Systemic view on reuse potential of building elements, components and systems - comprehensive framework for assessing reuse potential of building elements

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ABSTRACT

The physical impact of the increasing building mass in industrial and developing parts of the world is undeniable. In Europe, the building industry accounts for 38 percent of the total waste production, 40 percent of the CO2 emissions and 50 percent of all natural resources used within the building sector. (EIB 2015) Such negative impact of the construction sector is primarily related to the fact that built environment has been optimized for a linear system and one end of life option, demolition.
The design of building products with high reuse potential is a necessity to move towards a construction industry that (1) creates building products with an increasing resource productivity; (2) is less dependent on virgin resources and; (3) contributes to the elimination of the concept of waste.
As part of the EU Buildings as Material Banks project this paper will discuss the broader framework of a tool that will be able to assess reuse potential of building and its components and enhance their future environmental and economic value propositions.
Due to the systemic nature of the tool the paper will showcase several case projects and the assessment of reuse potential indicators, measuring functional, technical and material dependences on three levels of a building's composition (i.e. building, system, and component). Further to this the relation will be made between indicators of reuse potential with different value propositions based on which the framework for measuring environmental and economic impact of different reuse options will be established. Finally the paper will elaborate on gaps between design related data and existing capacity of Building Information Modeling (BIM) for the purpose of integrating the Reuse Potential Tool with BIM .

Keywords: Reversible building, design for disassembly, reuse potential, reuse options.

TOWARDS HIGH REUSE POTENTIAL OF BUILDING ELEMENTS

One can say that buildings are characterised by their static rigid structures that cannot be modified without demolition. They are not designed to be transformed to meet changing requirements without demolition and waste generation, and their products are not designed to be recovered and reused. Major barriers for high reuse of building elements can be summarises in eight points:

- Lack of valid data about the technical composition of the building and quality of the elements
- Lack of instruments for certification of reusable elements.
- Lack of protocols for design, and disassembly

- Lack of reversed logistics strategies in place
- Lack of market strategies. Is there a market for reuse and how to define these in procurement documentation?
- It is not known how to manage the risk of investment in reusable structures over longer period of time?
- Buildings are demolished not only due to low disassembly potential of their structures but also due to the lack of decision making protocols to support and guide the preparation of disassembly.
- Costs of new elements are often cheaper than the costs of recovered elements

These barriers are directly related to the design and decision making protocols and life cycle management strategy. However understanding of decision making and management strategies can start only once we have full understanding of reversibility of building, reuse options of elements and how to increase their reuse potential through design.

Transformable buildings with reusable elements, have potential to form a driving vehicle for utilizing built environment in the future as a material bank for new buildings or products. At the core of this new design approach lay two concepts (1) capacity of building to transform building space and structure to meet new requirements and (2) potential to reuse physical structures and elements in new building products and buildings. A base line for both concepts, aiming for high transformation capacity and high reuse potential is disassembly, upon which reversibility of building space and reversibility of building structure to initial set of elements can prosper.

The model of Durmisevic (2006) highlights key indicators for such reversible buildings in relation to their transformation and disassembly without waste generation. It brings into focus two indicators of reuse (independence and exchangeability of building products) and associated eight criteria for design of building configuration with high disassembly /reuse potential as precondition for multiple reuse options (see figure 1). The model is used as a base line for development of the comprehensive framework for assessing reuse potential of elements and understanding their environmental and economic impact.

Indicator of independence is provided through separation of functions on building, system and component levels and development of independent functional modules. Exchangeability is provided by minimization of complexity and number of relations between different elements and typology/morphology of connections that support reuse.

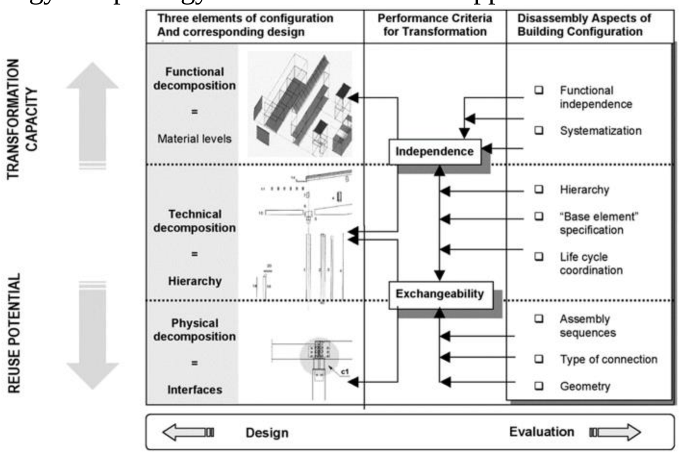


Figure 1. Model of Durmisevic that provides guidelines and asses capacity of building structure to be transformed and disassembled without damaging building elements

