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FOUNDATION

Vital Cities and Reversible Buildings

Conference proceedings

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04-07/10/2017

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Preface

Sarajevo Green Design Foundation together with University of Mostar and University of Dzemal Bjedic and city of Mostar hosted a 3rd international Green Design Conference 04-10 October 2017 in Mostar. This year's Green Design Conference was also a part of International Green Design Biennale (a seventh international Green Design event in Bosnia and Herzegovina). The conference is organized in collaboration with **EU Horizon 2020 'Buildings as Material Banks'** Project and aimed at addressing the many inter-related aspects of green design of cities, buildings and products, from urban strategies to social cohesion, design for reconfiguration and reuse design for change, sustainable energy strategies. Beside EU BAMB consortium Conference is organized in collaboration with University of Twente from Enschede the Netherlands ,ZUYD University of applied science from Heerlen the Netherlands and Green Council form Sarajevo, Bosnia and Herzegovina.

The emphasis of the conference is on innovative design and engineering methods that will contribute to the process of redefining the quality of life in cities and rethinking the way we create, make and use artifacts and resources that will enable circular economy and circular built environment. Unique feature of the conference was its attempt to bring together scientist, creative and production industry together and involve them in multidisciplinary debate during the town hall meetings and evening keynote addresses. Innovation in sustainable construction has been presented through papers addressing new design approaches, new tools and methods that will support transition towards circular resource use and circular economy as well as case studies addressing new product development and development of BIM frameworks for circular world of construction.

Conference topic integrates issues from green cities, transformation of cities and mobility to spatial adaptability and flexibility of building systems, BIM, Heritage, up to material productivity, bio based construction and energy saving. Development of the research agenda with respect to conference topic deals with issues such as, life cycle performance of buildings, design methodology and protocols for reversible buildings / buildings as material banks, BIM, systems development, reuse, renewable materials, 3D manufacturing, and development of performance measurement tools. Major themes that have been covered by conference proceedings addressed topics as Reversible Buildings, Building Information Modeling, Green Cities and Green Materials and Technologies.

Elma Durmisevic, GDC2017, Conference Chair

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TOWARDS A BETTER-INFORMED DESIGN PROCESS

Integrating Design For Change Principles Into New Collaborative And Data-Oriented Approaches?

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Abstract

The construction, maintenance and demolition of buildings represent a vast share on our environmental impact and generates a tremendous amount of waste. Our fast-evolving society also contributes to an increase of change rates in buildings and thus, waste. To solve those issues and move towards a circular built environment, Design for Change (DfC) was developed. In DfC, buildings are designed as time-dependent structures considering change. However, the current assessment of DfC principles is manual and not completely reproducible. Indeed, it relies on the expertise and personal analysis of an assessor and thus, may differ depending on his interpretation.

Therefore, there is an opportunity to develop an objective method allowing designers to make better-informed decisions based on feedback. The information is gathered from a digital model throughout the design process and evolves by continuously updating and assessing parameters in accordance with the evolving buildings' complexity - first with rule of thumbs and later with exact calculations.

This paper proposes to combine BIM and DfC through tools development and optimisation of the designers' decision-making process. This combination will benefit to both, the BIM implementation for architects by either generating an added value at early stage and the propagation of DfC by generalizing its concepts into reproducible and automated feedback.

To do so, two major tools have been developed. The first proposes an analysis of Adaptability and Generality of buildings based on the room proportions and height, the potential of daylight, natural ventilation and the design choices. While the second maps the building into a network of components and qualifies their potential for reuse/disassembly.

The two tools within the general design framework, will allow designers to integrate BIM and DfC earlier in the design process, contributing to the development, sharing and democratization of DfC by making it easier to implement and assess.

