five categories:

- Systems: Interrelationship between parts and elements and resulting system complexity. Key indicators: product

standardization, geometry, functional independence, part relationships, number of components, nature of connections and fixings.

- Technical: Physical assembly and disassembly of connections. Key indicators: edge and interface detailing, connection type, accessibility, tolerance management.
- Materials: How material properties influence DfD performance. Key indicators: toxicity, durability, resilience, material diversity, chemical composition.
- Process: Methods by which components are assembled, disassembled, and reassembled. Key indicators: fabrication location, production and transport processes, on-site assembly, tools, storage, safety, knowledge and skill levels, operational complexity, time.
- Data/Information: Availability and quality of supporting information enabling effective DfD implementation. Key indicators: construction and material documentation, disassembly instructions, safety guidance.

Literature Review

Context

The building and civil sector consumes approximately 3 billion tons of raw materials annually ([World Economic Forum & The Boston Consulting Group, 2016](#)) and accounts for 32% of global energy consumption ([Lucon O. et al., 2014](#)). In response to this resource intensity ([Benachio et al., 2020](#)), ([Joensuu et al., 2020](#)) the EU has introduced significant policy and legislative initiatives focused on sustainability ([European Commission, 2012](#)) energy efficiency ([European Commission, 2011](#)) and circular economy principles ([European Commission, 2014](#)). Ireland is advancing similar objectives through the Climate Action Plan ([Department of the Environment, 2023](#)) and Circular Economy Act ([Govt Ireland, 2022](#)) supported by frameworks from the Irish Green Building Council ([IGBC, 2022](#)), ([IGBC, 2025](#)).

Circularity and design for disassembly

Circularity represents a paradigm shift from linear "extract, produce, dispose" models to regenerative systems maintaining continuous resource flow ([Ellen MacArthur Foundation, 2014](#)). Building on earlier frameworks ([Shooshtarian et al., 2021](#)) including cradle-to-cradle ([McDonough & Braungart, 2002](#)), regenerative design ([Lyle, 1996](#)), and closed-loop strategies ([Stahel, 1982](#)), circularity is increasingly recognised as significant within the built environment ([Mhatre et al., 2021](#); [Charef & Lu, 2021](#)). However, standardised definitions remain elusive, with numerous frameworks, criteria, and metrics proposed ([Kirchherr et al., 2017](#); [Saidani et al., 2019](#)), ([Parchomenko et al., 2019](#)).

Design for disassembly is widely regarded as central to circular construction, facilitating recovery and reintegration of building materials and elements back into supply chains ([ISO, 2021](#)), ([Bakx et al., 2016](#); [Mazzoli et al., 2022](#); [Gasparri et al., 2023](#)).

Despite its relevance, both circularity and DfD remain under-researched, particularly regarding comprehensive life-cycle assessment methodologies ([Ness & Xing, 2017](#); [Ghisellini et al., 2018](#); [Hossain & Ng, 2018b](#); [Singh et al., 2021](#); [Andersen et al., 2022](#); [Benachio et al., 2020](#)).

The literature identifies several methodological gaps, including the need for holistic circularity assessment methods and tools in construction ([Tokazhanov et al., 2022](#)), for the early design stages ([Munaro & Tavares, 2021](#)), and case-based verification ([Hossain et al., 2020](#); [Bucci Ancapi et al., 2022](#)), ([Wuni, 2022](#)). Additionally, there is a call for the development of comprehensive indicators ([Hossain & Ng, 2018](#); [Hossain et al., 2020](#); [Ahn et al., 2022b](#); [Khadim et al., 2022b](#); [Tokazhanov et al., 2022](#)) and the quantification of performance, benefits and value ([Bucci Ancapi et al., 2022](#); [Wuni, 2022](#); [Gasparri et al., 2023](#)). There are ongoing technological knowledge gaps, particularly in advancing DfD to enable deconstruction for reuse, facilitate disassembly and promote greater standardization ([Hartwell et al., 2021](#)). Furthermore, it is essential to investigate the relationship between modularity and circularity, as well as the role of off-site manufacturing and construction, through practical case studies ([Machado & Morioka, 2021](#); [Osobajo et al., 2022](#)). The development of circular solutions and typologies faces several barriers ([Eberhardt et al., 2022](#)), and there is a recognized need for further exploration of circularity in the retrofitting of existing buildings, an area that has been largely under explored ([Andersen et al., 2022](#); [Gasparri et al., 2023](#)).

Modular construction / Retrofit

Modular construction involves off-site fabrication of building elements in controlled factory environments, with prefabricated modules transported for final assembly at construction sites ([Modular Building Institute, 2024](#)). Claimed advantages include standardization, simplicity, mass production potential, cost reduction, shortened timelines, improved maintenance, adaptability, ease of disassembly, and design flexibility through interchangeable components ([Kamrani & Salhieh, 2002](#); [Miller, 1998](#); [Miller T.D., 1997](#); [Du et al., 2019](#)).

Across Europe, modular construction is increasingly applied to energy retrofits, supported by research, innovation, and demonstration projects. The International Energy Agency's Annex 50 evaluated demonstration projects using prefabricated façades in apartment retrofits, reporting benefits including enhanced energy efficiency, improved occupant comfort, higher construction quality, cost-effectiveness, better space utilization, and substantially reduced retrofit durations with minimal occupant disruption ([Zimmermann, 2011](#)).

D'Oca et al. ([2018](#)) reviewed approximately 30 EU-funded deep energy retrofit projects, many incorporating prefabrication in energy systems or façades ([D'Oca et al., 2018](#)). Notable examples include the INSPIRE project (2012–2016), which developed timber-based modular façade systems integrating micro heat pumps and ductwork, and the MORE-CONNECT project, which achieved NZEB standards with multifunctional prefabricated façades and roofs, reducing installation time from two months to five days. A wide range of modular retro-

fit strategies has been developed, including opaque wood-based vertical panels (Callegari et al., 2015), flexible wood-based façade systems adaptable to different structural types (Sandberg et al., 2016), preassembled insulated panels for façade and roof retrofitting (Pittau et al., 2017; Torres et al., 2021), and systems incorporating renewable energy technologies applied across diverse climatic conditions and building typologies (Du et al., 2019; D'Oca et al., 2018). While these projects demonstrated the technical feasibility of modular retrofits, few included rigorous physical DfD demonstration and auditing, a gap this research seeks to contribute to.

The literature identifies several challenges, with Hu Du et al. outlining key issues in their review of Modular Façade Retrofit with Renewable Energy Technologies (MFRRn). These challenges are categorized into technical aspects, including modular design, fixation method, integration of renewable energy systems, and addressing site-specific variations and tolerances. Financial issues such as performance, market penetration, business models, and supply chains, along with concerns related to warranties and servicing, are also highlighted, (Du et al., 2019). Torres et al. identify two major technical challenges: the integration of systems across a diverse range of real-world buildings and the adaptation of these systems to accommodate structural irregularities, (Torres et al., 2021). In a review of European projects, Pope identified several key challenges for scaling up modular energy retrofitting, including the development of multi-stakeholder supply chains, regional regulatory variations, the establishment of common protocols, data transfer systems, and tools for building data capture and sharing. Additionally, addressing the diversity of building typologies and archetypes, and developing innovative financing solutions, particularly for tenant-owner issues, were noted as critical factors. Pope further emphasized that, until the market reaches sufficient scale to drive down costs, increase investment, and stimulate workforce growth, governmental support may be necessary to advance the sector, which may otherwise remain marginal, (Pope, 2024). In their comprehensive review of four Horizon 2020-funded modular retrofit projects, S. D'Oca et al. emphasize that the primary challenges are not technical in nature, but rather relate to awareness, knowledge gaps, and excessive investment costs (D'Oca et al., 2018).

Modular System Design and Development Case demonstrator and design concept

The Irish demonstrator retrofit targeted a significant 65% energy upgrade to two 1970s social houses of masonry wall and timber roof construction, which had undergone some previous retrofitting works. The principal innovation was to design and pilot a novel modularized wall panel for wall over-cladding based on circular and DfD principles.

The system was based on adaptation of an existing light gauge steel (LGS) structural wall system into a prefabricated 'closed' wall unit for over-cladding application. Concept designs were developed for overall energy retrofit, including architectural elevations for modular plug-and-play wall over-cladding and extension to the front elevation.

The proposed modular wall panel comprised 89mm LGS stud framing with bio-based quilt insulation between studs, membrane, and 25mm compressible insulation with neoprene edge seals to reduce thermal looping behind the panel. The external build-up included wood fibre board, breather membrane, battens, cement board, and render finish, designed to achieve a target U-value of 0.18–0.20 W/m²K, in excess of Irish regulatory retrofit wall back stop U-value of 0.35 W/m²K and toward new build standard of 0.18 W/m²K for walls.

Hierarchical design for disassembly strategy

A key element of design development was integrating circularity principles with particular emphasis on advanced DfD. This approach was shaped by circularity/DfD assessments undertaken in the Drive 0 project and findings from wider literature review. The Drive 0 assessments, informed by Alba Concepts (van Vliet et al., 2021) and indicators proposed by Durmisevic (2006), were simplified and adapted throughout the project. A critical review revealed both their value in supporting design but also limitations, including narrow methodological scope, evolving indicators, inconsistent data sources, lack of weighting for bio-based materials, absence of building hierarchy perspective, and lack of unifying benchmark (Daly, 2023).

These insights led to strong design focus on DfD as a central enabler of circularity, particularly within the technical cycle. The design strategy aimed to enable DfD across all construction levels—panel, component, and material—ensuring value retention at each level. This approach allowed modular panel de-installation from the host wall for potential reuse or further disassembly into components (e.g., wall-to-window/cill interfaces) and base materials for reuse or recycling. See [Figure 3](#).

STAMPD method

The critique of the Drive 0 framework and focus on DfD led to the creation of a proposed holistic DfD assessment method—STAMPD, (Systems, Technical, Material, Process, and Data). Developed from detailed literature review—beginning with Durmisevic (2006a), Guy et al. (2007), Akinade et al. (2017), Vliet (2018), Drive 0 Deliverable 6.1 (2020), and ISO 20887 (ISO, 2020a)—the STAMPD framework harmonises a broad range of DfD indicators into a coherent structure.

The method distinguishes between what is physically assembled (Technical, System, Material) and how it is assembled and disassembled (Process, Data). From an initial pool of 49 indicators identified in literature, 29 were refined and harmonized into the STAMPD framework. The 29 indicators are distributed across Systems (6), Technical (7), Materials (5), Process (6), and Data (5), with each indicator tied to a specific construction hierarchy level (element, component, material), providing transparent coverage across the modular retrofit system. This framework was then developed into a detailed assessment tool with a simple scoring system, for pilot application during design of the modular 2D wall system prototype. STAMPD also served as a guide and framework to report and assess the DfD audit, which in turn was used for valida-



Figure 3 | Showing case dwellings, pre-retrofit works and proposed modular panel assembly. Source Authors and Coady Architects

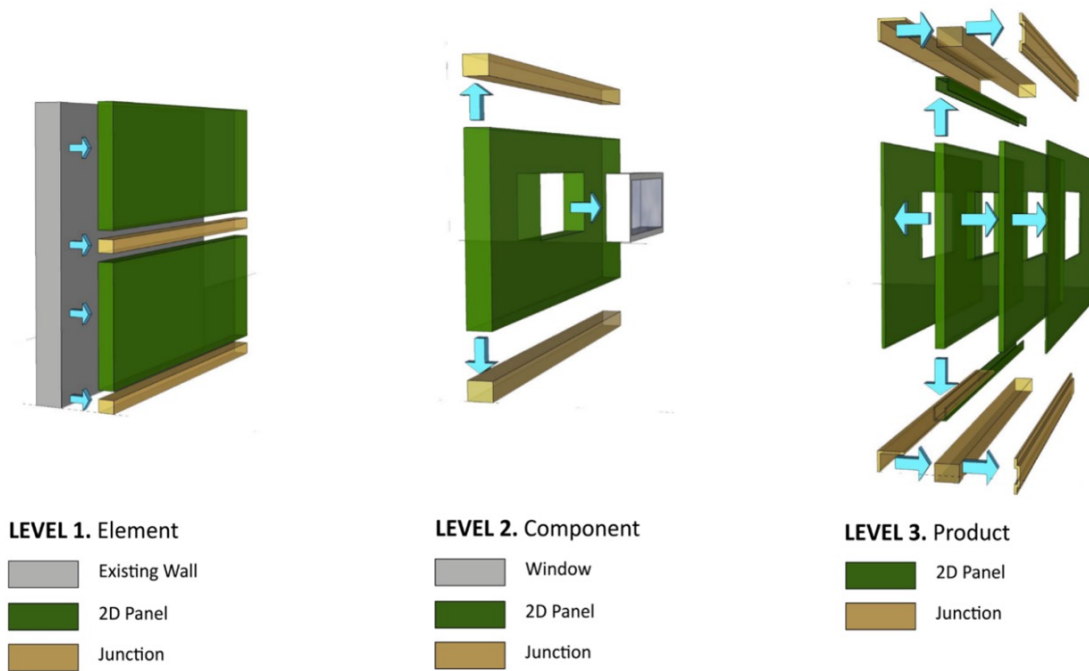


Figure 4 | Concept graphic showing proposed panel system hierarchical disassembly over three levels, wall, component and product / material

tion support of the STaMPD method, (Daly & Gallego Barril, 2025). See Figure 4 for summary overview of method including list of 49 indicators and associated categories.

