Salvageability of building materials

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ABSTRACT: In the context of reducing environmental impact of constructions by facilitating salvage of building components and materials, the term Design for Disassembly (DfD) is commonly discussed. However, in the different sets of guidelines describing how to design reusable and recyclable buildings, more aspects of the design are stressed. Components should be prepared for all the stages of the salvaging process, including sorting, transport, new design and reassembly. The paper presents a comprehensive systematisation of the DfD principles. The aim is to make up a clear, pedagogic system, as well as to link the design principles to an assessment tool. Also, the system can function as a checklist when designing salvageable materials and components. The paper concludes that since many design aspects are relevant in facilitating the salvaging of building components, the term *design for disassembly* is misleading, and could be replaced by the term *design for salvageability*.

1 INTRODUCTION

1.1 *DfD guideline compilations*

Solutions for environmental challenges in general and for climatic changes in particular are frequently and increasingly debated. The building industry has put much focus on reducing energy demands during user phase of constructions, and a new building code imposing even stricter U-values has recently caused fury among architects and builders in Norway. However, when it comes to greenhouse gas emissions, Norwegian statistics show that a greater part originates in the production of building materials (Byggemiljø 2007). This raises the question of a possible shift of focus to material production, transport, use and considerations in demolishing phase. Since much of the environmental effort that has been invested in the production of building material can be salvaged through reuse and recycling, the demand for salvaged building material is believed to increase in a not too distant future.

Design for Disassembly (DfD) is discussed in a number of studies as a line of action in reducing environmental impact of building constructions. When focusing on durable components and flexible design, several service lives are seen as feasible. With the strategy of DfD there will presumably be less pressure on new material resources and reduced waste, in spite of the increasing turnover of buildings. Several researchers have presented lists of design principles or guidelines for DfD. A brief description of the selected compilations of guidelines is given (chronologically) below:

Bjørn Berge (Berge 2000, p.12-14) describes three principles of *ADISA (assembly for disassembly)*, which are: *separate layers, possibilities for disassembly within each layer,* and *use of standardized monomaterial components*. The three principles comprise some details in implementation and reasoning.

Scot Fletcher (Fletcher 2001, p.96-99) classifies a total of 37 DfD guidelines into three levels: *systems level* (adaptable buildings which can change to suit changing requirements), *product level* (element manufacture/ construction which allows upgrading, repair and replacement) and *material level* (reuse, recycling and the natural degradation of materials). The *systems* guidelines are further subdivided into four sections under the headings: *design, information, market and disassembly*.

Catarina Thormark (Thormark 2001, p.68) structures 18 design guidelines into three groups: *choice of materials, design of construction* and *choice of joints and connections*. A separate column in the table gives reasons for the guidelines.

Paola Sassi (Sassi 2002, p.3) focuses on two main areas: 1/ *the process of removal of building elements and materials from building structure* and 2/ *the requirements for reprocessing of building elements and materials to enable reintegration in a new building*. Within these areas the following points are further described: 1/ *information, access, dismantling process, hazards, time,* and 2/ *reprocessing, hazards, durability* and *information*.

Philip Crowther (Crowther 2003, p.200-201) relates 27 DfD principles to five generative fields of knowledge: *industrial design, architectural technology, buildability, maintenance* and *research*. Furthermore the principles are connected to the hierarchy of recycling (p.300-301) in a separate table. The reasoning for the selection of principles and for their classification is elaborated in separate sections.

The CIRIA guide by W. Addis and J. Schouten (CIRIA 2004, p.26) synthesizes 19 principles (based on Crowther), and relate these principles to their desired outcome: *component reuse, component manufacture* and *material recycling*.

The SEDA guide by C. Morgan and F. Stevenson (SEDA 2005, p.23) summarises seven principles for deconstruction detailing. The design implementation and the reasoning are further elaborated in the following sections.

