PAPER • OPEN ACCESS

Design for Disassembly (DfD) in construction industry: a literature mapping and analysis of the existing designs

To cite this article: Katarzyna Ostapska *et al* 2021 *J. Phys.: Conf. Ser.* **2042** 012176

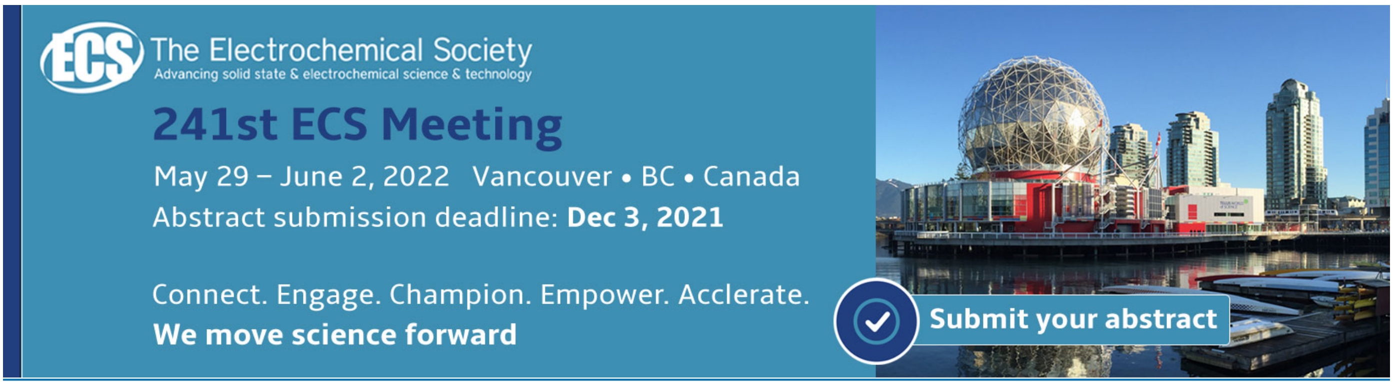
View the article online for updates and enhancements.

You may also like

- A bridge column with superelastic NiTi SMA and replaceable rubber hinge for earthquake damage mitigation
Sebastian Varela and M 'Saiid' Saiidi

- Potential of Circular Economy in Sustainable Buildings
Leonora Charlotte Malabi Eberhardt, Harpa Birgisdottir and Morten Birkved

- Temperature-dependent dynamics of stochastic domain-wall depinning in nanowires
Clemens Wuth, Peter Lendecke and Guido Meier



This content was downloaded from IP address 109.247.167.60 on 19/11/2021 at 12:00

Design for Disassembly (DfD) in construction industry: a literature mapping and analysis of the existing designs

Katarzyna Ostapska, Klodian Gradeci, Petra Ruther

SINTEF Community, Høgskoleringen 7B, 7465 Trondheim, Norway

katarzyna.ostapska@sintef.no

Abstract. A systematic search of scientific literature on the topic of Design for Disassembly (DfD) in the architecture, engineering, and construction (AEC) industry was performed with a special focus on study cases. The results were augmented by electronic magazine search due to the non-representative amount of data found in the scientific database. Results show the domination of wood and steel solutions among architects and engineers designing for disassembly. Frame structural system is preferable. DfD structures are mainly located in Europe but observed in the whole world and growing exponentially since 90'. The database with 117 built DfD study cases is made available online and will be further developed.

1. Introduction

'Disassembly potential is defined as the ability of a building's structure to be selectively taken apart with the intention of reusing and up-cycling some (or all) of its constituent parts ' [1]. The need to limit waste and transition to the circular economy (CE) is driving the development of DfD [2]. This paper aims at investigating the current state of research and advance in the application of DfD with a focus on the real-life implementation: modern built DfD structures. The historic and vernacular demountable architecture is an essential starting point for modern DfD concepts but remains outside the scope of the current study.

2. Methods

The systematic literature search, based on the identified relevant keywords was used to identify the relevant literature. The keywords were refined initially after preliminary searches for maximum inclusivity and precision in hits. The same search method was adapted to two data sources: scientific publication databases and online magazine publications. In the first, the field of AEC was ensured by search keywords, while in the second the group of the most popular magazines was selected a priori. The subject keywords were identical for both searches.