Two indicators of disassembly and reuse potential are defined by eight design criteria that can be analyzed and evaluated separately. But they can also be used as design guidelines for design of transformable structures with high reuse potential of its elements. (Figure 2 left). Eight design criteria are formed by three main design domains (figure 2 left): (i) functional domain– defines functional composition/ separation (ii) technical domain- defines hierarchy and dependence of elements by relational pattern and type, number of relations between the elements, and base elements (see figure 2 right) (iii) physical domain- defines exchangeability of elements by typology, geometry and morphology of connections and assembly/ disassembly sequences.

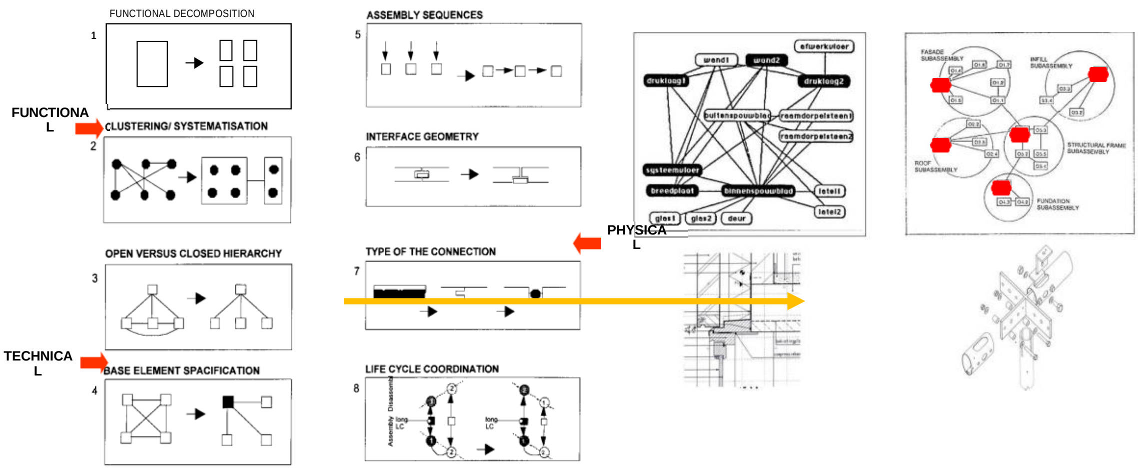
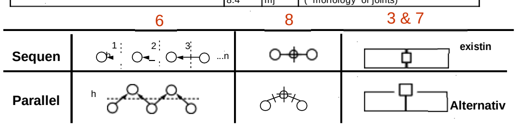


Figure 2. Left; eight criteria for high disassembly and consequently reuse potential from model Durmisevic (2006). Right diagram representing relations between elements within two buildings typical housing in the Netherland in 90's and Richard Hardon house UK. Figure right illustrate difference between complex unstructured and structured hierarchy and relational pattern between elements within building. Examples illustrate also the difference between reuse potential of structures with dedicated base element (each element has multiple relations) and without (only base element has multiple relations).

Figure 3 presents how design decisions about geometry of connection and base element can influence assembly/disassembly sequences and type of connections and how evaluation guides towards improvements made from the first solution to the alternative.

nr.	Design for Disasem bly Aspects	nr		Determ ining Factors
1	FD (Functional decomposition)			
		1.1.	fs	(functional separation)
		1.2.	fdp	(functional dependence)
2	SY (Systematisation)			
		2.1	st	(structure of material levels)
		2.2	c	(type of clustering)
3	BE (Base elements)			
		3.1	b	(type of base element)
4	LCC (Life cycle coordination)			
		4.1	ucl	(use life cycle coordination)
			tcl	(technical life cycle coordination)
			s	(coordination of life cycle and size)
5	RP (Relational pattern)			
		5.1	r	(type pf relational pattern)
6	A (Assembly process)			
		6.1	ad	(assembly direction)
			as	(assembly sequences)
7	G (Geometry)			
		7.1	gp	(geometry of product edge)
		7.2	spe	(standardisation of product edge)
8	C (Connections)			
		8.1	tc	(type of connections)
		8.2	af	(accessability to fix ings)
		8.3	t	(tolerance)
		8.4	mj	(morfology of joints)



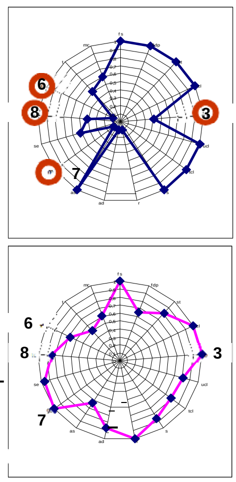


Figure 3. Assessment model with related spin diagram offering information on aspects that can be improved in order to increase disassembly of structure and associated reuse potential.