Structural and technical design

The panelized/modular wall system was designed to achieve structural integrity, thermal over-cladding, weathering, aesthetics, long-term durability, and disassembly capability in full compliance with relevant European and Irish standards. The frame forms a non-load-bearing over-cladding panelized system, secured to the existing masonry structure using adjustable brackets.

Design for disassembly features

Design workshops focused on supporting disassembly at all construction hierarchy levels. A key detail is shown in Figure 5: The horizontal access junction incorporates a steel bracket providing independent gravity support and restraint for each panel, eliminating the need to directly fix the panel to the host wall. A 150mm zone at head junction allows drop-on and lift-off installation and provides clearance under roof eaves. Maintaining space between first-floor window head and eaves was critical to facilitate horizontal studs in upper panels. Vertical junctions were butt-jointed and sealed with neoprene gaskets and elastomeric mastic, facilitating panel movement while ensuring weather-tightness.

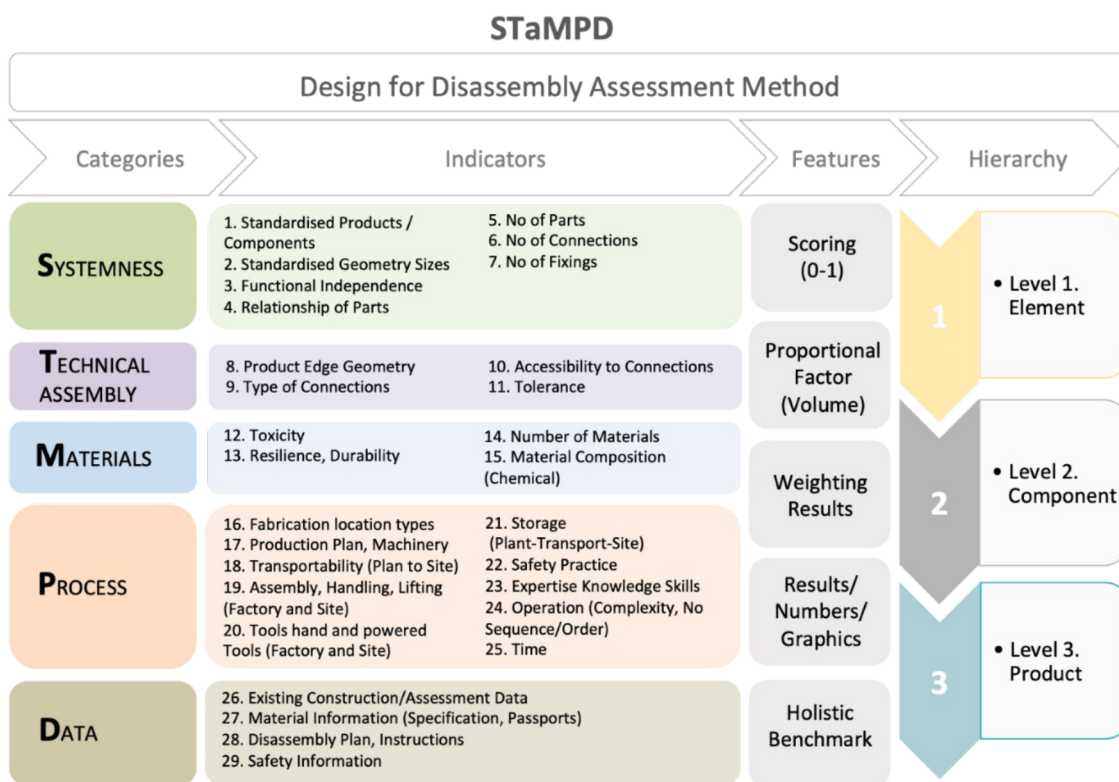


Figure 5 | Showing overall scope and structure of STaMPD method – main categories, Systems, Technical, Materials, Process and Data, indicators, key features and construction levels (Daly & Gallego Barril, 2025).

Structural compliance

Although non-load-bearing, panels were designed to support self-weight and withstand wind loads, transferring forces to existing masonry via the bracket and restraint system. Structural design adhered to principles outlined in Eurocodes (0–6) and corresponding Irish National Annexes¹, achieving compliance with Part A of the Irish Building Regulations ([Building Regulations 2012 : Technical Guidance Document. A, Structure](#)). Wind forces were evaluated in accordance with Eurocode 1, with Eurocode 0 load and safety factors. Frames and brackets were designed to Eurocode 3 requirements. Steel elements were protected according to EN ISO 12944² appropriate to exposure conditions. Existing masonry was assessed to Eurocode 6/SR 325³, ensuring sufficient capacity of bracket connections.

Figure 6 illustrates initial bracket design, which enabled drop-on/lift-off action for panel installation and removal from the existing wall, designed and installed according to established best-practice guidance ([British Standards Institution \(BSI\), 2021](#)). Panel lifting straps/anchors were designed to EN 13155⁴. Exposed steel components were hot-dip galva-

nized for corrosion protection and were redesigned/tested during the mock-up stage to allow greater movement, tolerance, uplift, and deflection.

Although conceived as non-load-bearing elements, the modular panel can function as a load-bearing wall, allowing potential future secondary structural reuse—facilitating circularity objectives through cascading value retention.

Prototype mock-up

A key requirement of the Drive 0 project was piloting proposed designs in a scale mock-up prior to full realization in case dwellings. This proved invaluable for design refinement and provided opportunity to undertake physical audit of proposed DfD performance. A comprehensive mock-up briefing plan and document was prepared, defining aims and objectives combining technical, aesthetic, and DfD performance auditing requirements.

The final mock-up design comprised several wall over-cladding panels and extension wall/roof panels—collectively representing all panel and junction types expected in full-scale retrofit. The mock-up was installed on an external wall at the manufacturer’s facility and left in situ for weathering exposure during final design stages (**Figure 7**).

DfD Audit Results

Stage 1: Manufacture, transport, and installation

Stage 1 encompassed the manufacture, transport, installation, and initial weather exposure of the modular panels, en-

¹ I.S. EN 1990–I.S. EN 1996, Dublin: National Standards Authority of Ireland (NSAI, 2010)

² EN ISO 12944:2018 – Corrosion Protection of Steel Structures, Geneva: International Organization for Standardization (ISO 2018)

³ S.R. 325:2013 + A1:2015 Recommendations for the Design of Masonry Structures in Ireland to Eurocode 6 (NSAI, 2015)

⁴ EN 13155:2020 Crane — Safety — Non-fixed load lifting attachments (CEN 2020)

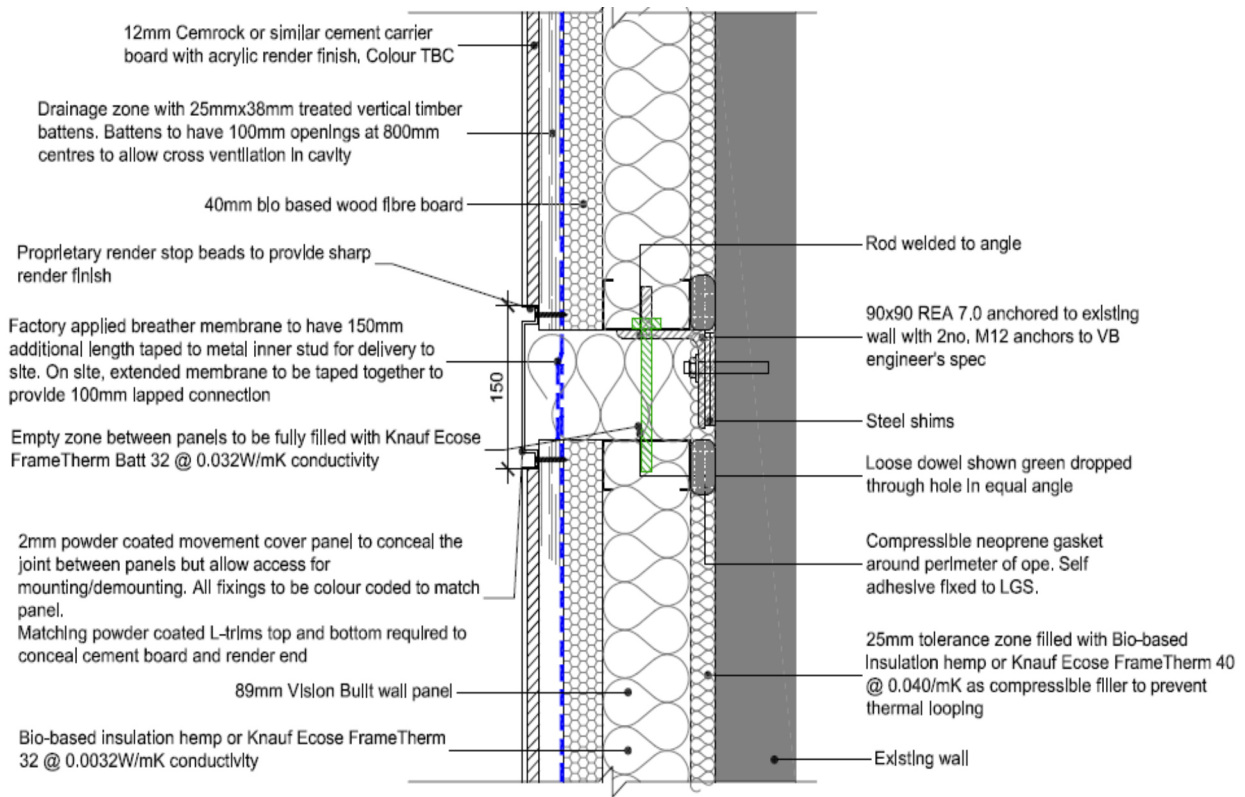


Figure 6 | Showing the horizontal panel-to-panel DfD connection at floor level that enables independent, non-stacked installation and full panel removal for reuse or further disassembly

The system uses a gravity-based fixing, with the panel base seated on a bracket bolted to the host wall and laterally restrained by a bolt. The same bracket restrains the head of the lower panel via a restraint bolt. All fixings are accessible within an approximately 150 mm lift-on/lift-off access zone, allowing straightforward installation and de-installation without affecting adjacent panels. Source Coady Architects / Vision Built.