The results of the searches were mapped to create an overview of the whole DfD domain and indicate research focus areas compared to AEC activity in DfD. The mapping was done based on two questions:

Question 1: **How** is DfD researched/done? Answer 1: Main ideas: content **map**.

Question 2: **Where** is research vs AEC? Answer 2: Differences/overlap: knowledge **gaps**.

The mapping consists of the analysis (paper selecting and reading), synthesis (paper classification and grouping, ideas picking), and organizing (quantitative evaluation, conclusions, perspective).

From a practical point of view, the extensive body of literature cannot be directly referenced in the paper and was made available via the online application with interactive data presentation and hyperlinks to data sources (references) [3].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

2.1. Literature search strategy

2.1.1. Scientific literature.
The systematic literature search was conducted in the scientific databases: *Scopus, Web of Science, Science Direct*. The search keywords are summarized in Table 1.

Table 1. Keywords used for systematic search of scientific literature.

Keyword: subject	Keyword: field
design for disassembly/deconstruction/reuse/demount/ adaptive design*	*architecture, construction, building, concrete, wood, brick, aluminum, steel*

The search resulted in 548 hits after excluding duplicates out of which 121 papers were selected as relevant after reading abstracts and additional 92 papers were added as a result of cross-referencing. A total of 213 full-text papers were analyzed for content.

2.1.2. Online magazines.
Based on the results from the scientific search, an additional search in selected online magazines was made to supplement the data on applied design for disassembly reported outside academic publishing. The search was performed on the most popular online architectural and design platforms *archdaily.com, dezeen.com, inhabitat.com, e-architect.com, woodinconstruction.com, feeldesain.com*. The search keywords were: *disassembl*/deconstruct*/reuse/demount*/adapt**. The searched results were manually filtered to only include existing designs (87) and planned or winning designs (19). The criteria for including a case study were defined by keyword search. Buildings that could potentially be considered easy to disassemble but were not declared as such by the designer, were not considered in this analysis. The subjectivity of the defining structure as designed for disassembly by the designer must be underlined here, as there is no universal agreement, standard, or certification.

2.2. Literature classification
The collected body of literature consists of 213 scientific articles or manuscripts and 106 online magazines reporting singular cases of design for disassembly. The literature was divided into categories for quantitative analysis. The categories were created based on reading full paper texts and are presented in Figure 1. While online architectural magazines focus predominantly on reporting existing cases of design for disassembly, the scientific literature covers other aspects, e.g., analysis of current state of DfD, Building Information Modelling (BIM) for DfD, methodology and framework for DfD, tools for DfD rating and certification.

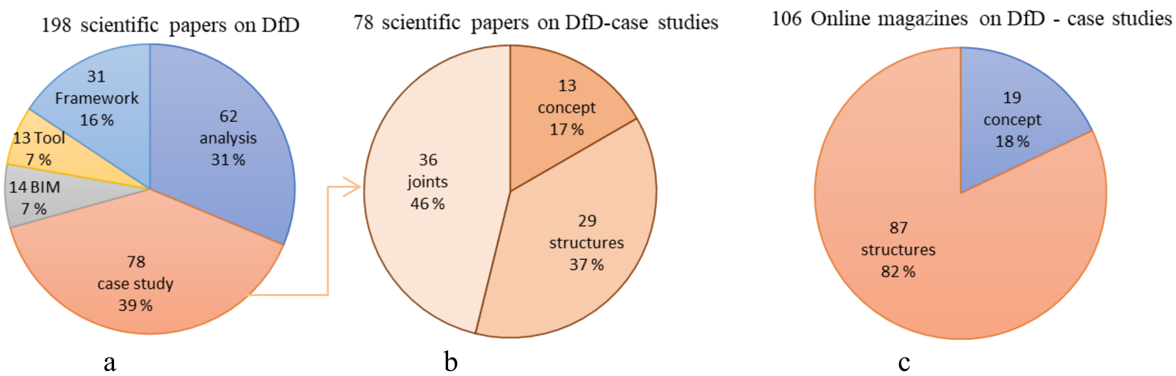


Figure 1. Classification of papers on DfD in AEC from the scientific database search overall (a) and case studies (b), and from the online magazine case study search (c)

