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Measuring reuse potential and waste creation of wooden façades

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Abstract. Building industry produces 38% of total waste and 40% of total CO2 emissions and uses 50% of all natural resources (EIB 2015). Taking this into account, decreasing the waste from any part of the building will help reducing total waste during the building life span. In this paper we will showcase the indicators for measuring of the waste creation from building façade upon transformation. Façade should follow transformations of the building without waste creation or without causing large financial or environmental impacts. The planning of building industry waste management begins in the design phase, as the waste prevention is the preferred option, and reuse, recycling, and other types of recovery are a second option according to EC. (Directive 2008/98/EC 2008). This paper will show the comparison between the conventional façade system made of wood and the prototype of GDC (Green Design Center) reversible façade system addressing the waste elimination. The reversible façade has been designed using design protocol for designing of low waste façade system for the future circular construction industry developed by Durmisevic 2017 as part of EU BAMB project. The protocol contains a rulebook with tools to measure the waste production during the transformation of building façade. This strategy aims to extend functional lifespan of external envelope of buildings and its components and materials, which would reduce the amount of consumed resources and generated waste during the lifespan of the façade. The contribution of this paper will also be in the field of connections in the building industry, as the importance of type of connections in the façade system with high reuse potential is noticeable.

Keywords: Reuse Potential, Transformation, Reversible Building Design, Building Waste Management, Environmental impact.

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1. Introduction

Our planet Earth has limited non-renewable natural resources such as fuel, materials, etc., which, when linked to the linear consumption of resources (from cradle to grave) in connection to increased consumption, leads to an unsustainable environment. At the same time, problem of pollution is getting bigger and bigger and waste generation is growing extensively as well. Building industry produces 38% of total waste and 40% of total CO2 emissions and uses 50% of all natural resources [1]. Taking this into account, decreasing the waste from any part or life cycle of the building will help reducing total waste during the building life span.

Environmental influence of architecture and built environment is underestimated in many countries, especially in developing countries. Bosnia and Herzegovina, the country recovering after war destruction, continues to have a problem regarding building regulations and waste management, as do many countries in Europe and the rest of the world.

Built environment, including urban landscape, architectural styles and material utilization in Bosnia and Herzegovina (before war 1992), was determined by cultural and traditional values, topographic and environment characteristics, and socio-economic conditions. After the war, many existing buildings are just construction waste, according to the plan of Federal Ministry of the environment and tourism [2], as the plan doesn't mention the specific regulations for their reuse, reconstruction and re-evaluation. The plan considers just waste disposal and partial recycling. The waste prevention is mentioned, but there are no measures to do so. If there were guidelines for these kinds of buildings to be designed/redesigned with capacity to be restored/modified and used longer, more stakeholders would be interested for their reconstruction and sustainable reuse. The capacity of existing buildings to be modified is unknown but in order to avoid the same mistake in the future, the suggestion is to make a plan and measures for the process of designing future building structures for adaptability using the methodology developed within Buildings and Material Bank (BAMB) project. This paper presents results of the research done within BAMB pilot project (Green Design Center in Mostar).

As the enclosure systems are the ones most exposed to physical damages and require frequent reparations (because of the extreme and fluctuated weather conditions, human vandalism, and fatigue of material), the main focus of this research has been on facade and how to construct it in more reversible and therefor more sustainable way. The goal was to include all parts of the enclosure system in circular low waste building industry and circular economy. In the case when the energy efficiency standards and requirements change, it will be necessary to have final layer of the wall which can be easily disassembled and removed without affecting surrounding elements, to allow the additional layers to be attached to the wall system and make it easy to assemble and put together again. This strategy aims to extend functional lifespan of the building external envelope and its components and materials, which would reduce the amount of consumed resources and generated waste during the construction, maintenance and demolition. The necessity for transformation possibilities of the façade is often shown, where elements and components of the façade system become objects of leasing and have the possibility to increase their value during their lifetime. (Good example is a pilot project at TU Delft developing a circular business model of leasing façade)

2. Study method

The planning of building waste management begins already in the early design phase, as the waste prevention is the preferred option, and reuse, recycling, and other types of recovery is a second option according to EC [5]. Façade should follow transformations of the building without waste creation or without causing large financial or environmental impacts during its total life cycle.