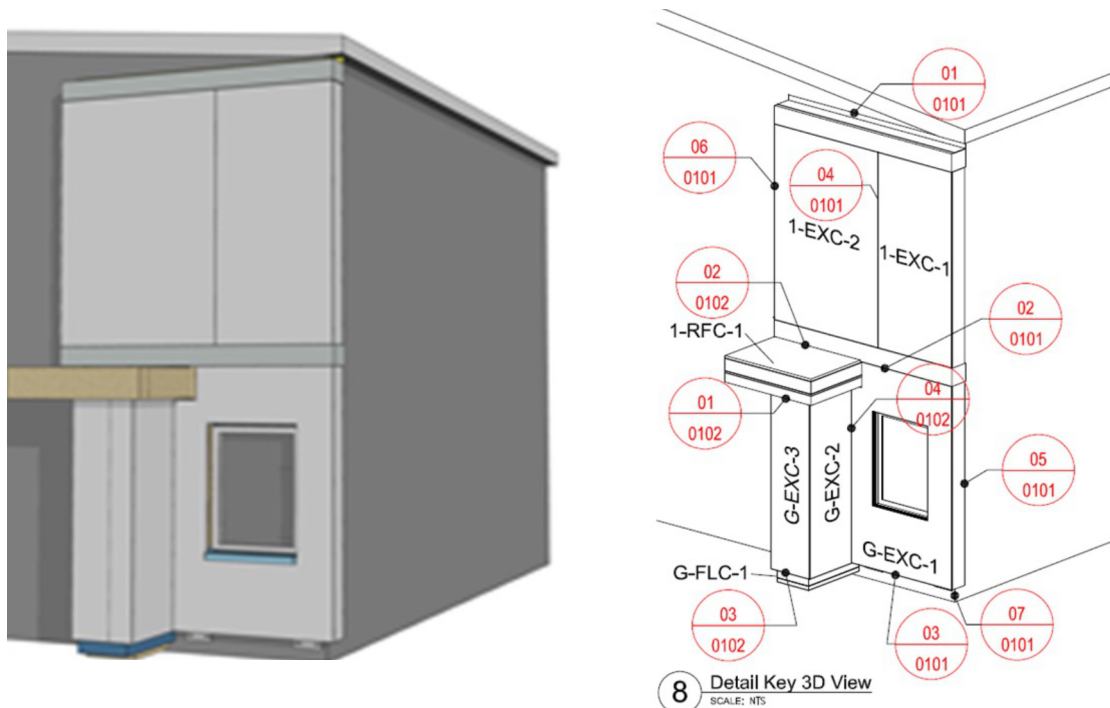


Figure 7 | Showing schematic drawings of mock-up in 3D, with references to panel types and junction details. Source Vision Built

Table 1 | Showing observational / recorded results from Stage 1 across all three levels (italic - negative impact)

Stage 1	Level	Systems	Technical	Materials	Process	Data
Manufacture	L - 1,2,3	Simple/non-complex. <i>Number of layers/ fixings.</i>	Dry reversible with repairable impact. <i>Jointing tapes/seals.</i>	No damage. <i>Number of layers/ fixings/offcuts.</i>	Factory, simple non-complex, layers, hand tools. <i>Wet render slow.</i>	Detail production drawings, bar codes.
Transport (Manufacture Reporting, interview and Photos)	L - 1			Minor damages. <i>Extra plastic required.</i>	Small panels, light/hand lift and forklift.	
Installation	L - 1	Functional Separation. Number of parts and fixings low.	Bracket simple & accessible. <i>Bracket limitations (lack of tolerance).</i>	<i>Materials used at joints are considered "sacrificial".</i>	No scaffold is required / short install time. <i>Issues with upper panels due to drilled holes mistake.</i>	Installation drawings / staff training. <i>No pre-survey wall (Plumbness).</i>
Insitu Inspection	L - 1		<i>Neoprene Gasket too firm and mushroom fixings too numerous.</i>	<i>Render quality and roof finishes poor.</i>		

abling observation of design performance, DfD implementation, and assembly logistics. See [Table 1](#) for summary of observations from Stage 1.

Manufacture (Levels 3-1)

Five wall panels and associated roof and floor elements were fabricated in accordance with mock-up designs. While not a disassembly process per se, this stage yielded key insights into reversibility and constructibility, as follows;

- System: The modular system was straightforward, comprising an LGS frame with layered build-up. However, bespoke panel sizes and excessive fixings (e.g., 254 screws in one panel) introduced unnecessary complexity.
- Technical: Screw-based mechanical fixings were predominant, offering moderate DfD potential as reversible, “dry” connections, though minor adhesive and sealant applications were sacrificial.
- Material: Bespoke fabrication generated offcuts of insulation, wood fibre, and cement boards. Membrane puncturing by fixings and over-compressed rear insulation indicated potential performance and reuse issues.
- Process: Fabrication followed a structured three-stage process (roll-forming, framing, and layered assembly) using simple hand tools, with rendering and outsourced roofing causing time delays.
- Data: Detailed manufacturing drawings and QR codes (for LGS only) supported traceability and potential future disassembly, though QR visibility was later compromised by subsequent layers.

Transport (Level 1) (Manufacturer reporting)

Panels were transported 100 km between factories using open truck transport. Palletisation, insulation spacers, and plastic wrapping were effective, though minor render damage occurred, requiring repair.

Installation (Level 1)

Installation revealed tolerance and alignment challenges, particularly due to variations in host wall plumpness.

- System: Panel-to-bracket and panel-to-panel junctions were standardized, with clear hierarchy and order of assembly.
- Technical: The bracket system functioned but lacked sufficient adjustability, leading to excessive shimming and misalignment.
- Material: Horizontal joints were partly sacrificial, requiring membrane cutting and seal removal, limiting reuse.
- Process: Installation took three days with minimal equipment, demonstrating good constructibility but limited tolerance to host wall deviation.
- Data: Drawings and sequencing information were available, but absence of a pre-install wall survey caused significant on-site adjustments.

In-situ inspection

Post-installation inspections identified key design deficiencies:

- Bracketry: Lack of multi-directional adjustment led to misaligned joints and necessitated redesign for three-plane movement.
- Backing insulation: Over-compressed neoprene gaskets and excessive fixings were revised to improve thermal performance and compressibility.
- Finishes: Poor render quality and inconsistent jointing prompted a switch to dry board finishes for future stages.
- Roofing: Workmanship issues led to revised detailing between designers and installers.

Stage 2 was reconfigured to test these design refinements and evaluate DfD performance under reassembly conditions.



Figure 8 | Original mock-up showing - above LHS rear of panel with compressible insulation and perimeter gaskets, RHS original brackets and below - LHS first panel installation in progress, RHS wall panels installed

See [Figure 8](#) showing key images of initial prototype installation.

Stage 2: De-installation, disassembly, and re-assembly

Stage 2 tested the revised design through complete de-installation, partial and full disassembly, and subsequent re-assembly with new bracket design. See [Table 2](#) for summary of impacts with negative material impacts in blue/italic.

De-installation (Level 1)

Element level: Panels were removed intact, demonstrating the practical feasibility of design for disassembly (DfD) at the element scale.

- System / Technical: Horizontal joints and bracket fixings performed effectively; however, bonded vertical seals limited full independence during panel removal.

- Material: Membranes and rubber sealing components were irreparably damaged during disassembly, while core panel materials remained undamaged and suitable for re-use.
- Process / Data: Disassembly was carried out efficiently using standard hand tools and forklifts, supported by prior assembly knowledge and straightforward documentation.

Disassembly (Levels 2-3)

Two panels were disassembled—one at the component level (Level 2) and one at the material/product level (Level 3).

- Level 2: Window-cill assemblies exhibited low independence, requiring destructive removal and demonstrating that conventional detailing is not compatible with DfD principles.
- Level 3: Full disassembly confirmed high material recoverability; all major components were separable with minimal damage. Bonding of cement board and render con-

Table 2 | Showing observational / recorded results from Stage 2 across all three levels, (italic - negative impacts)

Stage 2	Level	Systems	Technical	Materials	Process	Data
De-install	L - 1	Horizontal joints work well. <i>Vertical joints bonded.</i>	<i>Vertical tolerances very small, affecting panel independency.</i>	No observed panel impact., <i>Joint material impact.</i>	Quick and non-complicated / forklift / manual lifting and hand tools.	Staff instructed before disassembly <i>No de-installed drawings.</i>
Disassembly	L - 2	<i>Window-Panel not functional independent.</i>	<i>Geometry of product edge between window and cill overlaps.</i>	Cement board repair and re-finishing <i>Seals and tapes non reusable.</i>	Hand tools conventional window de-installation. <i>DfD connections should be included.</i>	<i>No disassembly data.</i>
Disassembly	L - 3	Simple fixing. <i>High number of layers and fixings.</i>	<i>Disassembled process in one direction.</i>	Core materials can be re-used. <i>Non weathering at head of panels damaged back insulation and some parts of breather membrane/Cement board and render has limitations in re-use.</i>	Quick and simple.	No previous data was provided. <i>Junctions and elements were coded during disassembly to reassembly.</i>
Reassembly	L - 2	Number of parts and components was simple and easy.	<i>No DfD considered.</i>	<i>Cement board & render damaged.</i>		<i>No reassembly data.</i>
Reassembly	L - 3	Simple layer. <i>Excessive number of fixings.</i>	Same as original / Addition of base channel for panel adjustability on brackets.	Wood fibre board minor impact / fully re-usable.	Simple procedure / Hand tools / New dry cement board.	Mark ups on drawings and products / materials during disassembly aided re-assembly.

Table 3 | Showing observational / recorded results from Stage 1 across all three levels

Stage 3	Level	Systems	Technical	Materials	Process	Data
Re-installation	L - 1	Simple / Functional separation / Hierarchy and order of assembly.	Positive revised bracket detail back insulation fit tighter.	Dry cement board finish changed.	Simple / 1 day / no scaffold required / scissor lift and wheel loaders required / simple hand tools.	Original installation drawings with addition of new bracketry.

Table 4 | Summary of Material Impacts, description, scoring and potential re-application

Levels	Item	Score	Material impacts	Biobased	Recovery potential
L1 Element	Wall Panel	5	No impact	Partial	Reuse
		1	Membrane tape and Rubber strip damaged beyond repair		Recycle
L2 Component	Window	5	No impact	Biobased	Reuse
	Cill	5	No impact		Reuse
	Junction	5	No impact		Reuse
		1	Membrane tape cut		Recycle
		3	Cement Board was cut		Repair
L3 Material/Product	Cement board	3	Cut to sizes	Biobased	Repurpose and Recycle
	Wood fibre	3	Cut to sizes		Reuse, Repair, Recycle
	Breather membrane	3	Staple holes		Repair, Repurpose and Recycle
	Neoprene gaskets	1	Damaged beyond repair		Recycle
	Screws	1	50% damaged		Recycle

Overall: Damaged non recoverable materials were limited to sacrificial jointing materials and % of fixings with over 90-90% of materials re-applied following dis-assembly in the re-fabrication of panels for re-installation.

strained reuse potential, while weathering led to minor degradation of gaskets and membranes.

Re-assembly (Levels 2-3)

Both panels were reassembled using predominantly original components.

- Level 2: Reassembly was straightforward but visually impaired by prior cement board damage; future redesign required to enable reversible window-cill connections.
- Level 3: Reassembly introduced revised dry board finishes and new bracket slots for tolerance adjustment. Approximately 50% of screws were replaced due to wear or mis-



Figure 9 | Mock-up Stage 2 with LHS revised brackets allowing for minor tolerance in three planes, Centre - revised upper panels with new cement board lining and RHS – revised backing insulation



Figure 10 | Showing final mockup full scale panel installation under eaves method being tested

alignment; most wood fibre and insulation materials were reused successfully.

See [Figure 9](#) showing revised bracket design, with adjustability in two planes, and revised dry cement board test finishing.

Stage 3a/b: Re-installation and supplemental testing

Stage 3a involved reinstallation of panels incorporating revised bracketry, backing insulation, and dry finishes, as well as a 3b a supplemental under-eaves installation trial. See [Table 3](#) for Stage 3 impacts.