3. Results and Discussion

3.1. Results of systematic scientific literature database search (Fig 1a and b).

3.1.1. Analysis of current state of DfD

The group of 62 out of 213 scientific publications was identified as analysis of DfD in AEC and was further scanned for main common topics and several subcategories were detected:

a) **Identification of barriers** is a focus within the group of 7 out of 62 papers. The most often repeated barrier is the lack of evaluation criteria, assessment methodologies, and specific guidelines that allow to include and weigh together the benefits for society, economy, and environment coming from DfD. The challenges lay in connecting input and feedback from many industries, that function independently in the linear economy but are required to cooperate for a successful transition into the circular economy.

b) The **ethical assessment** of current practices in AEC are addressed mainly in 11 papers, where the aspect of re-evaluation of priorities in society [3], educating strategies [4] and sourcing from vernacular architecture [5] [6], directing research focus [7], reassessing urban development [8], and the clash of DfD with current economy principles [9].

c) The **feasibility studies** focus on exploring different approaches to DfD (joint classification, building decomposition into layers, design for adaptation/reuse/recycling, material selection, material banks), assessment methods (life-cycle inventory, analysis, and costing, circularity indicator vs embodied energy, end-of-life scenario), methodologies of implementations (frame structures, modular structures, kit-of-the-parts systems, dry technologies vs wet technologies), and demonstrate their usefulness or validity on the synthetic data or real case studies.

d) The three identified **review papers** focused on the design process for DfD [10], DfD within building information modelling BIM [11], and building strategies for the circular economy [12].

e) The last subgroup contains three papers [13] [14] [15], reporting **standardization work and guideline** preparation in Canada and Scotland.

3.1.2. Case studies within DfD

Among 78 papers classified as case studies, 37% concerned existing structures designed for disassembly, while 17% covered concept designs of structures for possible implementation. Almost half of the study cases discussed in the scientific literature were focused on DfD joint development, testing, and analysis. Both joint designs, structures, and concepts were almost always specified in terms of technology and material choice. The analysis of case studies based on the main structural material is shown in Figure 2, where depending on the case study group the percentage of a given material is illustrated.

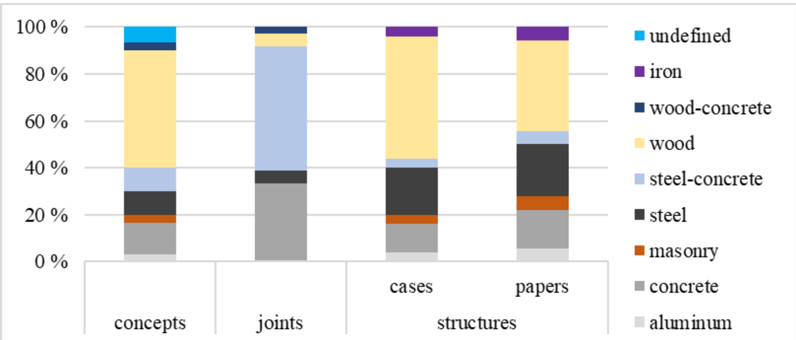


Figure 2. Case studies based on the main structural materials

3.1.3. BIM for DfD

Building Information Modelling (BIM) was addressed in 16 papers. Several implementations were developed: building salvage performance, deconstruction strategy evaluation, deconstruct-ability assessment, steel deconstruct-ability, digital material bank, reusability assessment.

3.1.4. Tool for DfD implementation, rating, and certification
Proposed measures for assessment of the potential for disassembly to guide the design were identified in 17 scientific papers, e.g.: recyclability index of materials [4], building circularity indicator [5] [6], LCA augmented with DfD [7] [8], deconstruction cost prediction tool [9], DfD with additive manufacturing [10], constructive language system [11], sequential disassembly planning for building [12] with optimization [13], DfD with radio frequency identification [14] [15], programmatic flux for transformation capacity assessment [16], material recovery certificate [17].