Keywords:
Design For Change (DfC), Building Information Modelling (BIM), Decision Making Tools, Adaptable Design, Data-driven architecture

1 INTRODUCTION

In past times, the architects and the designers had their imagination and their line sketches as the only tools to create and represent their projects. While this allowed them to free their creativity, it also induced that most of their decisions were based either on their experience or on their personal vision but less frequently on objective and quantified parameters. With the development of digital 3D models, the idea of having a tool that uses objects instead of lines slowly came through, allowing the software to store data and "understand" the model as well as representing it. This is the beginning of Building Information Modelling (BIM), a kind of software as well as a process, strongly relying on data. Through that data, Building Information Modelling can represent physical and functional characteristics of a facility.

However, even though BIM proved its usefulness for plan production, some architects still discuss its added value at early stage design. In this paper, we show that BIM used earlier in the design stage and throughout the entire design phase will allow the designer to make better informed decision by providing him objective feedback regarding his design choices. This will help the designer to face the new challenges of the construction industry regarding material and waste management which also tend to complexity the design process. For instance, in the scope of Design for Change (DfC), the designer conceives his building to allow changes (changes in use, in inhabitants or in function). The principles of Design for change rely on several rules ensuring the Generality or the Adaptability of the building. However, they are currently assessed manually by specialists in a non-reproducible way.

Therefore, this research tends to combine BIM and Design for Change by developing tools, allowing designers to make better informed decisions regarding transformability throughout the whole design process. It is believed that the combination of those two fields will benefit the BIM implementation for architects by generating an added value at early stage but also allowing the propagation of Design for Change principles by generalizing its principles into reproducible and automated feedback for the designer.

It is believed that both field – BIM and DfC will benefit from each other:

Concerning BIM and information technologies, the tools are often developed to optimise the construction process. However, BIM generates an extra-load of work for the designers at early stage leading to new questions such as the redistribution of cost within the architectural practice. However, from the literature in data-driven design, parametric design and scripting for architecture, it is clear that some of the information generated within the BIM model – either automatically by placing objects or manually by adding extra information – will allow the designer to grasp a wider aspect of the design but also to generate variations, analysis or results leading towards better informed decisions [1]–[4]. Therefore, allowing to designers to realise and experience this added value will contribute – according to the “Foog Behaviour Model” [5] - in a behaviour change by either increasing designer’s motivation or ability to create better informed designs.

Additionally, DfC will benefit from the information generated within the BIM environment to feed the simulations, analysis or assessments. While DfC provides a rather concrete list of strategies to create more sustainable buildings [6], the analysis or the assessments are still manual, time consuming and dependent on an expert evaluator. Although, architects are interested into sustainable developments, they may not have the time or the knowledge to conduct this analysis by themselves. Inevitably leading to an abortion of these principles. However, by connecting DfC with BIM, part of the information is directly managed within the software reducing the effort needed to fulfil the same task and thus, increasing the ability [5].

Consequently, combining BIM and DfC, will either ease the BIM implementation for architects wanting to integrate DfC principles within their process while reducing the extra work need or, facilitation the dissemination of DfC principles by ensuring an easy access to information, analysis and assessment fully integrated into tools currently used in practice. In other words, for both, it proposes to provide more with at best less and at worst the equivalent amount of work.

2 METHODOLOGY

As it was stated during the introduction, this research focuses on the interaction and potential added value provided by the combination of information technologies on one hand, and new sustainable development approaches such as DfC on the other.

Therefore, the methodology of the research started first with a rather traditional review on the literature and progressively switched towards a more innovative approach:

a) Literature study of BIM processes, tools and approaches
b) Literature study about the design process in general
c) Literature study of DfC principles, assessments methods and approaches.
d) Elaboration of a BIM handbook and BIM generic protocol with the ADEB-VBA (Association of Major Construction Companies[7], [8])
e) Review and Analysis of the current assessment methods in DfC and transformability (e.g. mainly manual assessments,).
f) Highlighting the potential of the BIM & DfC principles by determining key aspects of the first benefitting to the second (e.g. data handling, generation and storage of information…)

Finally, several small proof-of-concepts tools and two major tools have been developed and will be assessed to discuss the added value of the DfC integration within BIM.