- System/Technical: The new bracket design provided improved tolerance to dimensional variation and enhanced joint quality.
- Materials: The switch to dry cement board finishes eliminated wet trades and reduced damage risk.

- Process/Data: Installation efficiency remained high, requiring one day and minimal equipment. Updated drawings and experience from prior stages supported accuracy.

Stage 3b. A supplementary test successfully demonstrated installation under eaves using a counterweighted hoist, later applied in the real retrofit. See [Figure 10](#) showing test installation of full panel with counterweighted hoist and mock-up of eaves projection. (Manufacturer reporting)

DfD, material impact, and re-application potential

The DfD audit confirmed strong disassembly performance across all levels, with minimal impact on primary materials and clear potential for reuse, repair, or recycling. See [Table 4](#) showing summary of key material impacts, and reapplication potential.

- Level 1 (Element): Panels could be fully removed intact, retaining economic and environmental value. Only membrane tapes and rubber seals were irrecoverable.
- Level 2 (Component): Window-cill assemblies showed the lowest DfD performance due to conventional detailing and destructive removal, though repair was feasible.
- Level 3 (Material/Product): High material recoverability was achieved, with only minor cosmetic damage to wood fibre boards. Cement boards bonded with render were non-reusable but recyclable; roughly half of fixings were recoverable.

Overall, the DfD audit demonstrated that the modular wall system achieved practical reversibility, high material recovery, and reassembly potential. Damaged non recoverable materials were limited to sacrificial jointing materials and % of fixings with over 90–90% of materials re-applied following dis-assembly in the re-fabrication of panels for re-installation, validating its circularity and reuse objectives within the STaMPD framework.

Summary of audit findings

The DfD audit demonstrated that the prototype modular wall system achieved advanced disassembly, material recovery, and reassembly performance across three test stages, with minor material impact and identification of areas for further design improvement.

Stage 1 exposed several challenges—particularly in bracket adjustability, joint detailing, and material handling—that restricted functionality, reversibility, and generated material impacts. These findings informed targeted design refinements, including enhanced bracket tolerance, reduced wet trades, and dry finishes.

Stage 2 confirmed DfD performance and provided opportunity to modify and re-test design changes. Panels were fully removable at element level, major components could be disassembled and reused, and most materials were recoverable with minimal degradation. Limitations, such as bonded seals, sacrificial membranes, and conventional window-cill interfaces, highlighted areas where further redesign was required to achieve advanced circular reversibility.

Stage 3 validated the upgraded system in reinstallation, demonstrating improved alignment, faster assembly, and reduced damage risk. Supplemental tests under eaves installation showed adaptability to real-site constraints, reinforcing practical applicability of the modular solution.

The DfD audit verified that the system supports high-value circularity pathways, including reuse at element/component level, repair and repurposing at material level, and integration into future retrofit contexts. While some details still constrain full reversibility, the iterative testing process showed that modular LGS panels can be engineered to deliver robust disassembly performance, maintain integrity of primary materials, and enable meaningful reuse within the STaMPD circular retrofit framework.

Validation of Stampd

Validation methodology

The robustness of the STaMPD Design for Disassembly (DfD) assessment method was evaluated through a comparative validation exercise undertaken by two independent researchers. Each assessed both the original design-stage intent and the outcomes of a post-construction physical DfD audit. The purpose was twofold: first, to determine whether the design-stage application of STaMPD could reliably predict actual disassembly performance; and second, to examine the consistency of results across assessors.

The analysis compared the original design-stage scores with revised scores informed by physical audit observations, while also examining interpretive differences between Researcher A and Researcher B. Variations in scoring were attributable to differences in professional judgment and emphasis rather than to any alteration of the method's structure or scoring logic.

Overall score comparison: Design-stage and post-audit

Across both evaluations, the overall STaMPD scores demonstrated strong alignment between design-stage predictions and post-construction findings. Variations between design-stage and post-audit revised scores are represented as a simple percentage difference.

Researcher A identified only marginal variation, with total score differences remaining below 2% across all system levels. This close correspondence indicates that, when applied by experienced practitioners with in-depth system knowledge, STaMPD can accurately anticipate realized DfD performance. Researcher B recorded more pronounced shifts, with Level 1 decreasing by 11%, Level 2 by 7.6%, and Level 3 improving by 9.75%. These differences stemmed primarily from more conservative initial scoring, improved material-level performance observed during disassembly, and a stronger appreciation of process and data indicators once operational evidence became available. The mean absolute deviation across all system levels was 5.6%. Importantly, both researchers concluded that the DfD design intent was broadly achieved in the constructed prototype. The observed differences reflect interpretive sensitivity rather than methodological inconsistency, thereby reinforcing confidence in STaMPD's predictive validity.

Category-level analysis

At the system level, both researchers reported comparable performance patterns across Levels 1, 2, and 3. Researcher A identified a minor 3% variation following the audit, confirming stability in the original assessment. Researcher B observed a slightly greater reduction, primarily due to the physical mock-up revealing non-uniform geometries, varied panel functions, and deviations from design-stage assumptions regarding standardization. Both assessments converged in identifying Level 3 as the weakest-performing layer, largely due to the density of fixings and connections—an issue con-

firmed during physical disassembly and prioritized for optimization.

Technical assembly performance remained strong overall. While Researcher A noted a 4% variation following the audit—attributed to observed fixing density, redundant connections, and minor material damage—Researcher B recorded only a marginal reduction. Practical challenges, particularly during the removal of delicate window panels and rendered finishes, highlighted the difficulty of anticipating interface vulnerabilities through drawings alone.

Material performance was positively evaluated at design stage, reflecting the absence of hazardous materials and theoretical reuse potential. Post-audit reassessments identified modest reductions, primarily due to jointing damage, over-compressed bio-based insulation, and cement board window cills that could not be reused. Both researchers agreed that while strategic material choices aligned with DfD principles, detailing and interface design significantly influence actual reuse outcomes.

Greater divergence emerged within the Process category. Researcher A reported only minor variation, attributing discrepancies to installation duration, sequencing constraints, and tolerance management. In contrast, Researcher B recorded a substantial improvement in post-audit process scores, enabled by direct observation of site practices, safety procedures, and operative workflows that had been uncertain at design stage. This contrast underscores the sensitivity of process indicators to experiential evidence and highlights inherent limitations in early-stage evaluation.

Data performance similarly improved following the physical audit. Initial design-stage scores were low due to limited available information. Post-audit reassessment recognized the effective use of annotated drawings, component marking, and tacit knowledge developed during the mock-up. While the magnitude of improvement differed between researchers, both concurred that data-related indicators benefit significantly from prototyping and cannot be fully resolved through documentation alone.

Inter-rater reliability

Comparison of both assessments reveals high levels of agreement within the Systems, Technical, and Material categories, particularly at product level, as well as shared conclusions regarding overall design intent achievement. Greater divergence was evident in Process and Data indicators and, to a lesser extent, in component-level material scoring.

These differences were attributable to several factors: variation in assessment timing relative to the mock-up; differing professional judgments when interpreting qualitative criteria; alternative strategies for handling incomplete information; and distinct levels of prior engagement with specific system types.

The findings suggest the need for clearer scoring guidance, standardized approaches to managing missing data, structured assessor training, and potentially staged assessments aligned with project phases to reduce interpretive variability.

Visual comparison of results

[Figure 11](#) and [Figure 12](#) illustrate the comparative outcomes for both researchers. In Researcher A's assessment, design-stage and post-audit scores show minimal variation, supporting the method's predictive reliability. Researcher B's results demonstrate moderate shifts, particularly within Process and Data categories, reflecting enhanced information availability following physical testing.

Validation summary and implications

Taken together, the validation exercise demonstrates that STaMPD produces stable and credible outcomes at design stage while remaining responsive to empirical evidence from physical disassembly. Design-stage assessments predicted realized DfD performance within a relatively narrow margin, with higher reliability observed in physically measurable categories than in process- and information-based indicators. Both researchers independently identified identical priority areas for refinement, including reduction of fixings, improved interface detailing, enhanced finish protection, and more robust disassembly documentation.

The exercise highlights both strengths and limitations of the method. STaMPD offers a structured, hierarchical framework for comprehensive DfD evaluation, supports identification of targeted design improvements, and facilitates communication within multidisciplinary teams. However, it remains dependent on professional judgment, particularly in process- and data-related categories, and is sensitive to information availability at early design stages.

These insights directly inform the proposed development of STaMPD 2.0, which proposes a streamlined, more practical framework by reducing indicators to four to five per category, introducing detailed scoring descriptors to reduce subjectivity, and incorporating measurable indicators such as ranges for the number of fixings. Material-level indicators will be applied only at the base product or component level, with results aggregated upward, while weighting will prioritize Technical, System, and Material categories over Process and Data emphasizing higher-level outcomes to reflect value retention. The framework is envisaged to function within a broader circularity or sustainability assessment approaches. Further validation supports could be expanded through measurable indicators, expert review, multi-stakeholder pilots, and case study or deconstruction testing.

Overall, the validation provides strong empirical support for continued refinement and broader application of the method within modular retrofit contexts.

External Benchmarking

Rationale for external benchmarking

The STaMPD validation exercise (Section 7) demonstrated internal consistency between design-stage assessment and physical audit outcomes. However, to position these findings within broader circular construction discourse and evaluate performance against established standards and comparable projects, external benchmarking is essential.

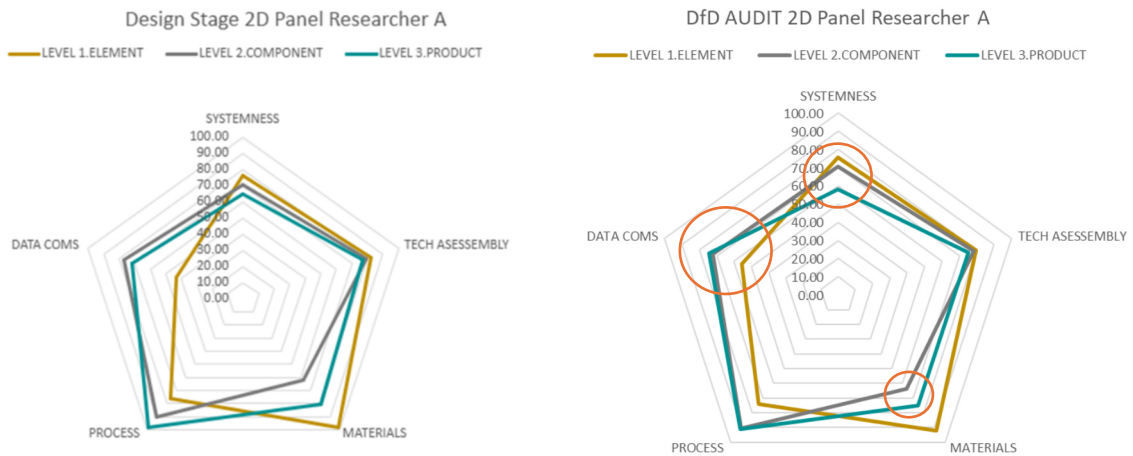


Figure 11 | STaMPD Results Researcher A

LHS: Design-stage assessment; RHS: Post physical DfD exercise. Minor variations (<3%) observed, notably in Data Level 1, Systems Level 3 and Materials Level 2 confirming relative predictive reliability. Systems, Technical, and Materials categories showed close alignment, with Process and Data showing slight improvements post-audit