This study is using method by Durmisevic for designing and assessing reversibility and reuse potential of building and its elements. The model identified 8 main indicators of reversibility and high reuse potential [3]:

1. Functional independence: rating the level of separation of functions that have different changing rates and use expectances;

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2. Systematization: clustering of elements into an independent modules based on functionality, assembly/disassembly, life cycle coordination of elements and their expected use life cycle assembly;
3. Relational dependency and relational pattern: minimization of number of relations representing functional and technical dependences between elements within a building;
4. Base element of the configuration: design of base element that functions as intermediary between the elements within the configuration;
5. Life cycle coordination of elements: coordination of use and technical life cycle of elements within buildings in relation to their disassembly sequences;
6. Assembly/disassembly sequences: allowing for more parallel then sequential assembly's within a building;
7. Geometry and morphology: design the geometry of product edge that will allow for recovery of elements without damaging themselves or elements, and geometry of product edge that is suitable for reuse;
8. Type of connections: use the type of connection that will allow separation and easy recovery of elements.

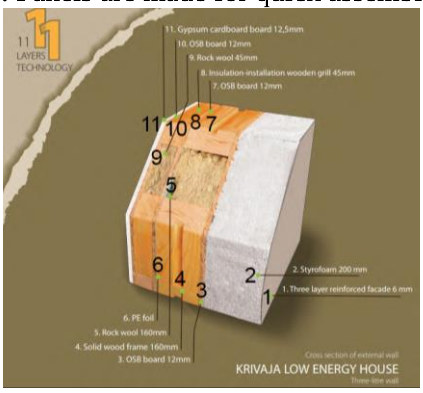
Indicators are defined in a way to enable understanding of three main dependences that emerge within each building/product structure being: (i) functional dependences, (ii) technical dependences and (iii) physical dependencies [3].

In this case, seven of eight indicators are used for measuring the reuse potential of reversible design for GDC in Mostar. The life cycle coordination indicator is not considered because there are no valid or reliable data of the technical life cycle of elements and materials used.
The study compared conventional façade system with reversible façade system and identified three transformation scenarios' in order to be able to measure waste creation/saving from building façade upon transformations (when applying conventional and reversible façade system). Different levels can be examined (element, component, system and building level) [3]. Each indicator for each level can be computed according to the tables by Durmisevic [3].

3. Case studies

In this paper the analyses of two different cases of wooden façade system have been made (conventional and GDC-reversible façade system) using the method by Durmisevic [4] and comparing their results. Reversibility of the GDC wall system and traditional wooden wall system has been evaluated in order to be able to compare the reversibility factor of the façade system with environmental impact after transformations. The first one is conventional (existing) façade system made of wood (see Figure 1.), which is developed for passive house system. The second case study is the prototype of the wall of the Green Design Center building in Mostar (see Figure 2.).

The first case study (see Figure 1.) is a conventional façade system in wood consists of primarily fixed multilayer panels (3-layer reinforced façade, Styrofoam, Rockwool, OSB board, wood, gypsum board). Panels are made for quick assembly on site.



1. Three layer reinforced façade 6mm
2. Styrofoam 200 mm
3. OSB board 12 mm
4. Solid wood frame 160 mm
5. Rock wool 160 mm
6. PE foil
7. OSB board 12 mm
8. Insulation-installation wooden grill 45 mm
9. Rock wool 45 mm
10. OSB board 12 mm
11. Gypsum cardboard board 12,5 mm

Figure 1. Existing facade system made of wood [7]

The second case study (see Figure 2.), the Green Design Center façade prototype consists of components and elements which can be separated (laminated wood construction frame with final layer of wooden panels - slats, wooden boxes with sheep wool insulation and interior wooden panels). The wall prototype is designed for quick assembly and disassembly on site. Use of natural and bio based materials was the preferred option in this case. The design principles for reversible buildings have been used during the design and development of the prototype.