Elma Durmisevic (Durmisevic 2006, p.272-274) lists a total of 37 DfD guidelines, and relate these to three levels (*building, system* and *material* level) within three life cycle coordination scenarios: scenario 1/ *use life cycle < technical life cycle*, scenario 2/ *use life cycle > technical life cycle,* and scenario 3/ *use life cycle = technical life cycle*. A particular focus is set on design configurations that facilitate disassembly.

The classification systems of these lists as well as the level of detail and the number of points vary. Some studies also explain the specific reason(s) for each principle, and link the principles to their desired outcome. However, the overall aim is more or less the same: material resource efficiency through facilitating reuse and recycling.

1.2 *Characterisation and classification of principles*

The characters of the principles may be divided in three groups:

- Behavioral statements that deal with values and general environmental goals
- Performance standards that are more explicit in their aim and offer specific targets of achievement
- Prescriptive guidelines that offer the designer the most direction in achieving an aim (See Crowther 2003, p.167-168 for further explanation).

All the surveyed lists express, as a behavioral statement, environmental material resource management as the final goal. The lists with few points usually consist of performance standards that are later elaborated in text. The lists with a greater number of points usually consist of prescriptive guidelines that give detailed design information. The characters of the principles are sometimes also mixed within one single list.

The varying classification systems of these lists are keys for understanding their similarities and differences. The guidelines may be classified according to:

- Type of technical benefit such as ease of handling or ease of sorting
- Scale of application such as materials, joints, and overall structure
- Technical level of reuse, such as material recycling, component reuse, and building relocation (See Crowther 2003, p. 297-298 for further explanation).

There are examples of all these classification systems in the surveyed guideline lists. Some of the lists combine two systems so that the principles are related to e.g. both scale of application and technical benefit. Also, some lists give reasons for the guidelines so that the link to their benefit becomes clearer. The question is what the appropriate classification system for an overall systematisation of the DfD guidelines could be.

One may ask if there is a need for yet another list of guidelines. What we do lack however, is a comprehensive system with a consistent and explanatory layout. This system should clarify different levels of scale and be linked with technical benefits (at an intermediate level) as well as with the purpose/ objective of each principle.

1.3 *From guidelines to assessment tools*

Some studies present DfD assessment methods as well as lists of design guidelines. A brief description of three methods is given (chronologically) below:

Catarina Thormark (Thormark 2001, p.70) gives an outline of a method for assessment of the *ease of disassembly*. Assessed parameters for the purpose of *reuse* are: *risks in the working environment, time requirement, tools / equipment, access to joints,* and *damage to the material caused by disassembly*. As this is an outline for a method only, for the purpose of *material recycling* and *combustion*, relevant parameters are to be filled in. The possible scores are distributed evenly among the parameters.

Paola Sassi (Sassi 2002, p.4) presents a method for assessment of *suitability for reuse/ recycling/ down-cycling* that is based on more than 60 case studies on building products and construction methods. Parameters are divided into *cost*- and *technically* linked criteria, listed according to the goal for the disassembly. Assessed parameters for the purpose of *general dismantling* are: *installation systems and fixing methods, access to and handling of building elements, hazards (toxins, structural, handling), time required to dismantle elements,* and *information required to dismantle elements*. Assessed parameters for the purpose of *reuse as second hand item* are: *reprocessing requirements to enable reuse, durability, components and subcomponents, hazards, requirements for performance compliance, information required for reinstallation,* and *fixings required for reinstallation*. Assessed parameter for the purpose of *reuse as new (ADDITIONAL criteria)* is: *requirements to ensure aesthetic standard*. Finally, the assessed parameters for the purpose of *down-cycling* and *recycling* (assessed separately) are: *reprocessing requirements, durability,* and *hazards*. The technically linked criteria are given a higher weighting and consequently a higher possible score than the cost linked criteria. Except for this, the possible scores are distributed evenly among the criteria.