3.1.5. DfD Framework
Twenty papers described framework proposals for DfD to implement in the AEC industry. The subgroups of frameworks identified that: included DfD as an element of life cycle analysis (6 papers), postulated new approach based on higher importance of reusability (12 papers), stressed adaptability issue (2 papers), and raised the importance of design for deconstruction safety (1 paper).

3.2. Results of case studies analysis
Online magazines were searched only for built or planned to be built DfD structures. The search was undertaken after the scientific database search produced insufficient data to present an overall perspective on DfD in AEC. Case studies collected via systematic literature search in scientific databases and online magazines were then analysed together (117 structures) to provide information about the timeline of DfD development, main structural material, structural system, geographic location, and total area. The data were presented in Figure 3-6, and referenced with details in the online repository [3].

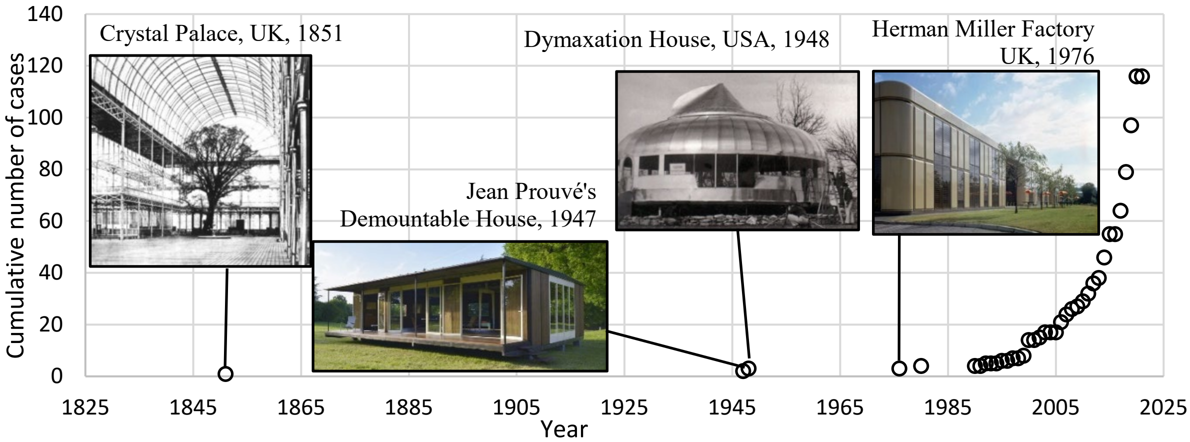


Figure 3. Timeline of the cumulative number of structures designed for disassembly between 1851-2020

The historic structures that are DfD prototype buildings are graphically presented in Figure 3 before the rise in modern DfD constructions that starts in 90'.

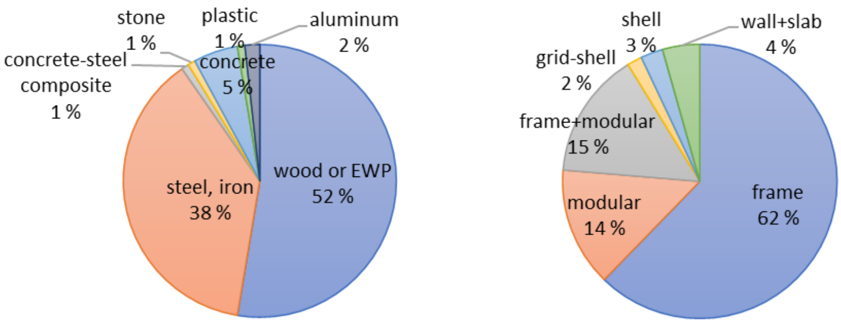


Figure 4. Main structural material, (a) and structural system applied (b) in 117 built DfD structures (EWP- engineered wood product)

The characterization of DfD structure size based on aggregated area is shown in Table 2.