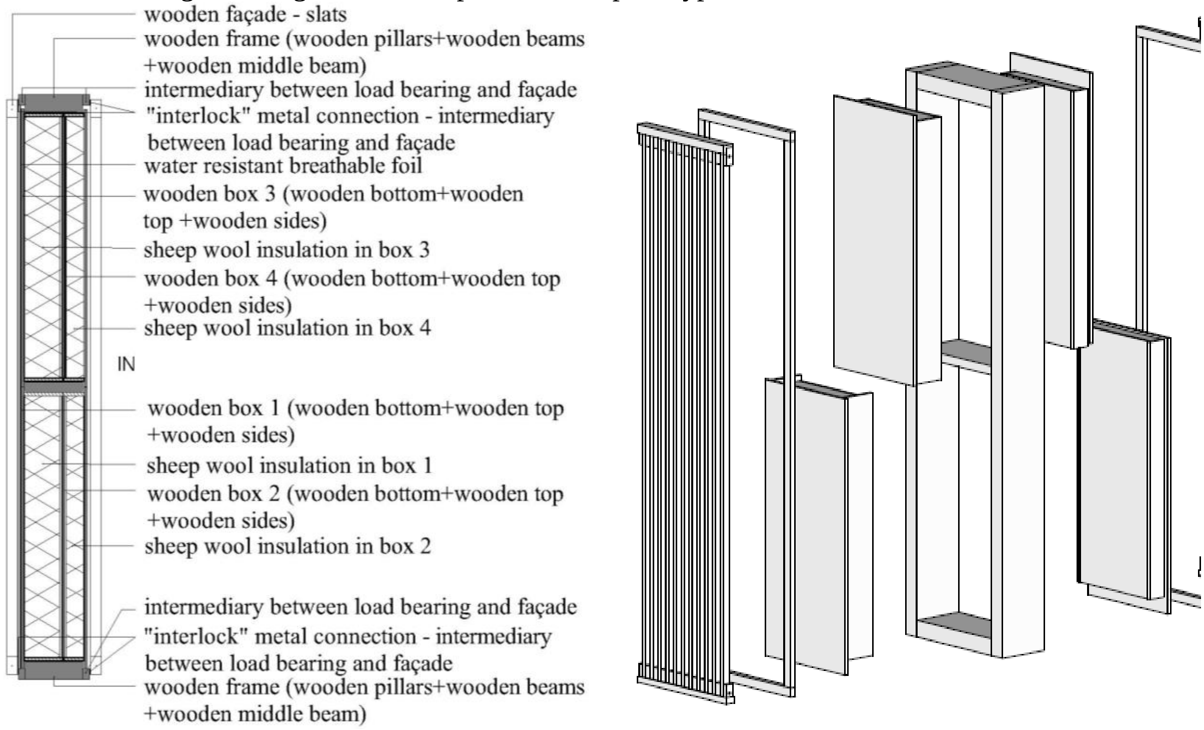


Figure 2. Façade system made of wood developed for Green Design Center in Mostar [4], [5]

4. Application of Reversible Building assessment with focus on Reuse Potential (method Durmisevic)

According to the method, each of the reuse potential indicator is presented as a number Rp ranking for 0.1 (low reuse) to 1.0 (high reuse) [0,1]. The results are divided into three categories:
(1) if $Rp < 0.3$, than this system will be characterized as irreversible and the end of life options of the materials and elements within system is recycling/down cycling;
(2) if $0.3 > Rp < 0.6$, then its end of life options would be repair, direct reuse and remanufacturing;
(3) If $Rp > 0.6$, than besides direct reuse and repair of its parts, the system can be reconfigured and upgraded and its dimensions adjusted to fit new requirement. [8]

Schemes presented here illustrate the evaluation or reversibility of conventional passive façade system and reversible façade system designed for GDC and their final score (see Figure 3). Each indicator is calculated separately for every case study. Looking at the diagram (Figure 3), it is visible that the existing façade system made of wood has low reuse potential, as most indicators have low score.

The reasons of the choices of the values of the indicators are the following:

1. The system is designed for quick assembly of compact panels on site, but does not allow assembly or separation /disassembly/ of its parts (score 0,1);
2. The functional dependence of this system is acceptable, as it is designed for planned interpretation for different solutions (score 0.8);
3. The structure and material level is really low, as the system consists of materials and elements which cannot be easily separated (score 0,2);

4. There is no base element in the system (score 0,1);
5. The relational pattern is vertical, which is good (score 1);
6. The geometry is half standardized (score 0,5);

The connections have very bad score due to the use of many connection points (screws and nails) and chemical connections (adhesives) (score 0,2).