Elma Durmisevic (Durmisevic 2006, p.203-212) introduces a knowledge model for assessing *Transformation Capacity (TC)* of structures. The method is implemented in case studies on an office building and a facade-system, and in three case-studies of inner wall constructions. The focus is on *disassembly potential* (General dismantling) only, and the model is divided into four levels of abstraction. The two main indicators are *independence* and *exchangeability*. At an intermediate level these are further divided into a *material,* a *technical,* and a *physical level of decomposition*. As sub aspects are listed *functional decomposition, systematization, base elements, life cycle coordination, relational pattern, assembly process, geometry,* and *connections.* Finally, the input-level consists of 17 determining factors, that each receives an even amount of possible score.

The assessed parameters in all these three tools are classified according to the objective for the disassembly. The objectives refer to the recycling hierarchy, and include:

- General dismantling
- Reuse
- Material recycling
- Combustion

However, there is generally no direct connection between the specific design guidelines and the assessed parameters. Sassi’s parameters do correspond more or less to a predefined set of criteria, but these are, however, expressed as performance standards rather than as specific guidelines. This means that the evaluation will be performed at an intermediate level, which may open for a high degree of interpretation.

We would like to investigate if the traceability of the assessment can become more apparent by applying the specific guidelines directly in the method. We therefore suggest the possibility of transforming the overall system for DfD guidelines to an assessment tool. In this way we will achieve a direct link between the guidelines and the assessed parameters.

2 SUGGESTED SYSTEMATISATION

2.1 *Multi-purpose system*

The aim of the overall systematisation of the guidelines is threefold: It should make up a clear, pedagogic system suitable for communicating both the basic points and the details of the principles to architects and others involved in the building design process. Secondly, the system should be convertible to an assessment tool to be used when choosing building components for a new design with respect to their potential at the stage of deconstruction. Also, the system could function as a checklist when designing salvageable materials and components.

The design guidelines are classified by combining the three systems of classification previously described (Fig. 1). Since the principles are relevant at different scales of application regarding construction, it is suggested to first arrange them at a *component-*, a *construction-* and an *industry*-level of *scale*. The component- and construction-level focus on building design, while the industry-level focuses on legal and financial aspects that represent constraints for the building industry. In an intermediate section, each level consists of relevant *criteria* that describe the core points of a group of design *strategies*. The criteria are expressed as performance standards, whereas the strategies themselves describe how to achieve these standards. Some criteria are relevant at more than one level. For instance the theme *information* is relevant at all three levels, but addresses different topics. At the component- level; tagging of materials and components, at the construction- level; updated as-built drawings and guidance for deconstruction, and at the industry- level; dissemination of knowledge to designers and builders. The strategies can further be connected to their primary *objectives*, which may be *maintenance, adaptation, building relocation, reuse of components* or *material recycling*. Through these objectives, salvage of building material will presumably be achieved, which in turn aims at the more general goal of resource efficiency and overall sustainability.

The objective column of the scheme shows that each strategy may have relevance for one or more objectives. Besides the visualization of the relevance of each strategy, a weighting of importance can also be performed. Not all strategies for a criterion are necessarily relevant in each case even though listed in the overall scheme, whereas others may be highly stressed. The result will also depend on goals and priority-setting of the users. Thus, the complementing of the matrix could be subject for a study on its own, and the spaces are therefore left blank at this point.

The next step is the transformation into an assessment tool. The reasoning for the specific principles can help singling out the relevant guidelines for each assessment. In a case study on massive wood construction components (Nordby et al. 2007b), the principles that are relevant for assessing the reusability of whole components are collected and weighted for use in this particular context. The assessment thus represents a pilot study of using the design guidelines directly for an evaluation of building constructions.

2.2 *Prioritizing themes*

From the surveyed compilations, a set of strategies has been selected. Naturally, some strategies are more basic than others. The strategy *use mechanical not chemical connections* is included in all the surveyed lists in one form or the other. Actually, there are several physical levels where this strategy may apply; when materials are joined together to form a component, when components are joined together to form a building layer or constructional part, and when constructional parts are joined together to form a building. For this reason, the criterion *flexible connections* is relevant at both the component- and construction-level.