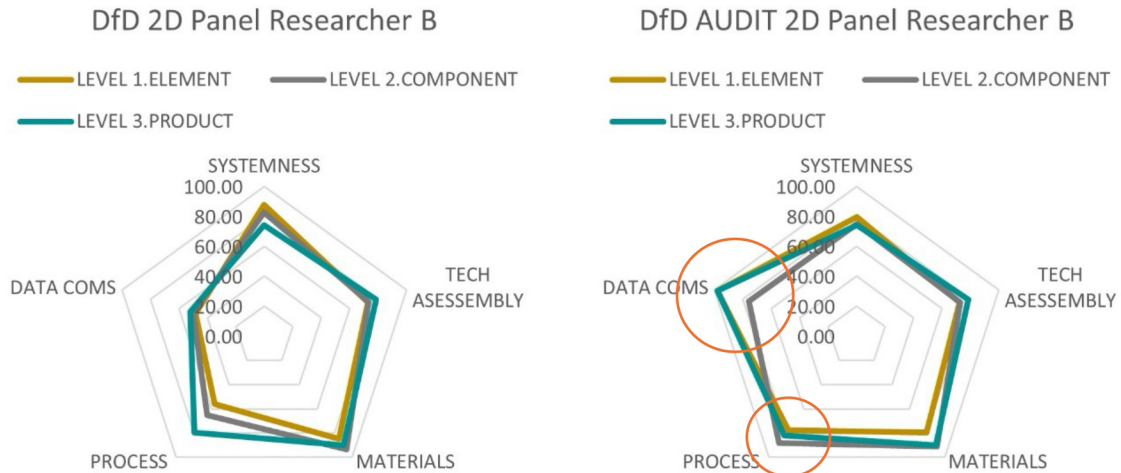


Figure 12 | STaMPD Results Researcher B

LHS: Design-stage assessment; RHS: Post physical DfD exercise. Moderate variation observed, particularly in Process and Data categories, reflecting enhanced site observation and improved operational knowledge. Level 2 performance improved for component interfaces, while Level 3 adjustments reflected material reuse insights

External benchmarking serves three critical purposes in this research:

- Normative Validation: Comparing audit findings against ISO 20887:2020 (the primary international standard for DfD) establishes whether the modular system meets recognized industry benchmarks.
- Methodological Triangulation: Cross-referencing with established DfD frameworks (particularly Durmisevic's foundational work) provides additional validation of performance assessment

- Empirical Contextualization: Comparing with European demonstrator projects (CPH Demo 2, B.R.I.C.) that have undergone similar physical testing situations the Irish Drive 0 case within real-world circular retrofit practice

This hybrid benchmarking approach—combining normative standards, research frameworks, and case examples—was adopted to ensure transparency, replicability, and compatibility with physical audit-based study methodology, without reliance on proprietary assessment tools.

Table 5 | Comparison of observed performance under ISO 20887 principles

DfD Metric	Irl Drive 0 Case	CPH Demo-2 (CIRCUIT)	B.R.I.C. (BAMB)
Disassembly potential (% by volume)	(Not quantified by volume; empirically verified as high (element-level 100% reuse potential, other levels . 90%)	16 % → 89 % (BAU → Optimised)	Not specified (qualitative)
Connection type optimisation impact	Accessible, reversible mechanical	High (major effect)	Reversible connections standard
Empirical recovery/reuse data	Quantified through audit- strong re-apply potential	Not reported	Window frames 50 % reuse; panels and fasteners labelled
Documentation & labelling	Not structured	Not reported	Panels labelled during B.R.I.C. reuse process
Modular independence	High	High	High

ISO 20887:2020 – Design for disassembly and adaptability

ISO 20887:2020 ([ISO, 2020](#)) formed the primary reference benchmark. Key DfD guidance principles were drawn from the standard to establish qualitative criteria for benchmarking ([Table 5](#)):

- Levels/Hierarchical: Assessment across construction hierarchy
- Accessibility: Access to connections and fixings
- Independence: Functional separation of layers and elements
- Reversibility: Ability to disassemble and reassemble without damage
- Treatment/Finishes: Avoidance of treatments impeding disassembly
- Circular Models: Alignment with circular economy pathways
- Simplicity: Reduction of complexity in assembly
- Standardization: Use of standard products and dimensions
- Safety: Consideration of worker safety during disassembly

The system demonstrates strong alignment with technical DfD principles but weaker alignment with information and data requirements. The use of predominantly mechanical fixings enabled reversibility, and the over-cladding layer could be removed independently of primary structure. Fixings were generally accessible from exterior face, supporting logical reverse-installation disassembly sequence. However, partial non-alignment was identified in relation to procedural and informational requirements. While disassembly was feasible, absence of formalized disassembly documentation, component identification, or material passports limited full compliance with ISO 20887. Minor material damage observed during removal further reduced conformity with the standard's emphasis on damage minimization and reuse optimization.

The system can be characterized as significantly compliant with ISO 20887, exhibiting strong design intent for disassembly but limited formalization of supporting information.

Combined DfD frameworks

To enable numerical comparison with published studies, an alternative DfD scoring framework was applied, adapted from established research-based indices drawing from Durmisevic ([2006](#)) Seven performance metrics were evaluated on a four-point scale (0 = poor; 4 = excellent), based on direct observations from physical audit ([Table 6](#)).

The system achieves a total score of 23 of 28, showing broad alignment with combined criterion and high scoring. Particularly strong performance was observed in layer independence and reusability. This result positions the system well above average for façade assemblies, which are frequently constrained by bonded materials, concealed fixings, or non-reversible interfaces.

Case comparison with European demonstrators

To contextualize performance within contemporary European research, the audit results were compared with two Horizon 2020 demonstrators featuring explicit evaluation of DfD metrics:

CPH Demo 2 – Modular façade Dfd potential

The CPH Demo 2 demonstrator evaluated how design adjustments influence Dfd potential. Using a volume-based metric: Baseline “Business As Usual” Dfd potential: < 16 % by volume; Optimized modular connections (screws replacing nails/staples): ~ 89 % by volume ([CIRCUIT, n.d.](#)) . The improvement was achieved by replacing fixed connections with reversible mechanical fixings and optimizing connection sequencing. This demonstrates that connection strategy alone can dramatically influence Dfd performance.

B.R.I.C. – Disassembly and reuse outcomes

The B.R.I.C. pilot building underwent annual construction and disassembly cycles, focusing on reversibility and component reuse: - 117 interchangeable, self-supporting insulated timber façade cassettes with reversible joints; Recovered components after first disassembly - Window frames: 50 % reusable - Screws recovered and panels labelled for reuse - Cladding boards and structural timber elements reused without damage. B.R.I.C. demonstrates that modular façades with reversible joints and labelling systems can achieve actual material recovery, providing a practical benchmark beyond design-stage projections ([BAMB, n.d.](#)) ([Table 7](#))

Table 6 | High-level comparison of observations with combined DfD criterion

ISO 20887 Criterion	Evidence from Physical Audit	Performance
Levels / Hierarchical	Levels based DfD, underperformed L2.	Very good
Reversible connections	Bolted / screwed fixings observed, excessive	Good
Accessibility of fixings	Majority accessible from exterior face	Very good
Independence of layers	Distinct layers / functions, reversible in order	Very good
Treatment / Finishes	No treatment or finishes impeding DfD	Very good
Circular Models	Strong Re Stage potential minimal impacts	Very good
Simplicity	Potential for further reduction in layers	Moderate–Good
Standardisation	Standard products used but cutting	Good
Safety	Excellent safety consideration	Very good
Documentation	Good design data, poor DfD data	Moderate

Table 7 | presents a high-level comparative summary of the Drive 0 DfD audit to these case studies

Metric	Score	Justification
Fixing reversibility	3	Mostly mechanical, some sacrificial
Fixing accessibility	3	Removable and minor obstructions
Number of disassembly steps	3	Multi-step but logical
Tool dependency	3	Standard tools only
Damage risk	3	Edge damage observed – one level
Layer independence	4	Highly independent
Reuse potential	4	High element re-usability across levels

Benchmarking synthesis

The benchmarking exercise highlights the value of physical audit methods in evaluating DfD performance, with several key insights:

Design strategy dominates DfD performance

Both the Drive 0 audit and CPH Demo 2 highlight that mechanical fixings and connection sequencing are primary determinants of disassembly potential. Minor adjustments in connection design can substantially increase DfD performance metrics.

Empirical validation is critical

While CPH Demo 2 quantifies potential DfD gains, B.R.I.C. provides real-world evidence of disassembly and reuse cycles. The Drive 0 audit sits between these, combining practical observation with semi-quantitative scoring to provide actionable performance data.

Component recovery and labeling are essential for circularity

B.R.I.C. demonstrates that labeling and sequence management directly impact reuse rates. Drive 0 currently lacks formalized documentation, representing an area for improvement to maximize circular outcomes.

Modular over-cladding systems are inherently adaptable.

Across all comparisons, systems' layer independence and modularity support disassembly and reuse. Drive 0's performance aligns closely with these benchmarks, indicating robust design for façade-level circularity.

Overall Assessment: The Drive 0 modular over-cladding system achieves high practical DfD performance, comparable

to leading EU demonstrators, while identifying opportunities for improved documentation, labelling, and reuse planning. These findings validate the physical audit methodology and provide a framework for future design optimization in modular circular façades.

Methodological Contribution: While several projects, such as Drive 0, assess theoretical circularity DfD performance across project cases, the emerging range of demonstration project and DfD audits presents opportunity for cross project benchmarking. The proposed hybrid external benchmarking approach, combining normative standards ([ISO 20887](#)), research frameworks ([Durmisevic, 2006](#)), and case evidence ([CIRCUIT.B.R.I.C.](#)), provides a pathway for future benchmarking of modular circular and especially DfD performance, future evaluations of façade and envelope systems and supports development of evidence-based circular construction strategies.

Critical Discussion

Key findings

This research examined the integration of DfD principles within a prefabricated over-cladding retrofit system through detailed physical auditing. Three principal findings emerge.

First, advanced DfD is achievable in practice. The modular prototype demonstrated that DfD intent can be realized across construction hierarchy levels. Panels were removed intact at element level, components were disassembled with manageable impacts at interface level, and materials were largely recovered without significant damage. These results confirm that circular retrofit strategies can move beyond theoretical aspiration to operational feasibility.

Second, design-stage assessment can reliably predict performance. The STaMPD method demonstrated predictive ac-

curacy within 2–11% of post-audit results, validating its function as both a design guidance framework and an evaluative tool. While interpretive variability occurred between assessors, overall alignment confirms that structured design-stage assessment can anticipate realized DfD outcomes with reasonable accuracy.

Third, performance varied across hierarchy levels and assessment categories. Element-level (Level 1) and material-level (Level 3) performance was strong, whereas component-level interfaces (Level 2), particularly window-to-cill connections and joint detailing, revealed limitations. These findings highlight the importance of interface design in translating modular strategies into full circular performance.

Collectively, the results demonstrate that modular retrofit systems can be engineered to support reuse, repair, and material recovery, while also revealing practical constraints requiring further refinement.

DfD performance across the construction hierarchy

The audit confirms that DfD performance varies systematically across hierarchy levels.

At element level (Level 1), panels were removed intact, retained structural and thermal integrity, and were reinstalled without difficulty. This confirms that system-level reversibility is achievable in prefabricated retrofits. The adjustable bracket system was critical: gravity-based support with lateral restraint enabled independent lift-on/lift-off removal within a defined 150 mm access zone. Mechanical fixings and clear sequencing contributed to predictable disassembly. These results align with international guidance emphasizing modular independence and accessible connections.

At component level (Level 2), performance was constrained by interface detailing. Disassembly of window-cill-cladding assemblies required cutting of cladding layers, limiting immediate reuse. Vertical joints sealed with butyl rubber and taped membranes generated additional material impacts. These findings reinforce that modularity alone does not guarantee circularity; detailing, tolerances, and joint systems strongly influence realized performance. While panel independence was achieved, sub-element interfaces require further rationalization and redesign.

At material/product level (Level 3), core materials, including insulation, wood fibre boards, and structural steel, showed high recoverability with minimal damage. Recovery exceeded 90% for primary materials (Section 6.4, [Table 4](#)). Losses were concentrated in jointing components, membranes, and sacrificial sealing elements, and approximately half of screws required replacement. This indicates strong material-level circular potential but also highlights opportunities to optimize fixing strategies and minimize consumable components.

The hierarchical variation validates the importance of multi-level assessment. System-level modularity enables reversibility; interface detailing constrains component performance; and material specification determines recovery outcomes. Comprehensive DfD therefore requires coordinated design attention across all scales.