3 CURRENT DFC METHODS, PRINCIPLES AND OPPORTUNITIES

Although, several researches are being conducted in the field of transformability and design for change. There is a lack of fully objective assessing tools and methods.

First, many sources provide guidelines or advices to follow in order to design more sustainable buildings [6], [9] but not a generic analysis method.

Second, some sources propose assessments methods but they are strongly dependent on the person in charge of the assessment[10]–[13]. Therefore, an external expert is needed which generates extra work and cost for the parties[14]. Therefore, the expert is rather called to assess the final product rather than help throughout the design. Additionally, the results of the assessment might differ from one expert to another which makes it difficult to compare buildings.

Finally, assessing DfC principles necessitate a tremendous amount of data. As an example to assess if you can dismantle part of your building you must check [6]:

- If the connections are reversible;
- If the connections are accessible;
- If they are easy to remove (not too labour intensive, do you need specific tools, how long does it take);
- If the weight of the subparts can be managed by a person or by a machine;
- The combination assembly sequence should also be considered (if an object with a long lifespan is connected and dependent on a lower grade material it will probably be wasted);
- …

Therefore, by considering a) we have information related concerning do’s and dont’s DfC but b) no objective, assessor independent and fully reproducible method and c) a huge amount of data is necessary. It seems that the development of a design supporting method based on tools managing data – and information technologies such as BIM – represents a key opportunity in spreading the implementation of DfC by easing its use, reducing the cost of implementing and introduce the concept to beginners. However, for this method to work, it should be compatible with the traditional design approach and therefore, should consider the various phase of the architectural process and the varying amount and reliability of information.

4 TRADITIONAL DESIGN PROCESS

Although there is no one unique view on the traditional architectural process, it appears clearly in the literature that the main general phases are considered[15, p. 27], [16, p. 25][Figure 1]: a) a design phase divided into a more conceptual and a more detailed phase; b) the construction phase the elaboration of the final details and as-builts and c) the maintain phase and d)renovation, reconversion, repurpose [Figure 1].