It is widely recognized that it should be possible not only to disassemble components and constructions, they should also be prepared for the other stages of the salvaging process, including sorting, transport, new design and reassembly. The remaining criteria at the component- and construction-level of scale reflect these other desired characteristics: A *limited material and component selection* simplifies dismantling and sorting and enables quality control of components before reuse. *Durable design* facilitates dismantling and reassembly, and increases the amount of components suitable for reuse. A *layered construction* will grant structurally independent and exchangeable building parts. *High generality* of components and constructions makes reuse more probable because of the architectural flexibility for a second service life. Finally, *information and access* facilitates the planning of dismantling and the dismantling proc-

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SCALE	CRITERIA	STRATEGIES	Maintenance	Adaptation	Relocation	Reuse	Recycling
Component	Limited material selection	1. Minimise the number of different types of materials in component, including connections for sub-assemblies					
		2. Plan for using a minimum number of connectors and of different types of connectors between components					
		3. Avoid secondary finishes					
		4. Avoid toxic and hazardous materials					
	Durable design	5. Design durable components that can withstand repeated use and outlast generations of buildings					
		6. Provide adequate tolerances for repeated disassembly and reassembly					
	High generality	7. Aim for standard dimensions and modular design					
		8. Aim for small scale and lightweight components					
		9. Reduce the complexity of components, and plan for using common tools and equipment					
	Flexible connections	10. Use reversible connections for subassemblies					
		11. Plan for using reversible connections between components					
		12. Allow for parallel disassembly of components					
	Information and access	13. Provide identification of material and component types					
		14. Identify and provide access to connection points					
Construction	Limited component selection	15. Minimise the number of components and of different types of components					
		16. Minimise the number of connectors and of different types of connectors					
	Layered construction	17. Design a layered construction with structurally independent systems					
		18. Arrange the layers according to the expected functional and technical life-cycles of the components					
	High generality	19. Aim for modular construction and use a standard structural grid					
		20. Reduce the complexity of constructions, and plan for using common tools and equipment					
	Flexible connections	21. Use mechanical not chemical connections between building parts					
		22. Allow for parallel disassembly					
		23. Design joints to withstand repeated use					
	Information and access	24. Identify and provide access to connection points					
		25. Provide updated as-built drawings, log of materials used and guidance for deconstruction					
Industry	LC-supportive legislation	26. Introduce/ reinforce landfill-tax or -ban which limits/ prohibits the land-filling of salvageable construction and demolition waste					
		27. Introduce/ reinforce construction regulations which address life cycle design					
	Financial incentives	28. Support the use of salvageable materials and constructions					
		29. Support research and development of salvageable designs					
	Substantiated Information	30. Provide dissemination of knowledge to designers and builders of the environmental, social and economic benefits of salvageability					
		31. Provide quantification of economic benefits of salvageability in the life cycle of buildings					

Figure 1. Suggested systematisation of design guidelines for salvageability.

ess, and it also simplifies the sorting and reuse process. Most of these principles are found in the extensive compilation by Crowther, and their general benefits are thoroughly discussed there.

The criteria at the industry level describe the desired characteristics of a construction industry aimed at environmental efficient material resource management (see Sassi 2004). *Life-cycle supportive legislation* is today implemented to varying extents in different European countries, whereas *financial incentives* to support the use and development of flexible designs are probably best known through the IFD-programme of the Netherlands. *Substantiated information* about the benefits of salvageability should be disseminated to designers and builders along with the general knowledge about environmental solutions.

One guideline that is listed in several of the surveyed compilations is the *use of recycled materials*. The reason for this guideline is to support the recycling industry. In our understanding this action is not a strategy directly linked to achieving salvageability, but rather a principle that may be supported by financial incentives. This strategy therefore belongs at the industry level.