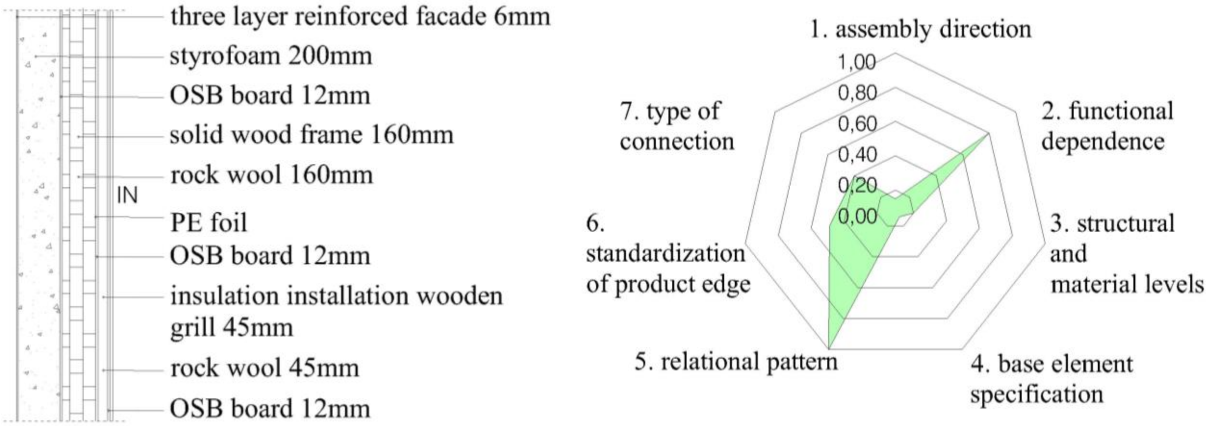


Figure 3. The section (left) and the overview of the main criteria of reversibility and the final score of the reuse potential of the 11 layers wall - existing façade system in wood (right) using method Durmisevic

Looking at the diagram (Figure 4.), it is visible that the GDC wall façade system in wood has high reuse potential, according to the high score of most indicators. The choices of the values of the indicators are the following:

1. The system is designed for easy disassemble all its parts on all levels (components, elements and materials if necessary) (score 1);
2. The functional dependence of this system can be fully planned and enables modular zoning (score 1);
3. The structural and material level is high, as the system consists of elements and components (score 0,8);
4. There is base element and intermediary in the system (score 1);
5. The relational pattern is vertical, which is good (score 1);
6. The geometry is standardized and pre-made (score 1);
7. The average score for connection indicator is good, but some direct connections with additional fixing device have to be improved (score 0.87).

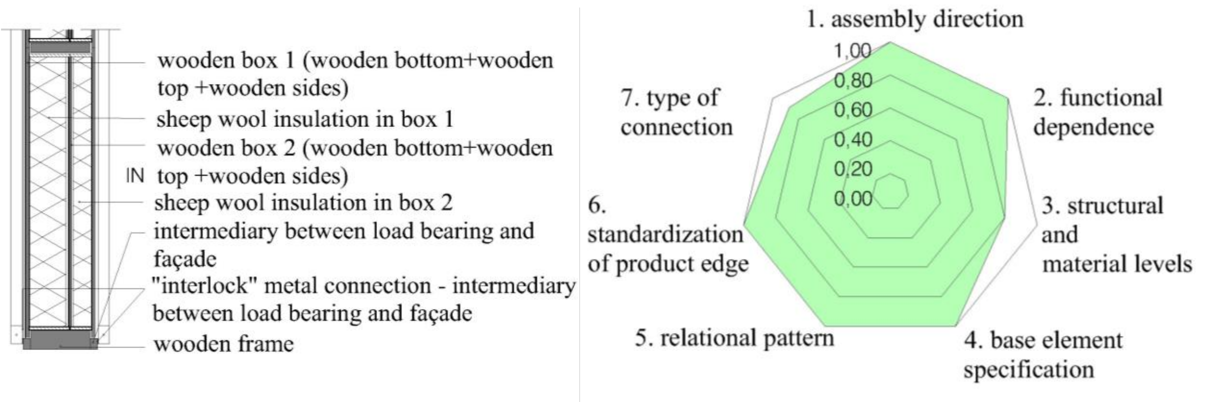


Figure 4. The section (left) and the overview of main criteria of reversibility and final score of the reuse potential of a GDC wall -developed façade system (right) using method Durmisevic

5. Application of the method for evaluation of the environmental impact and waste creation

Mentioned design criteria have direct relation to environmental impact and economic costs of the two case study systems. In addition, the link has been made between the evaluation results and waste generation and costs of four transformations (see Figure 5. and Figure 6.).