For example criteria 4 from the model deals with existence of base element of the structure and indicates whether the configuration has recognised intermediary which functions as a base of configuration and intermediary between elements. To provide independence and exchangeability of elements within two product configurations, each product configuration should define its base element, which integrates all surrounding elements of that configuration (Durmisevic 2006). This element functions as intermediary between elements as well as between independent configurations. As shown in figure 4 on the left, elements of the facade system marked with red are base elements of the façade system and at the same time intermediary between facade and loadbearing structure. Without this intermediary number of relations between the façade elements and loadbearing structure would be much bigger and would complicate recovery of façade elements.

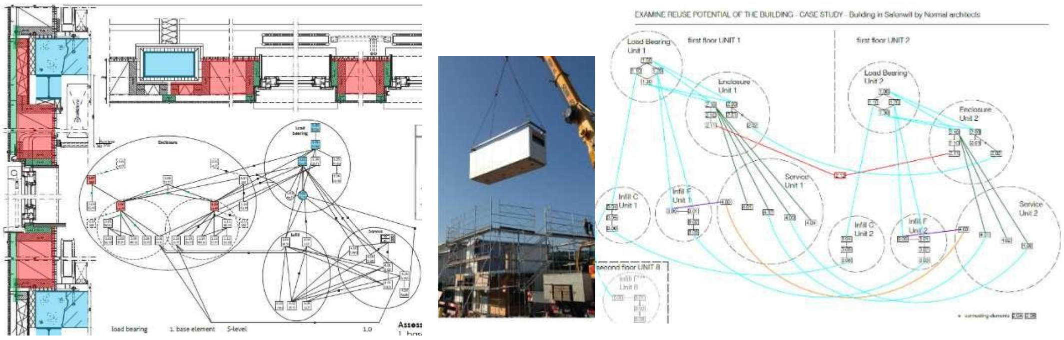


Figure 4. Analyses of reuse potential using model of Durmisevic: left, façade system of Erasmus building analysed by Beurskens right housing project in Switzerland analysed by Androsevic.

While conventional construction method of Erasmus building indicates many functional and physical dependences between elements of the building on different levels of assembly that can complicate recovery operations on building and system level, the modular building of Sarajevo based office indicates more structured and open relational diagrams with recognised functional clusters. This high independence of modules makes disassembly on building level feasible, however exchangeability indicator of elements within the modulus is very low because physical connections between elements within modules indicate that due to many chemical and direct connections the reuse potential of elements is compromised.

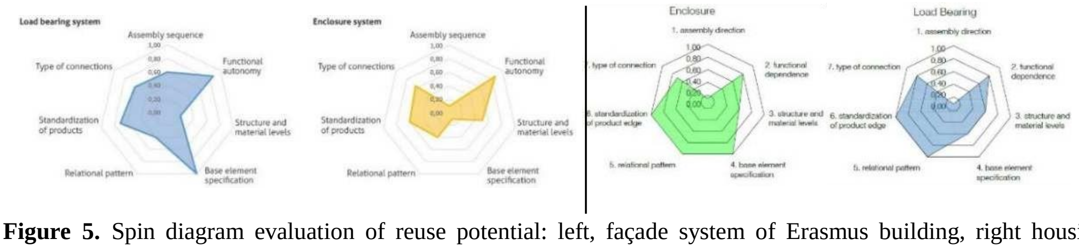


Figure 5. Spin diagram evaluation of reuse potential: left, façade system of Erasmus building, right housing project in Switzerland, indicating the aspects that can be improved upon and cause difficulty during disassembly.

FRAMEWORK FOR ASSESSING REUSE POTENTIAL AND ITS ENVIRONMENTAL AND ECONOMIC IMPACT

In order to be able to measure reuse potential of building elements their disassembly potential needs to be assessed. If parts of the building do not have disassembly potential building cannot be adapted to the new requirements without demolition and building elements cannot be recovered. Once building elements are recovered their reuse options can be assessed based on efforts needed to reuse the elements. Processes around different reuse options (1 direct reuse, 2 reuse by repartition, 3 reuse by reconfiguration, 4 reuse by adding strength ed) and the efforts and logistics needed, will ultimately determine reuse potential and its environmental and economic impacts. Systemic view on reuse potential and framework for its assessment is presented in figure 5.