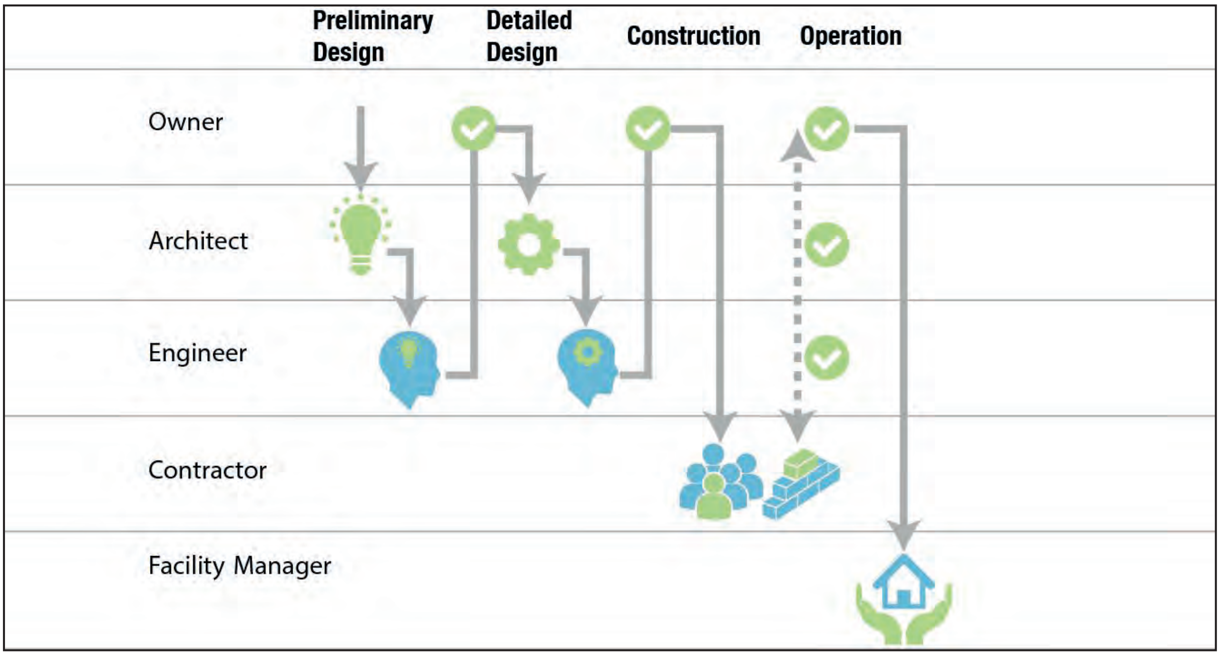

Figure 1: Simplified view of the traditional design process based on (Denis et al.,2017) [7]

This paper mainly focuses on the design part and will therefore discuss more in depth the sequence from the conceptual design towards the construction of the building. It should be noted that the design process follows the BIM process map developed with a panel from BIM experts (contractors, architects, third-party office) [7], [8], [17], and the tools are made within a BIM software (Revit and Dynamo – Visual Programming Tool by Autodesk) ensuring the BIM-compliance of the approach and the tools. From the literature, it seems rather clear that they are at least two major parts within the design process. The first being more related to the preliminary design also called ideation or conceptual design phase – traditionally before the building permit – then, for the building permit, the materialisation begins and leads the designer towards the later phase: the detailed design phase.

While the first relates mainly on geometry, rules of thumb, principles and concepts, the second is dependent on the specific elements chosen: their properties, their materials, their connections… This evolution in terms of complexity and level of information

4.1 Conceptual design phase Tool

In general, the conceptual design stage mainly focus on the elaboration of the spatial program, the general spatial layout and several choices such as the amount of windows, the ratio between closed and opened parts, the geometry of the building, the accesses and circulations. Many of those concepts are not fully measurable (at least very precisely) yet due to a lack of information but it is possible to use rules of thumb to orient the design within a range of potentially good solutions [18], [19].

In this section, we will discuss the development of a tool considering four key aspects that could be discussed from the conceptual stage:

- Spatial layout;
- Room dimensions (proportions, area);
- Potential for Daylight;
- Potential for Natural ventilation.

This list is not extensive but already shows the potential of such combination between information technology and sustainable development.

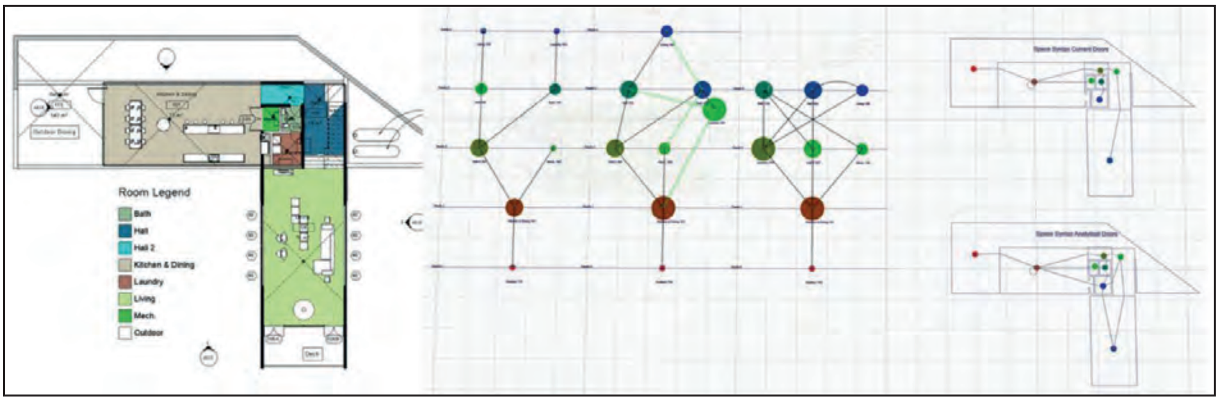

Figure 2: Spatial layout analysis of a building, the three depth-diagrams represent the current situation, the weighted potential situation (considering the wall composition) and the potential situation (fully transformable walls). In addition to those visual feedbacks values are calculated to assess mathematically the Adaptability and Generality of plans