STaMPD as design and assessment tool

STaMPD functioned both as a design framework during prototype development and as a performance evaluation method during the audit.

Predictive accuracy

The close alignment between design-stage and post-audit scores demonstrates that STaMPD can reliably predict DfD outcomes when applied by informed professionals. Predictive accuracy was strongest in physically measurable categories—Systems, Technical, and Materials—where documentation and specifications provided sufficient clarity. Greater variability occurred in Process and Data categories, reflecting the difficulty of anticipating operational practices and information flows during early design stages.

Category-Level Insights. The category structure proved effective in identifying targeted optimisation areas:

- Systems assessment highlighted excessive fixings and layering at Level 3 as avoidable complexity, establishing clear design priorities for simplification.
- Technical indicators confirmed the effectiveness of the bracket and lift-on/lift-off strategy while identifying window and joint interfaces as constraints.
- Materials assessment demonstrated alignment with DfD principles at strategic level, though it underscored the importance of detailing and protection to preserve reuse potential.
- Process findings showed benefits of factory prefabrication—improved quality control and reduced on-site time—while revealing ongoing challenges in tolerance management.
- Data indicators were weakest at design stage but improved during audit as ad-hoc documentation and experiential knowledge emerged, highlighting the role of structured information systems in enabling circularity.

Inter-rater reliability

Differences between Researcher A and Researcher B, particularly in Process and Data categories, reveal that STaMPD requires professional judgment and is sensitive to information availability. Interpretive variability reflects methodological comprehensiveness rather than instability but suggests refinement is needed.

Improvements may include clearer scoring thresholds, protocols for handling incomplete data, staged assessment aligned with design phases, and assessor calibration exercises. These insights inform the proposed STaMPD 2.0 development, balancing rigour with practical usability.

Validation summary

Overall, STaMPD proved effective as both design guidance and evaluation framework. It provided structured, hierarchical assessment capable of identifying optimization opportunities and predicting realized performance within acceptable margins. However, refinement is necessary to reduce data in-

tensity and minimize subjectivity before broader industry adoption.

Modularity, calability, and structural considerations

Although demonstrated on a limited dwelling typology, the prototype was conceived for broader application.

Modular benefits and circular preconditions

The audit confirmed recognized benefits of prefabrication: factory-controlled quality, shortened installation time (three days for Stage 1; one day for Stage 3), reduced occupant disruption, and flexibility to accommodate windows and junctions within a standardized framing logic.

However, modularity alone did not guarantee circularity. Specific DfD-enabling features were essential: independent brackets avoiding panel stacking, accessible fixing zones, mechanical (not adhesive) connections, and tolerance management through adjustable supports. Circular performance required deliberate integration rather than passive reliance on modular construction.

Structural and typological considerations

Scalability depends on structural and contextual factors. Panel weight was manageable using mechanical assistance; alternative framing systems may alter load paths and fixing requirements. The bracket system accommodated ± 15 mm dimensional variation, but larger or multi-storey buildings may require rail systems or alternative adaptive fixings.

Host wall diversity—solid masonry, cavity walls, framed structures—will necessitate site-specific structural assessment. Hollow block or variable substrates may require modified bracketry to ensure adequate load transfer. Trade-offs between ease of disassembly and long-term structural robustness must be carefully managed.

Economic and industrial dimensions

While technical feasibility was demonstrated, economic analysis was beyond the study's scope. Nevertheless, DfD influences cost through factory fabrication, reduced on-site labour, potential material value retention, and lifecycle adaptability. Industrial scalability requires sufficient market volume, simplified component systems, and coordinated supply chains.

The Drive 0 collaboration between academic, architectural, and manufacturing partners illustrates the integration required for modular retrofit scaling, but also the coordination complexity involved. Insights from manufacturing sectors—particularly part reduction, standardization, and sequencing optimization—offer potential pathways to improve cost-efficiency and circular outcomes.

Further research is required to examine scalability across diverse building archetypes, optimize joint systems, integrate economic evaluation, and assess long-term durability and reuse pathways. Economic scalability requires further life-cycle cost analysis, a key future research priority outlined in Section 10.4.

Methodological limitations and future research

Several limitations shape interpretation of results.

The prototype represents a single façade typology at limited scale, restricting generalizability. Broader validation across building types, heights, climates, and construction methods is necessary. The STaMPD method is focused on generic DfD performance and not a particular construction method or application context and should be applicable across construction types and scales, with findings on utility having wider relevance and utility.

Certain audit stages, notably transport and supplemental Stage 3b relied partially on manufacturer reporting due to access constraints, introducing potential observational bias. However technical researcher was present for all key DfD actions - manufacture, assembly, disassembly and reassembly stages. Continuous researcher presence in future studies would strengthen evidence reliability.

STaMPD, while effective, remains data-intensive and interpretively sensitive. Further refinement is required to streamline indicators, clarify scoring, and improve usability for industry practitioners. Additionally, economic performance was not assessed; lifecycle costing and material value retention modeling are essential for commercial viability.

Future research priorities include expanded case applications, integration of economic metrics, long-term monitoring of installed systems, comparison across alternative structural systems (e.g., timber and concrete), and exploration of regulatory alignment with circular economy policy frameworks.

Recommendations for research and practice

For Research: Future development should prioritize STaMPD 2.0 refinement through streamlined indicators, measurable sub-criteria, and staged assessment protocols. Broader multi-stakeholder validation is necessary to test reliability across disciplines. Integration of lifecycle cost analysis with DfD performance metrics will strengthen decision-making frameworks. Expanded application across typologies and climates will improve generalizability, while knowledge transfer from manufacturing engineering may enhance efficiency. Finally, exploration of regulatory integration could support market adoption.

For Practice: DfD thinking should be embedded from early design stages, simultaneously addressing element, component, and material levels. Physical prototyping is recommended to validate assumptions and reveal interface challenges before full deployment. Designers should prioritize simplification—reducing fixings, rationalizing part counts, and standardizing components. Factory prefabrication should be leveraged for quality control and systematic documentation. Comprehensive disassembly information, including sequencing guidance and component identification, should be developed. Particular attention must be paid to interfaces and tolerances, recognizing these as primary determinants of practical disassembly. Adoption of material passports and collaborative, multi-disciplinary design processes will further strengthen circular outcomes.

Conclusion

Summary

This research presents a novel comprehensive physical audit of hierarchical design-for-disassembly (DfD) performance in a modular retrofit system, addressing critical gaps in circular construction practice. Through detailed examination of a prototype modular wall system across manufacture, assembly, installation, disassembly, and reassembly, the study provides empirical evidence that advanced DfD principles can be realized in retrofit applications. Key contributions include:

- **Empirical Validation of Hierarchical DfD:** Confirms DfD intent can be achieved at element, component, and material levels, with differentiated performance across scales.
- **Method Validation:** Demonstrates predictive accuracy of STaMPD design-stage assessment (within 2–11%) through physical testing.
- **Practical Implementation Insights:** identifies key technical enablers (adjustable brackets, mechanical fixings, accessible lift-on/lift-off zones, factory prefabrication) and constraints (bonded joints, sacrificial membranes, conventional window-cill detailing, excessive fixings, limited formalized documentation), providing concrete guidance for design optimization.
- **Benchmarking Framework:** Establishes a hybrid evaluation approach combining ISO 20887, academic frameworks, and European demonstrator case evidence for comparative DfD assessment.

Key findings

The audit revealed advanced disassembly, material recovery, and reassembly performance, with three principal observations:

- **Hierarchical Performance Variation:** Element-level DfD (Level 1) was strong, with panels removed intact and reinstalled fully. Material-level DfD (Level 3) achieved >90% recovery. Component-level DfD (Level 2) was constrained, particularly at window-cill interfaces, highlighting the need for design refinement.
- **STaMPD Validation:** Physical categories (Systems, Technical, Materials) were predicted accurately, confirming STaMPD as both design guidance and evaluation tool. Process and Data categories were more variable, reflecting early-stage information limitations and the need for clearer assessment criteria.
- **Enablers and Constraints:** Enablers included independent adjustable brackets, mechanical fixings, accessible lift-on/lift-off zones, and factory prefabrication. Constraints included bonded joints, sacrificial membranes, conventional window-cill detailing, excessive fixings, and limited formalized documentation.

External benchmarking shows Drive 0 performance aligns with leading European modular façade systems (CPH Demo 2,

B.R.I.C.), while identifying areas for improvement in labelling, documentation, and reuse planning.

Implications for research and practice

For Research: Physical auditing is essential to validate design-stage assessment and circular design claims. Hierarchical assessment is critical, as performance varies across levels. Future research should refine STaMPD into a streamlined, practical tool with clearer criteria, staged protocols, and reduced subjectivity. Broader validation across building types, integration of economic analysis, and long-term performance monitoring are recommended. The methodology provides a replicable framework for evaluating circular construction systems.

For Practice: Modular prefabricated retrofit systems can deliver advanced DfD when deliberately designed for disassembly. Key actions include early hierarchical DfD integration, physical prototyping, simplification and standardization of components, factory prefabrication, and systematic documentation. Interface design—junctions, connections, and tolerances—is critical for practical disassembly, while adjustable fixing systems accommodate real-world variations. Material passports and component labeling support future material recovery and circular value retention. Iterative design, prototyping, and hierarchical assessment are central to achieving circular outcomes. Scaling requires addressing economic viability, supply chain coordination, and regulatory integration.

Future directions

STaMPD 2.0 Development: Harmonize indicators (4–5 per category), define measurable criteria, provide scoring guidance, and implement staged protocols. Pilot multi-stakeholder studies to refine reliability and training requirements. Integrate with lifecycle and circularity assessment frameworks.

- **Broader Case Applications:** Test across diverse building types, climates, retrofit scales, and alternative modular systems (timber, concrete, hybrid). Assess disassembly of non-circular existing structures to inform retrofit strategies.
- **Economic and Lifecycle Integration:** Develop frameworks linking DfD performance with lifecycle costs, material value retention, and business models (leasing, material banking, performance contracts). Assess economic impacts of simplification, standardization, and documentation on industrialization potential.
- **Regulatory and Industry Integration:** Align DfD assessment with building codes, circular economy legislation, and certification schemes. Apply manufacturing sector knowledge including design for robotic assembly lines, automated prefabrication sequencing, and standardization of modular interfaces to improve construction efficiency and repeatability. Develop guidance, training, and case repositories to support adoption.

Closing Statement: This research demonstrates that circular retrofit is technically feasible, empirically verifiable, and directly informs policy and practical implementation, providing a foundation for scaling DfD solutions across the building stock. Physical auditing establishes a rigorous approach to validating circular design claims. Transitioning to circular construction requires integrating design innovation, assessment methodology, industry collaboration, and supportive policy frameworks. Advanced DfD can be achieved in real-world modular retrofits through hierarchical design thinking, iterative prototyping, and comprehensive performance assessment. As the building sector confronts decarbonization and resource efficiency imperatives, modular retrofit systems incorporating circularity principles offer a promising pathway. These findings provide actionable insights for regulators, designers, and contractors, supporting broader adoption of circular retrofit strategies and a truly circular built environment.

Acknowledgements: This research was undertaken by the author / researchers based on literature review design developing during the Irish demonstration case of the Drive 0 project under EU Horizon 2020 funding Grant No 841850, (See www.Drive0.eu for project details). The development of the Irish modularized wall panel was a collaboration between the research partner Technological University Dublin and the industrial partners Coady Architects and Vision Built light gauge steel system manufacturers.

Authorship Contribution Statement: Patrick Daly: Principle investigator / researcher, project coordinator, researcher / supervisor, undertaking - conceptualization, methodology, investigation, data, analysis, visualization, paper writing, review and editing; Paula Gallego Barril: Research assistant; supporting in investigation, analysis, data collation, visualization and bibliography.

Conflict of Interest: No potential conflicts of interests are reported by the authors

Ethics Approval: Not applicable to this research

Consent to Participate: Full consent to participate was obtained by all project partners.