Avoiding toxic material is not defined as a separate criterion. The subject is relevant in sustainable construction, but not necessarily for salvageability. It should therefore be considered only if it disturbs the recycling processes, e.g. gives rise to health hazards in the work environment. For the reuse of whole components or relocation it is not necessarily relevant.

As far as production conditions are regarded, prefabrication is not considered a desired means in itself. Prefab building may imply, at least in a country like Norway, long transport distances including fuel emissions both in the building- and recycling processes. Therefore, the suggested guideline *use prefabrication* is omitted as a strategy. Focus is rather set on simple construction methods, small scale and lightweight components that can be manually handled, and the use of common tools. By facilitating local and also do-it-yourself building, local reuse is simultaneously facilitated, and environmentally this is the most beneficial strategy.

One criterion completely left out is *time use*. The time required to dismantle elements is crucial for the economical feasibility, and in the field of industrial design this parameter is usually heavily weighted. However, when discussing salvageability, the question of financial cost is not considered relevant. Focus is on environmental cost, which today is not consistently reflected in the economic system. Therefore, strategies that are purely cost-linked are omitted.

The presented systematization reflects the values and priorities of the authors. However, this list could be expanded to include other criteria and more strategies. The main point is that it can function as an overall scheme that relate the design strategies to *scale* of application, *criteria* at the intermediate level, and to the desired *objectives* according to the recycling hierarchy.

2.3 *Denomination*

Design for Disassembly and Design for Deconstruction are terms commonly applied when the aim is expressed as material resource efficiency through reuse and recycling. However, as this study shows, in the different sets of guidelines describing how to design reusable and recyclable buildings, more aspects of the design are usually stressed. Design aspects also relate to the processes of sorting, transport, new design and reassembly, and therefore the term Design for Disassembly can be perceived as confined and misleading. Our suggested replacement is *Design for Salvageability*. The intention of this expression is to include all lines of actions that contribute to salvage of building materials in one way or the other. Maintenance, adaptation and relocation of buildings are considered as possible objectives for the strategies, as well as component reuse and material recycling. It is, however, possible to tailor a more specific term within the concept of salvageability; e.g. when reuse of whole components is considered a prioritized target, the term would be Design for Reusability.

3 DISCUSSION

Different lines of action may lead to enhancing the environmental performance of building construction, and Design for salvageability is one of them. The proposed systematisation of guidelines defines criteria that can lead to environmental advantages assuming that there is no suboptimization. The strategies should therefore be checked against other environmental concerns.

The scheme relates the design strategies with:

- Levels addressing *scale* of application
- Operational *criteria* at the intermediate level
- Desired *objectives* according to the recycling hierarchy

When used as an assessment tool, the relevant strategies that relate to the objective of each assessment can be singled out and adequately weighted.

The fact that the same strategy can facilitate different objectives as well as support different overall goals can be confusing. Some of the criteria, like flexible connections, will facilitate all the listed objectives. In addition, flexible connections may be a means to user flexibility which can result in added value of the property. The objectives in the scheme are structured according to the recycling hierarchy, which indicate that some options are more environmentally sound than others. Reuse is considered a better choice than recycling because less processing means less energy spent and less emission released; hence the total environmental burden is less. The highest level in the hierarchy is considered to be maintenance, because frequent care saves the building from deteriorating with a minimum of environmental (as well as financial and practical) effort (Brand 1994).

Whereas the objectives of preparing buildings for adaptation and maintenance are now being performed because these benefits are in demand by clients (Sassi 2004), the objective of preparing buildings for relocation is usually reserved for temporary applications like school pavilions and exhibition spaces. The preparation for recycling and reuse, however, is mainly focusing on environmental gain, and will probably not be extensively performed as long as the financial and legislative constraints are designed to support short-term financial profit rather than sustainability in the life cycle of buildings.

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