Spatial layout and SAGA within a BIM environment

The spatial layout is the structure of the building. It will determine the interdependencies between spaces, and thus, show the potential versatility of a space. Indeed, a space plan with adjoining rooms has a lower potential in terms of adaptation towards change in function: as one room is completely dependent on the other, the change from public to private use may affect the other while completely independent rooms may not be influenced by each other. To measure the capacity of a building to adapt to change or to be independent of change, two concepts have been developed: Generality and Adaptability. Quite recently, a tool measuring the adaptability and generality of space called SAGA was developed by P. Hertogs. This tool *[20]* is currently working and several case studies are being studied to have a kind of benchmark. Although, the tool is already useful and provides some useful insights, it requests to remodel the plans in a two-dimensional environment, subdivide space into convex ones, draw the links between spaces and determine the permeability ratings of the walls to assess the adaptability. Thus, generating extra work for the designer. However, this information is very useful and finding a new way to gather automatically this information will benefit to the development of both BIM and SAGA. The SAGA-BIM tool provides the same outputs has the base tool but has the advantage of being completely integrated within a BIM environment. Therefore, it automates the collection of information (e.g.: wall composition, depth of spaces, connection between spaces, potential connection between spaces) and instantaneously the graphs and calculates the metrics [*Figure 2*].

Although, the analysis method is not new, the way its implemented (functional space is used instead of convex spaces, information gathered from components instead of manually entered) and the additional features provided by the tool (space are connected by doors and stairs ensuring also a three-dimensional analysis) show the potential of the implementation of Design for Change within information technologies by at least optimising current practice (automation and quick calculation) but also generating new possibilities.

Although the space layout is a key aspect of the building generality and adaptability it is not the only one. Indeed, the dimensions of the spaces also have a major impact on the buildings' potential to adapt to change.

Room proportion/shape analyser:

The SAGA tool provides information concerning the Generality and Adaptability of building in terms of space connectivity. However, the geometry of a space will also influence its polyvalence. Indeed, a square or rectangular room is more polyvalent than a circular or elliptic room.

Furthermore, the proportion of a space determines also the way it is used[21].

Even though, it seems visually rather easy to distinguish different kinds of shapes, translate this question into a mathematical relationship appeared more complex than expected.

First the definition of proportion (ratio between the smallest side and the biggest one) is rather efficient to compare squares or rectangles but has not meaning for other types of buildings. In addition to that, rooms, especially in older buildings, are almost never completely squared due to chimneys, columns, … Therefore, there was a need to define a mathematical relationship that was also valid for non-rectangular space. Because a space is always defined by a perimeter and an area their ratio seemed to be a good first estimation however, it failed to completely define a shape because it was depending on the size of the room.

Indeed, two squared room of different dimensions were not providing the same results:

Room 1; dimensions 5X5m => P=20; A=25; P/A=0.8

Room 2; dimensions 8X8m => P=32; A=64; P/A=0.5

Thereby, a ratio has been developed aiming at defining only the space proportion/shape without depending on its scale/dimension. Mathematically a good ratio as to be dimensionless therefore, using $P^2[m^2]/A[m^2]$ would ensure to have a dimensionless value. If we apply this formula to the previous example:

Room 1; dimensions 5X5m

=> P=20; P^2=400; A=25; P^2/A=16

Room 2; dimensions 8X8m

=> P=32;P^2=1024 A=64; P^2/A=16

It should be noted that this value increases for rectangular shapes and decreases for circular rooms. The value reached for the Golden Rectangle is around 17 (16.944). At the current stage of this research it is assumed that a ratio between 16 and 17 is optimal in term of versatility.

The values of perimeter and area are automatically extracted from the rooms geometries, avoiding additional work for the designer.