Table 2. Built area in DfD buildings.

area [m^2]	<20	20-100	100-500	500-1k	1k-5k	5k-10k	>10k
count	9	13	38	11	25	8	3

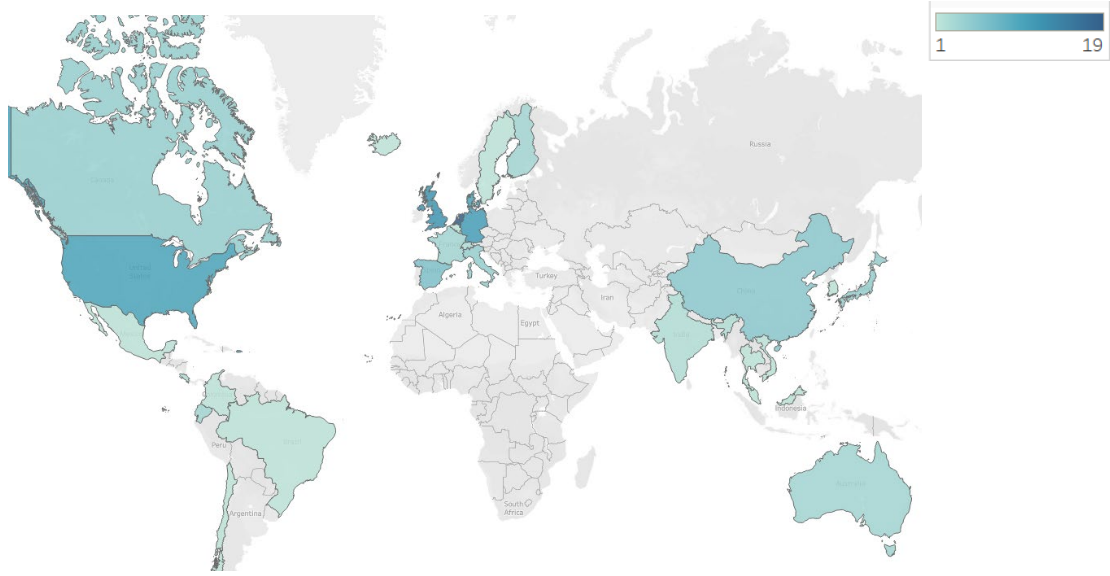


Figure 5. Geographical heat map of built DfD structures in the world (from 1 to 19 for a country)

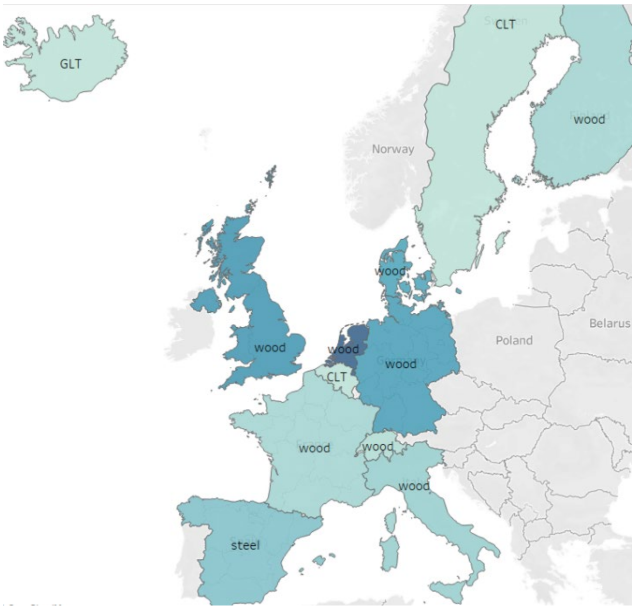


Figure 6. Geographical heat map of the built DfD structures in Europe with the prevailing structural material, maximum in the Netherland (19).
CLT – Cross Laminated Timber
GLT- Glued Laminated Timber

4. Conclusions

A literature mapping based on 213 scientific papers was performed and main research fields within DfD in AEC were identified. The focus is put on developing the most appropriate and feasible methodology for implementing DfD and special attention is given to the development of DfD structural detail: joint. Comprehensive scientific literature and online magazine search allowed to collect data of 117 study cases of DfD structures and statistic conclusions based on data analysis can be made:

- Built DfD structures are mainly reported in non-scientific publications.
- Research within DfD joints is focused on steel-concrete and concrete connections.