	traditional	GDC	weight
assembly	0,1	1	0,8
FD	0,8	1	1,4
systematisation	0,2	0,8	0,8
BE	0,1	1	1,4
RP	0,1	1	1,4
GE	0,5	1	0,8
Type Connections	0,2	0,87	1
extendability	0,2	0,6	0,7
space for upgreadability	0,2	0,6	0,7
	0,28	**0,91**	9

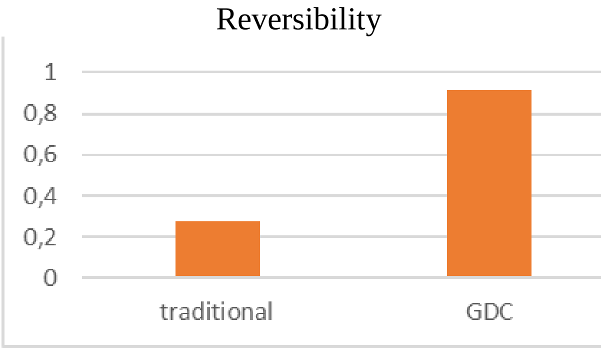


Figure 5. Evaluation of systems' reversibility per indicator (left) and total score per type of system (right) [5]

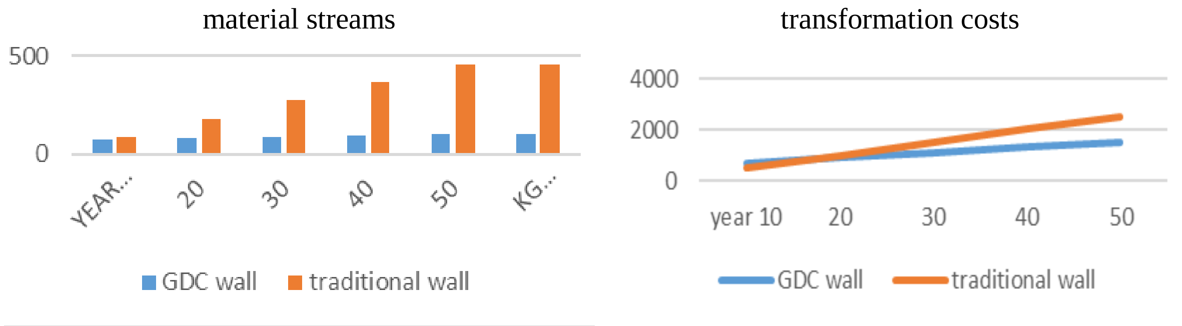


Figure 6. Material use during transformation (left) and Material and assembly costs during transformations (right) [5]

Material stream analyses indicate that the system can perform transformations without creating waste in comparison with the existing passive façade system on the market. This strategy aims to extend functional lifespan of external envelope of buildings and its components and materials, which would reduce the amount of consumed resources and generated waste during the lifespan of the façade.
Total material GDC wall per m² of façade = 73.00 kg (wood 64.50 kg and sheep wool 8.58 kg).
Most of the material can be reused during transformation phases or in other context since reuse potential of the system and its parts is very high. The calculation of waste and material use has been done with the assumption that 10% of materials is being replaced during each transformation.
Total material quantities for existing wooden wall per m² facade = 91.09 kg (3-layer reinforced façade 0.17kg, Styrofoam 10.00 kg, rock wool 9.22 kg, OSB board 16.20 kg, wood 46.00 kg, gypsum board 9.50 kg). [5] Due to the way in which materials are put together, all materials can be considered as construction and demolition waste. Couple of transformation scenarios have been considered in order to assess the waste during transformation processes.

The scenario that has been considered for both case studies (GDC and existing wall) is that the transformation will take place every 10 years, in the period of 50 years. The amount of material used and associated waste has been calculated for traditional and GDC reversible modular system. For transformation scenario, it has been considered that the existing window will not be necessary any more at the existing position and that the window has been replaced with the wall panel. The window itself will be placed again in the same building (new opening in different position in the building façade is needed, and the window can be relocated to this position).

In the first case study the façade is modular and the wall panel can be replaced with the mentioned window without any waste associated with the transformation process. The conclusion is that it will be possible to transform the façade and change the position of the windows and wall panels without any waste. The only cost will be the work of dismantling and assembling modular parts.