In (Yunitsyna 2015)[22], it is stated that in addition to the space connectivity, the space area defines also the potential versatility of a space. Indeed, it seems rather logical that a 5m² toilet room could not be used for a living room because of its dimension. Even though a small space is not general because it does not allow a lot of function, a very big space may not be general as well because not suitable for every function. Therefore, above a certain limit, a space would be considered as adaptable and not general (this space can be subdivided into adaptable spaces).

Furthermore, a 6-meter-height-room, is potentially adaptable into 2 floors and therefore, the potential future gain in [m²] will also be added by the software.

Keeping that into account the conceptual tool developed within this research loads every rooms of a buildings, measures its volume, area and minimum length (this is still an approximated value) to identify if a space is rather general and adaptable. While the space connectivity presented in the first section relies on a strong mathematical background the definition of general and adaptable area might differ from one country to another due to space regulations, culture and habits. However, once the limit values and the threshold have been determined the measure can easily compare several solutions.

To so, the tool is counting the amount of Adaptable and General [m²] of a building. The idea is to combine the Spatial layout, the room proportion/shape and the room area - and minimal length - to determine the amount of [m²] considered as Adaptable and General. By comparing, this amount to the real area of the building, it is possible to assess the Generality and Adaptability ratio of the building. To be adaptable or general a space should be adaptable in terms of dimensions and in terms of space connectivity. Although it is possible to extract the result of each subpart, the final value will consider the minimum common adaptable/general space by taking as an hypothesis that a space can be adaptable or general only if it is the case under all the aspects.

Once those concepts have been developed, we took and step back and questioned whether there were other aspects that could be considered. It seems that the most comfortable a space is, the more we are keen to stay in it or keep it for future use. Based on this idea, it was proposed to develop two additional plugins showing the modular (plugin solution) aspect of the conceptual tool but also experiencing other ways (i.e. the first two approaches are a combination of metadata and geometry) of dealing with information at conceptual stage.

Potential for Daylight

It might be evident that human being need light to work, move, see and basically live. Although, we could live with artificial lights several studies clearly state the importance of natural light in health[23]–[25]. As presented in the introduction, at conceptual stage it is rather difficult to assess precisely the amount of light within the building because the material properties are not defined. However, in the literature about sustainable design several strategies are presented such as respecting some windows to floor area ratio or geometric rules between the windows dimensions and location and the rooms. Intuitively we know that a window with a bigger height will allow light to enter deeper within a building. Respectively, it is more difficult to provide enough light to a very deep space.

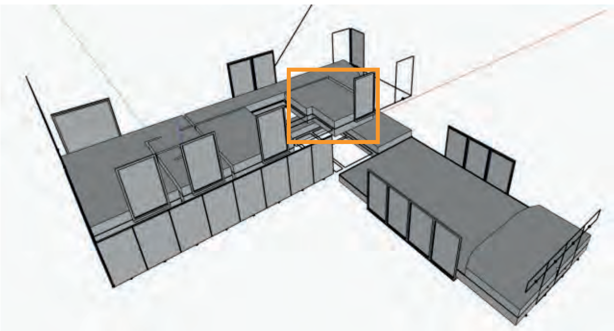

Figure 3: Three-dimensional model generated by the script, places where the floor is represented have potentially enough daylight and other not (orange).

In “101 rules of thumb for low energy architecture”[18] they propose to compare the height of the windows with the depth of a space. Although, this technique works in section, in a three-dimensional model we adapted it by generating a projected daylight surface on the floor of a room [Figure 4]. By keep the common surface within the room floor and the projected daylight surface (which may be deeper than the room of the window is over dimensioned), we find the actual proportion of the room respecting the rule of thumb. A ratio between this value and the total area of the room gives an idea of the daylight generality[1]. In [Figure 3], most of the building respects the rule of thumb, however a blind room has no value and also the top right corner of the building due to an absent window.