- Most of the modern built DfD structures are in Europe: Netherlands, Germany, and UK.
- Dominating main structural material in modrn DfD structures is wood (52%) and steel (38%)
- Preferred structural system in modern DfD structures is frame (77%)
- The number of modern DfD structures is growing exponentially since 90'

The database containing references to the analysed DfD structures was prepared and can be accessed freely at https://dfdstructures.herokuapp.com/ with an interactive modern DfD structures heat map.

References

[1] Durmisevic, E., Ő. Ciftcioglu, and C.J. Anumba. *Knowledge model for assessing disassembly potential of structures*. in *Deconstruction and Materials Reuse Proceedings of the 11th Rinker International Conference*. 2003.
[2] Crowther, P., *Design for disassembly : an architectural strategy.*, in *QUT Winter Colloquium*. 1998: Qeeunsland University of Technology. p. 27-33.
[3] Ostapska, K., K. Gradeci, and P. Ruther. *DfD case studies database for Architecture, Engineering and Construction industry.* 2021; Available from: https://dfdstructures.herokuapp.com/.
[4] Villalba, G., et al., *Using the recyclability index of materials as a tool for design for disassembly.* Ecological Economics, 2004. **50**(3): p. 195-200.
[5] van Vliet, M.M., *Disassembling the steps towards building circularity redeveloping the building disassembly assessment method in the building circularity indicator*, in *Construction Management & Engineering*. 2018, Eindhoven University of Technology.
[6] Mayer, M. and M. Bechthold, *Development of policy metrics for circularity assessment in building assemblies.* Economics and Policy of Energy and the Environment, 2017. **2017**(1): p. 57-84.
[7] Tingley, D.D. and B. Davison, *Developing an LCA methodology to account for the environmental benefits of design for deconstruction.* Building and Environment, 2012. **57**: p. 387-395.
[8] Eberhardt, L.C.M., et al., *Development of a life cycle assessment allocation approach for circular economy in the built environment.* Sustainability (Switzerland), 2020. **12**(22): p. 1-16.
[9] Tatiya, A., et al., *Cost prediction model for building deconstruction in urban areas.* Journal of Cleaner Production, 2018. **195**: p. 1572-1580.
[10] Soar, R. and D. Andreen, *The role of additive manufacturing and physiomimetic computational design for digital construction.* Architectural Design, 2012. **82**(2): p. 126-135.
[11] Schwede, D. and E. Störl. *System for the analysis and design for disassembly and recycling in the construction industry*. in *CESB 2016 - Central Europe Towards Sustainable Building 2016: Innovations for Sustainable Future*. 2016.
[12] Sanchez, B. and C. Haas, *A novel selective disassembly sequence planning method for adaptive reuse of buildings.* Journal of Cleaner Production, 2018. **183**: p. 998-1010.
[13] Sanchez, B., et al., *A selective disassembly multi-objective optimization approach for adaptive reuse of building components.* Resources, Conservation and Recycling, 2020. **154**: p. 104605.
[14] Paterson, G., P. Crowther, and S. Taylor. *Design for disassembly and recycling-using radio frequency identification (RFID) technology to facilitate whole life actions for sustainable construction*. in *CESB 2007 PRAGUE International Conference - Central Europe Towards Sustainable Building*. 2007.
[15] Iacovidou, E., P. Purnell, and M.K. Lim, *The use of smart technologies in enabling construction components reuse: A viable method or a problem creating solution?* Journal of Environmental Management, 2018. **216**: p. 214-223.
[16] Nienhuis, K., N. Woesthuis, and J.W. Frantzen. *PROGRAMMATIC FLUX, CAN YOU COPE?. A FIRST INTRODUCTION TO THE "TIMESHIFTING-MODEL"*. in *Deconstruction and Materials Reuse*. 2003. Rotterdam (Netherlands): in-house publishing.
[17] Architects, J.M.H. *Pavilion for the City Jubilee / J. Mayer H. Architects*. archdaily, 2015.