Funding: EU Horizon 2020 funding Grant No 841850.

References

- Ahn, N., Dodoo, A., Riggio, M., Muszynski, L., Schimleck, L., & Puettmann, M. (2022). Circular economy in mass timber construction: State-of-the-art, gaps and pressing research needs. *Journal of Building Engineering*, 53. <https://doi.org/10.1016/j.jobe.2022.104562>
- Akinade, O. O., Oyedele, L. O., Ajayi, S. O., Bilal, M., Alaka, H. A., Owolabi, H. A., Bello, S. A., Jaiyeoba, B. E., & Kadiri, K. O. (2017). Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills. *Waste Management*, 60. <https://doi.org/10.1016/j.wasman.2016.08.017>
- Andersen, S. C., Birgisdottir, H., & Birkved, M. (2022). Life Cycle Assessments of Circular Economy in the Built Environment—A Scoping Review. In *Sustainability (Switzerland)* (Vol. 14, Number 11). <https://doi.org/10.3390/su14116887>
- Bakx, M. J. M., Ritzén, M. J., Lichtenberg, J. J. N., Beurskens, P. R., Durmisevic, E., & Zero, T. (2016). A Morphological Design and Evaluation Model for the Development of Circular Facades. *Sustainable Built Environment: Transition to Zero 2016*, (April).
- BAMB. (n.d.). BAMB Project _ Build Reversible in Conception (B.R.I.C.) – Circular Construction Demonstrator. " Accessed: Jan. 19, 2026. [Online]. Available: <https://www.bamb2020.eu/topics/pilot-cases-in-bamb/bric/>
- Benachio, G. L. F., Freitas, M. do C. D., & Tavares, S. F. (2020). Circular economy in the construction industry: A systematic literature review. In *Journal of Cleaner Production* (Vol. 260). Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2020.121046>
- British Standards Institution (BSI). (2021). BS 8539:2012+A1:2021 Code of practice for the selection and installation of post-installed anchors in concrete and masonry.
- Bucci Ancapi, F., Van den Berghe, K., & van Bueren, E. (2022). The circular built environment toolbox: A systematic literature review of policy instruments. *Journal of Cleaner Production*, 373, 133918. <https://doi.org/10.1016/j.jclepro.2022.133918>
- Building regulations 2012: technical guidance document. A, Structure. (2012). Stationery Office.
- Callegari, G., Spinelli, A., Bianco, L., Serra, V., & Fantucci, S. (2015). NATURWALL© - A solar timber façade system for building refurbishment: Optimization process through in field measurements. *Energy Procedia*, 78. <https://doi.org/10.1016/j.egypro.2015.11.641>
- Charef, R., & Lu, W. (2021). Factor dynamics to facilitate circular economy adoption in construction. *Journal of Cleaner Production*, 319. <https://doi.org/10.1016/j.jclepro.2021.128639>
- CIRCUIT. (n.d.). CIRCUIT Project CPH Demo 2- Modular Facade DfD Optimisation Accessed: Jan. 19, 2026. [Online]. Available: <https://www.circuit-project.eu/cph-demo2>.
- Daly, P. (2023). A critical review of circularity - 'design for disassembly' assessment methods applied in the development of modular construction panels - an Irish case study. *E-Prime – Special Issue- Sustainable Construction – Advances in Electrical Engineering, Electronics and Energy*, 5. <https://doi.org/10.1016/j.prime.2023.100252>
- Daly, P., & Barril, P. G. (2025). Development and pilot application of a novel design for disassembly assessment framework and method entitled 'STAMPD'—applied in the design and prototyping of a modular circular wall over cladding system. *Journal of Building Design and Environment*. <https://doi.org/10.70401/jbde.2025.0021>
- Department of the Environment, C. and C. (2023). Climate Action Plan 2024.
- D'Oca, S., Ferrante, A., Ferrer, C., Perneti, R., Gralka, A., Sebastian, R., & Veld, P. op t. (2018). Technical, financial, and social barriers and challenges in deep building renovation: Integration of lessons learned from the H2020 cluster projects. *Buildings*, 8(12). <https://doi.org/10.3390/buildings8120174>
- Drive 0. (2023). <https://www.drive0.eu/>
- Drive 0, Zuyd University of Applied Sciences, SURD research team, Cottafava, D., Ritzén, M., & van Oorschot, J. (2020). Deliverable 6.1 Report on benchmarking on circularity and its potentials on the demo sites. https://www.drive0.eu/wp-content/uploads/2020/08/DRIVE0_D6.1.pdf
- Du, H., Huang, P., & Jones, P. (2019). Modular facade retrofit with renewable energy technologies: The definition and current status in Europe. In *Energy and Buildings* (Vol. 205). <https://doi.org/10.1016/j.enbuild.2019.109543>
- Durmisevic, E. (2006). Transformable building structures: Design for disassembly as a way to introduce sustainable engineering to building design & construction. TUDelft.
- Durmisevic, E., & Brouwer, J. (2006). Design Aspects of Decomposable Building Structures. Proceedings of the CIB Task Group 39-Deconstruction Meeting, (January).
- Eberhardt, L. C. M., Birkved, M., & Birgisdottir, H. (2022). Building design and construction strategies for a circular economy. *Architectural Engineering and Design Management*, 18(2). <https://doi.org/10.1080/17452007.2020.1781588>
- Ellen MacArthur Foundation. (2014). *Towards the Circular Economy: Vol. 1: Economic and business rationale for an accelerated transition*. Ellen MacArthur Foundation, 1.
- European Commission. (2011). Communication from the Commission to the European Parliament, the Council, the Euro-

- pean Economic and Social Committee and the Committee of the Regions. Energy Roadmap 2050. Brussels COM, 885 final.
25. European Commission. (2012). Communication from the Commission to the European Parliament and the council. Strategy for the Sustainable Competitiveness of the Construction Sector and its Enterprises. Brussels COM, 66(3).
 26. European Commission. (2014). Communication from the Commission - Towards a circular economy: A zero waste programme for Europe. European Commission, 398, 1–14. <https://ec.europa.eu/environment/circular-economy/pdf/circular-economy-communication.pdf>
 27. Gasparri, E., Arasteh, S., Kuru, A., Stracchi, P., & Brambilla, A. (2023). Circular economy in construction: A systematic review of knowledge gaps towards a novel research framework. *Frontiers in Build Environment*.
 28. Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, 178. <https://doi.org/10.1016/j.jclepro.2017.11.207>
 29. Govt Ireland. (2022). Circular Economy and Miscellaneous Provisions Act 2022.
 30. Groat, L., & Wang, D. (2004). Architectural Research Methods. In *Nexus Network Journal* (Vol. 66).
 31. Guy, B., & Ciarimboli, N. (2007). Design for Disassembly in the built environment. A guide to closed-loop design and building.
 32. Hartwell, R., Macmillan, S., & Overend, M. (2021). Circular economy of façades: Real-world challenges and opportunities. *Resources, Conservation and Recycling*, 175. <https://doi.org/10.1016/j.resconrec.2021.105827>
 33. Hossain, M. U., & Ng, S. T. (2018). Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: An analytical review. *Journal of Cleaner Production*, 205. <https://doi.org/10.1016/j.jclepro.2018.09.120>
 34. Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. In *Renewable and Sustainable Energy Reviews* (Vol. 130). <https://doi.org/10.1016/j.rser.2020.109948>
 35. IGBC. (2022). Building a Zero Carbon Ireland. <https://www.igbc.ie/wp-content/uploads/2022/10/Building-Zero-Carbon-Ireland.pdf>
 36. IGBC. (2025). BUILDING A CIRCULAR IRELAND A Roadmap for a Resource Efficient Circular Built Environment ACKNOWLEDGEMENT.
 37. ISO. (2020). ISO 20887 'Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance'.
 38. ISO. (2021). EN ISO 14021:2016/A1. I.S. EN ISO 14021:2016&A1:2021 Is the Adopted Irish Version of the European Document EN ISO 14021:2016, Environmental Labels and Declarations - Self-Declared Environmental Claims (Type II Environmental Labelling) (ISO 14021:2016), (7.4 Designed for disassembly).
 39. Joensuu, T., Edelman, H., & Saari, A. (2020). Circular economy practices in the built environment. In *Journal of Cleaner Production* (Vol. 276). Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2020.124215>
 40. Johansson, R. (2003). Case study methodology. <https://www.researchgate.net/publication/236143987>
 41. Kamrani, A. K., & Salhieh, S. M. (2002). *Product Design for Modularity*. Springer.
 42. Khadim, N., Agliata, R., Marino, A., Thaheem, M. J., & Mollo, L. (2022). Critical review of nano and micro-level building circularity indicators and frameworks. In *Journal of Cleaner Production* (Vol. 357). <https://doi.org/10.1016/j.jclepro.2022.131859>
 43. Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. In *Resources, Conservation and Recycling* (Vol. 127). <https://doi.org/10.1016/j.resconrec.2017.09.005>
 44. Lucon O., D. Üрге-Vorsatz, A. Zain Ahmed, H. Akbari, P. B., L.F. Cabeza, N. Eyre, A. Gadgil, L.D.D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, & M.V. Vilariño. (2014). 2014 Buildings. In O. , Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, & T. Zwickel J.C. Minx (Eds.), *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 671–723).
 45. Lyle, J. T. (1996). *Regenerative Design for Sustainable Development*. John Wiley.
 46. Machado, N., & Morioka, S. N. (2021). Contributions of modularity to the circular economy: A systematic review of literature. In *Journal of Building Engineering* (Vol. 44). <https://doi.org/10.1016/j.jobe.2021.103322>
 47. Mark Zimmermann. (2011). ECBCS Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings.
 48. Mazzoli, C., Corticelli, R., Dragonetti, L., Ferrante, A., Van Oorschot, J., & Ritzén, M. (2022). Assessing and Developing Circular Deep Renovation Interventions towards Decarbonisation: The Italian Pilot Case of "Corte Palazzo" in Argelato. *Sustainability (Switzerland)*, 14(20). <https://doi.org/10.3390/su142013150>
 49. McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the way we make things* (S. and G. Farrar, Ed.).
 50. Mhatre, P., Panchal, R., Singh, A., & Bibyan, S. (2021). A systematic literature review on the circular economy initiatives in the European Union. In *Sustainable Production and Consumption* (Vol. 26). <https://doi.org/10.1016/j.spc.2020.09.008>
 51. Miller, T. D. (1998). Defining Modules, Modularity and Modularization Evolution of the Concept in a Historical Perspective. *Proceedings of the 13th IPS Research Seminar*.
 52. Miller T.D. (1997). Modular engineering. *Proceedings of the 12th IPS Research Seminar Fuglsø*.
 53. Modular Building Institute. (2024). Modular Building Institute. <https://www.modular.org/>
 54. Munaro, M. R., & Tavares, S. F. (2021). Materials passport's review: challenges and opportunities toward a circular economy building sector. *Built Environment Project and Asset Management*, 11(4). <https://doi.org/10.1108/BEPAM-02-2020-0027>
 55. Ness, D. A., & Xing, K. (2017). Toward a Resource-Efficient Built Environment: A Literature Review and Conceptual Model. *Journal of Industrial Ecology*, 21(3). <https://doi.org/10.1111/jiec.12586>
 56. Osobajo, O. A., Oke, A., Omotayo, T., & Obi, L. I. (2022). A systematic review of circular economy research in the construction industry. In *Smart and Sustainable Built Environment* (Vol. 11, Number 1). <https://doi.org/10.1108/SASBE-04-2020-0034>
 57. Parchomenko, A., Nelen, D., Gillabel, J., & Rechberger, H. (2019). Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, 210. <https://doi.org/10.1016/j.jclepro.2018.10.357>
 58. Pittau, F., Malighetti, L. E., Iannaccone, G., & Masera, G. (2017). Prefabrication as Large-scale Efficient Strategy for the Energy Retrofit of the Housing Stock: An Italian Case Study. *Procedia Engineering*, 180. <https://doi.org/10.1016/j.proeng.2017.04.276>
 59. Pope, H. (2024). Industrialized Exterior Retrofit Projects: A Review. *IOP Conference Series: Earth and Environmental Science*, 1363(1). <https://doi.org/10.1088/1755-1315/1363/1/012056>

60. Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. In *Journal of Cleaner Production* (Vol. 207). <https://doi.org/10.1016/j.jclepro.2018.10.014>
61. Sandberg, K., Orskaug, T., & Andersson, A. (2016). Prefabricated Wood Elements for Sustainable Renovation of Residential Building Façades. *Energy Procedia*, 96. <https://doi.org/10.1016/j.egypro.2016.09.138>
62. Shooshtarian, D. S., Hosseini, D. M. R., Kocaturk, P. T., Ashrad, A. P. M., Arnel, P. T., & Doerfler, P. J. (2021). The Circular Economy in the Australian Built Environment: The State of Play and a Research Agenda.
63. Singh, S., Babbitt, C., Gaustad, G., Eckelman, M. J., Gregory, J., Ryen, E., Mathur, N., Stevens, M. C., Parvatker, A., Buch, R., Marseille, A., & Seager, T. (2021). Thematic exploration of sectoral and cross-cutting challenges to circular economy implementation. In *Clean Technologies and Environmental Policy* (Vol. 23, Number 3). <https://doi.org/10.1007/s10098-020-02016-5>
64. Stahel, W. R. (1982). Chapter 4 The Product Life Factor. An Inquiry Into the Nature of Sustainable Societies: The Role of the Private Sector.
65. Stake, R. E. (1995). *The Art of Case Study Research*. Thousand Oaks, CA: SAGE, CA.
66. Tokazhanov, G., Galiyev, O., Lukyanenko, A., Nauyryzbay, A., Ismagulov, R., Durdyev, S., Turkyilmaz, A., & Karaca, F. (2022). Circularity assessment tool development for construction projects in emerging economies. *Journal of Cleaner Production*, 362. <https://doi.org/10.1016/j.jclepro.2022.132293>
67. Torres, J., Garay-Martinez, R., Oregi, X., Torrens-Galdiz, J. I., Uriarte-Arrien, A., Pracucci, A., Casadei, O., Magnani, S., Arroyo, N., & Cea, A. M. (2021). Plug and play modular façade construction system for renovation for residential buildings. *Buildings*, 11(9). <https://doi.org/10.3390/buildings11090419>
68. van Vliet, M. (2018). Disassembling the steps towards building circularity redeveloping the building disassembly assessment method in the building circularity indicator. <https://research.tue.nl/en/studentTheses/disassembling-the-steps-towards-building-circularity>
69. van Vliet, M., van Grinsven, J., & Teunizen, J. (2021). Circular buildings disassembly potential measurement method.
70. World Economic Forum, & The Boston Consulting Group. (2016). *Shaping the Future of Construction. A Breakthrough in Mindset and Technology*.
71. Wuni, I. Y. (2022). Burden of proof beyond the triple bottom line: Mapping the benefits of circular construction. In *Sustainable Production and Consumption* (Vol. 34). <https://doi.org/10.1016/j.spc.2022.10.006>
72. Yin, R. K. (2018). Case study research and applications: Design and methods. In *Journal of Hospitality & Tourism Research* (Vol. 53, Number 5). <https://doi.org/10.1177/109634809702100108>

Appendix 1 | Showing “Impact and Re-application” assessment framework, scoring and guidance

Ranking of impact	Score	Description	Example
None	5	No damage has been caused at any stage. Component/material can be REUSED without any modification.	Brackets
Minor	4	Minor damaged has been caused at any stage. Component/material has to be modified on site to be reused.	Cement Board (Remove the render coat to be reused or fix a small crack in render)
Moderate	3	To be able to reused the component/material has to be modified on factory and be reused for any other purpose.	Fibre Board (Cut the damage area and reuse it for another small panel); Compressible Gasket (Bring it back to the factory and add a new adhesive for being reuse)
Significant	2	If the damaged caused into the component/material required to bring it to the manufacture process to be reused.	Window components
Severe	1	Severe damaged has been caused at any stage. Component/material can NOT BE REUSED after any of the process below described.	Steel studs waste after being cut (Bring to Recycling factory to create new roller steel)

Restages	Description
Reuse	Use of products or components more than once for the same or other purposes without reprocessing.
Reprocessing	Preparation for re-use such as removal of connectors, cleaning, trimming, stripping of coatings, packaging, etc.
Repair	Returning a product, component, assembly, or system to an acceptable condition by renewal or replacement of worn, damaged or degraded parts.
Remanufacture	Ability of a product to be disassembled and refabricated at the end of its useful life in a manner that provides restoration to a condition suitable for resale.
Recycle	Product or associated component that can be diverted from the waste stream through available processes and programmes and can be collected, processed and returned to use in the form of raw materials or products.

Appendix 2 | Showing KPIs and Data sources

Table A | High Level KPI’s and Dara Sources

KPI Category	Indicator	Measurement	Value / Result	Data Source	Notes
Design Performance	Target U-value	Thermal transmittance (W/ m²K)	0.18–0.20	Design specifications	Exceed Irish Building Regulations
DfD Assessment	Element Level	% of components reusable	100%	Physical audit	Stage 1 audit, Table 1
	Material Level	% of material suitable for reuse	>90%	Physical audit & Table 4	All Stages
Biobased	Biocycle Integration	% materials renewable / compostable	25-30%	Specification / Audit - Woodfibre board, studs	Table 4
Process Efficiency	Installation Time	Hours per façade module	1.5 days	Direct observation	Stage 1 assembly
STaMPD Validation	Overall Score Variation	% difference vs benchmark	2–11%	STaMPD scoring & comparative analysis	Table 7 & Section 7.2
External Benchmarking	Drive 0 Disassembly Potential	90 % by volume	empirically verified as high	Case study benchmarking	Element-level 100% reuse potential

Table B | Categories and Indicators used as basis for observation, recording reporting and data sources

Category	Indicators (Grouped)	Data Source - researcher	Notes
Systems	Standardisation of products, Geometry, Functional independence, Relationship of parts, Number of parts, Connections & fixing	Physical audit, design drawings	Measures interrelation of parts; high standardisation improves disassembly efficiency
Technical	Edge connection, Type of connection, Accessibility, Tolerance	Physical audit, manufacturer data	Evaluates core DfD connections; lower accessibility or tight tolerances reduce efficiency
Material	Toxicity, Resilience, Durability, Number of materials, Chemical composition	Material datasheets, site observation	Materials with low toxicity and high resilience support reuse and recycling
Process	Fabrication location, Production, Transport, Assembly, Tools, Storage, Safety, Knowledge & skill, Operation complexity, Time	Site observation, interviews, time studies	Captures assembly/disassembly workflow and operational efficiency Note - Transport and Final Stage 3b recorded by Manufacturer
Data / Information	Construction information, Material information, Disassembly instructions, Safety information	Manuals, BIM files, manufacturer guidance	Ensures correct execution; higher quality documentation facilitates safe and efficient DfD

Note: The collated observations, photos, sketches, drawings, material data and interview notes, comments and feedback were collated by Researcher in a comprehensive DfD Auditing Report, utilising the STaMPD framework as a reporting mechanism, which also facilitated re-scoring (Post DfD Audit) for comparison to design stage pre works Audit.

Call for Papers

Scope

Journal of Sustainable Built Environment (JSBE) welcomes original contributions that explore a wide spectrum of topics, including but not limited to:

Built Environment and Infrastructure

- Sustainable design, construction, and operation of buildings and landscapes
- Resilient urban infrastructure and green building certification systems
- Integration of natural and built environments, including landscape and ecological planning

Urban and Regional Planning

- Policies and strategies for sustainable urbanization and rural-urban linkages
- Compact city development, smart growth, and sustainable spatial planning
- Mitigation of urban sprawl and promotion of sustainable land use

Transportation and Mobility

- Development of sustainable and energy-efficient transportation systems
- Policies to promote active transportation and public transit
- Urban freight and logistics planning for sustainability

Environmental and Energy Systems

- Renewable energy systems and energy-efficient practices in the built environment
- Climate change adaptation and mitigation strategies at various scales
- Air quality management and sustainable urban ecosystems

Climate and Resource Management

- Circular economy and resource efficiency in urban and regional contexts
- Climate-resilient city design and planning
- Sustainable water, waste, and materials management in urban systems

Governance, Policy, and Economics

- Institutional frameworks and policies for sustainability
- Urban governance, stakeholder engagement, and participatory planning
- Economic instruments and financing mechanisms for sustainable development

Society and Communities

- Strategies for fostering social inclusion, equity, and resilience
- Community-driven approaches to sustainability and local development
- Cultural and historical preservation within sustainable planning

The journal particularly values interdisciplinary approaches that bridge architecture, urban planning, environmental science, engineering, public policy, and social sciences, providing holistic perspectives on sustainable development. Comparative research, case studies, and critical analyses offering global, regional, and local insights are strongly encouraged.

Submission Guidelines

JSBE accepts the following manuscript types (all word counts include references and notes):

Research Articles (4,000–8,000 words): Original empirical or theoretical studies presenting novel findings and rigorous conceptual arguments.

Review Articles (4,000–8,000 words): Comprehensive and critical evaluations of major academic debates, research traditions, or emerging thematic directions.

Case Studies (4,000–6,000 words): In-depth analyses of specific projects, communities, or cultural practices with broader scholarly and theoretical implications.

Note: Only original, unpublished works are considered. Translations of previously published material will not be accepted.

Peer review process

JSBE adheres to a double-anonymized peer review model to ensure the highest standards of academic integrity. Each submission undergoes an initial internal screening by the editorial office to evaluate its alignment with the journal's scope and adherence to formatting requirements. Manuscripts that pass this preliminary stage are subsequently assigned to a minimum of two independent subject-matter experts for rigorous external evaluation.

Open access policy

JSBE is a fully Gold Open Access publication. Upon acceptance, all articles are made immediately and permanently accessible online to a global audience without financial barriers. Detailed information regarding Creative Commons licensing, copyright retention, and institutional repository policies can be found in our comprehensive Policy Section.

Publication frequency & Timeliness

Schedule: JSBE is published bimonthly, with full issues released in January, March, May, July, September and November.

Online First: To facilitate the rapid dissemination of research, accepted manuscripts are published as "Articles in Press" (Online First) individually. These versions appear online following the completion of peer review, editorial revision, and production, prior to their inclusion in a formal paginated issue.

Submission logistics

Format & Channel: Authors are required to prepare manuscripts in Microsoft Word (.doc/.docx) format. All submissions must be managed through the journal's Electronic Submission Portal.

Compliance: Before initiating a submission, authors must ensure their manuscript strictly complies with the latest Author Guidelines.

Rolling Basis: The journal maintains a continuous submission cycle, accepting manuscripts year-round without fixed deadlines for general issues.

Article processing charges (APC)

To support the costs of open-access publishing, JSBE levies a one-time Article Processing Charge (APC) of USD 80 for each manuscript successfully accepted for publication.

Journal metadata & Contact

Submission Portal: <https://jandoopress.com/journal/jsbe>

Editorial Office: For all inquiries regarding the submission process or editorial decisions, please direct correspondence to contact@press.jandoo.ac.

Journal of Sustainable Built Environment (JSBE) is a peer-reviewed, open-access academic journal dedicated to advancing interdisciplinary research and fostering innovative solutions for sustainable development across the built environment. The journal serves as a platform for the dissemination of high-quality research and critical discourse on the challenges and opportunities in achieving sustainability in urban, regional, and global contexts.

Copyright © 2026 by the Author(s).
Published by Jandoo Press Co., Ltd.

X (Twitter)
@JandooPress

RedNote
JandooPress

Instagram
@JandooPress

WeChat Official Account
JandooPressCN

ISSN 2759-7318 (Online)
ISSN 2760-327X (Print)