6. Discussion on the studied examples

As the results show (see Figure 3.), the first case study, existing wooden façade (see Figure 1.) has low reuse potential, which means that it does not allow separation of components, elements and materials (to be reused or changed) and transformation of façade without waste creation. Most of the recently developed façade products available on the BiH market for passive housing use many synthetic materials and have similar structural problems when it comes to transformation and reuse. Most of the façade systems developed so far for high energy performance (energy positive buildings) are very fixed and do not accommodate easy adaptations. As a result, transformation is linked to demolition, waste creation and purchase of new material.

The second case study (see Figure 2.), the GDC façade prototype, is based on the observation that requirements for the use of buildings and façades of the building are changing very often. If the function of the building changes, the requirement for more or less: light, privacy, natural ventilation etc. will change as well. Furthermore, aesthetic requirement for the façade is also changing in relation to its use. The prototype of the GDC reversible façade is designed to have high reuse potential but can be improved. Indicator for the structure and material level can be high if the elements are clustered into prefabricated independent components.

The importance of the type of the connections in each façade system is noticeable. The connections have a big role for assembly and disassembly of the system and they are a very important factor regarding the waste creation.

One of the main aims of the GDC façade design was to design connections between the elements, so that parts of the structure which have longer life span (in this case the frame of the system) are not damaged or impacted by transformations, but the upgrade can be done to have the maximum score.
Also, the components and elements have to be designed in a way that will not restrict their potential use in context different than this façade system. For that reason, number of options have been studied regarding the intermediary between the frame and removable component and elements. After the survey of possibilities, it was found that the steel profile (the most appropriate solution) was not available in the area, and the team decided to look for a solution in wooden intermediaries. In this case, wooden intermediary would be fixed once to the main frame. Exchangeable elements would be fixed directly to the wooden intermediary. Assumption has been made that after five or six transformations, wooden intermediary would need to be replaced as it would have many drilled holes. This is a new approach to designing the connections in wood, as this is the way for extending the life cycle of the components in the system.

Considering all potential transformations, due to previously mentioned reasons, the GDC system also has the objective to develop a system, which will have capacity to transform its performance form delivering a closed insulated façade module to totally transparent or translucent modules or replacement of one of the insulation boxes by installation modules. In addition, the freedom of replacing the finishing of the system with wooden, polycarbonate or aluminum façade into green façade has to be possible. Additionally, it has been studied how different functions of the façade could be solved with independent parts of the façade system in order to allow for functional transformation of façade without demolishing parts.

During the survey of available connections within construction industry, the conclusion has been made that there are almost no reversible or easy connecting and disconnecting solutions. Construction industry was, and is developing towards easy assembly, but not easy disassembly solutions. Usually, there are no possibilities to separate its components, elements and materials in building systems.

While trying to find the solutions that will allow easy assembly and disassembly of all parts of the system, some connections have been found in the furniture design industry that can be used for building/construction industry. Of course, the development of new connections that satisfy these requirements has to be done in future, but some of existing connections in furniture design are tested in GDC wall prototype. The main problem is that many of these connecting elements are not made to be resistant to outside weather conditions and the additional protective layer needs to be considered. In the future, these connecting elements have to be made from other material, which is water, and weather resistant.

7. Conclusion

With new circular building design in mind, this study illustrates the importance of implementing reuse potential design protocols during design and evaluation phase in order to indicate what can be done in order to design reversible and sustainable building systems and how design solutions can be improved during the design process. In this case, the enclosure system has been designed for reversibility illustrating circular building design, which enables circularity and reusability of system and its components, elements and materials during different transformation stages of the building façade.

The study shows that there is a close link between the reuse potential of building systems, components, elements and materials and construction waste. If reuse and transformation potential is high, then the construction waste is low and vice-versa. Low construction waste leads to low environmental impact of the building or its parts. In this case, the case studies of façade systems show the weak points in existing facades and the way to design the façade with high reuse and transformation potential with low environmental impact and create very low amount of waste during its lifecycle.

The selection of waste management and reuse methods and technologies is crucial if a selected system is to be sustainable under the present economic and social conditions.

Example of the existing and future façade systems in BiH and their reuse potential can open the eyes to the new building design approach and building design protocols, not only in BiH, but also in countries around the world. It should be further developed and tested in other building systems.

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