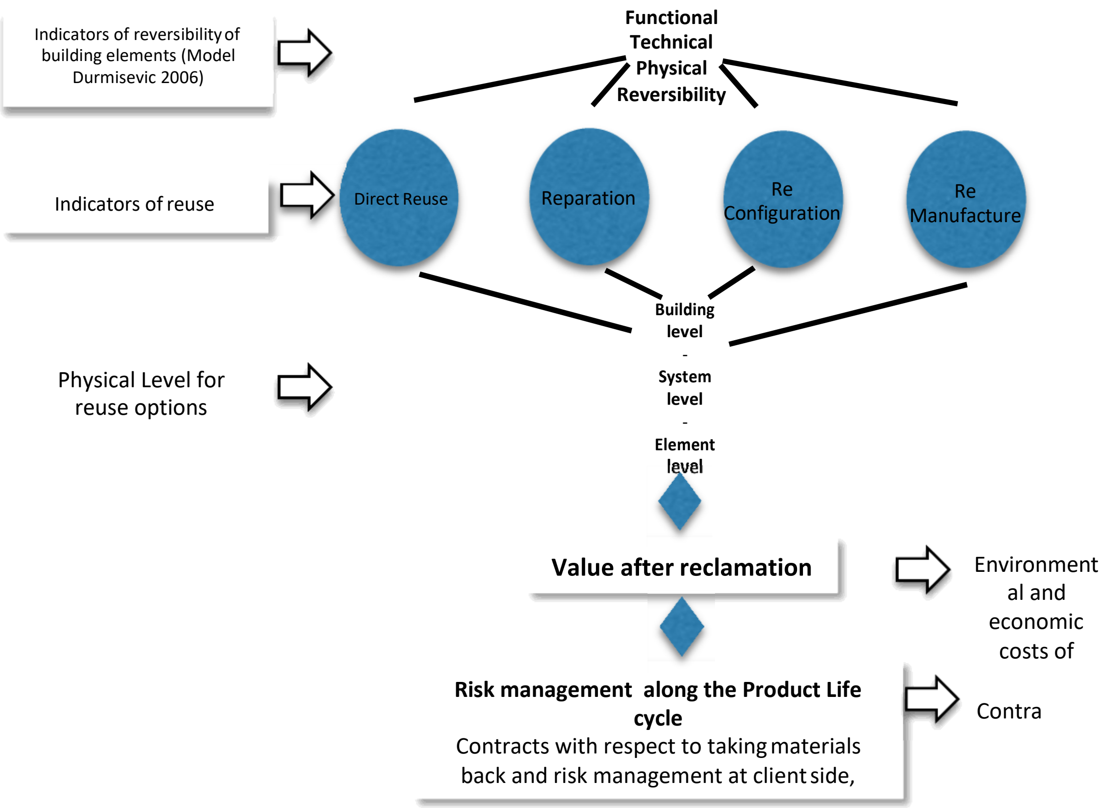


Figure 5. Framework for assessing reuse potential/ and their environmental and economic impacts.

The frmawork relay on model of Dumrisevic 2006, that covers two key indicators for high reuse potential (1) the functional/physical independence of elements and (2) the potential for their physical exchangeability. A third indicator has been added that looks at reuse options in order to provide accurate assessment of reuse potential (3) multiple reuse options of building systems/component/elements. Indicator of multiple reuse options is analysed based on the level of damage that can occur during the recovery process. Evaluations of this category is in progress as well as understanding how data that support reuse potential can be integrated into BIM and their evaluation process atomised.

CONCLUSIONS AND FUTURE WORK

Indicators have been identified after analyses of the barriers that construction sector face concerning circularity of material, and conducting analyses of case projects testing the model of Durmisevic2006. Through this process two indicators (1) independence and (1)exchangeability form model of Durmisevic have been tested, verified and third indicator that addresses multiple reuse options has been identified as third important indicator of reuse potential.

After analyses of the reuse potential indicators a study has been made in order to understand the possibility of integrating reuse data into a BIM model and where the gaps are. Understanding relational patterns that represent number and complexity of relations between elements and the typology of connections are key to accurate assessment of reuse potential and BIM has features that can help to atomise evaluation process in future. are (1) relational diagrams representing functional and technical dependency and (2) typology of connections. Understanding of these two feed into the understanding of processes around reuse and different reuse options in terms of time, efforts and costs that can be integrated into 4D BIM. This research aims at developing a workable model that can measure reuse potential. Further formalisation of the tool and BIM integration will be done in the later stage.

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