Light Area Calculation Function

```
/*Function to draw the light(HeadHeight) area or shadow(SillHeight)
area below a window. If you want to remove the shadow below the window
(due to the Sill Height). Use the same function but replace HeadHeight by
Sill Height, HeadHeight or SillHeight=h;
LocationPoint=lp;
 Width= w;
 Plane normal= n;
t = temporary values*/

def LightArea(h,lp,w,n,f)
{
hh=f*h;
/* The value of hh=2*h comes from
HUW KEYWOOD 101 Rules of Thumb for low energy architecture
Rule 74, p.162*/
t1=-2*hh;
line0 = Line.ByStartPointDirectionLength(lp, n, hh);
line1 = Line.ByStartPointDirectionLength(line0.EndPoint, n, t1);
vz=Vector.ZAxis();
vector=n.Cross(vz);
line2a = line1.Translate(vector, w/2);
line2b = line1.Translate(vector, -w/2);
p1=line2a.EndPoint;
p2=line2a.StartPoint;
p3=line2b.StartPoint;
p4=line2b.EndPoint;
rectangle = Rectangle.ByCornerPoints(p1,p2,p3,p4);
surfacerectangle = Surface.ByPatch(rectangle);
solidrectangle = surfacerectangle.Thicken(1);

c1 = lp.Translate(vector,-w/2);
c2 = lp.Translate(vector,w/2);

circle1 = Circle.ByCenterPointRadius(c1,hh);
circle2 = Circle.ByCenterPointRadius(c2,hh);

surfacecircle1 = Surface.ByPatch(circle1);
surfacecircle2 = Surface.ByPatch(circle2);

cylinder1 = surfacecircle1.Thicken(1);
cylinder2= surfacecircle2.Thicken(1);

//Put Solidrectange, cylinder 1 and 2 in a list

solidlist= {solidrectangle,cylinder1,cylinder2};
out=List.Transpose(solidlist);
return= out;
//debug "return= out";
};
```

Figure 4: Script calculating the potential for daylight (generality). If one wants to calculate generality, future potential windows must be located with a given permeability rating (depending on the ease of disassembly).

Potential for Natural Ventilation

Similarly, to daylight potential, the natural ventilation has been investigated. In [18, p. 162] a distinction between single-side and cross-ventilation is considered. This distinction was an opportunity to show the potential of scenario planning within BIM. Indeed, the analysis tool must evaluate the natural ventilation potential differently whether it is a single-sided or a double-sided ventilation. To do so, the script uses a input vector (geometric input or coordinates) as the major “wind direction” (provided by the designer. By comparing this with the normal vector of each window, the script will determine the inlet and outlets. A space with inlets and outlets is a cross ventilation while a space with only an inlet is a single sided ventilation. For single-sided ventilation, a maximum depth value is given by the height of the window. A deeper space may lack of fresh air. For double-sided ventilation, a slightly complex script had to be developed [Figure 5]. It works in a similar way has the one for

1 It should be noted that due to software limitations an actual area is not really calculated but a volume with a one meter height (the value of the volume equals the area). Indeed, the intersection between surface is less reliable than the three-dimensional intersection.

daylight: by generating a “sufficiently ventilated surface” and comparing it with the room surface.

Ventilation Area Calculation Function

```
def VentArea(h,lp,w,n)
{
hh=2*h;
/* The value of hh=2*h comes from
HUW KEYWOOD 101 Rules of THumb for low energy architecture
Rule 74, p.162*/
t1=-2*hh;
line0 = Line.ByStartPointDirectionLength(lp, n, hh);
line1 = Line.ByStartPointDirectionLength(lp, n, t1);
vz=Vector.ZAxis();
vector=n.Cross(vz);
line2a = line1.Translate(vector, w/2);
line2b = line1.Translate(vector, -w/2);
p1=line2a.EndPoint;
p2=line2a.StartPoint;
p3=line2b.StartPoint;
p4=line2b.EndPoint;
rectangle = Rectangle.ByCornerPoints(p1,p2,p3,p4);
surfacerectangle = Surface.ByPatch(rectangle);
solidrectangle = surfacerectangle.Thicken(1);
out=solidrectangle;
return= out;
//debug "return= out";
};
```

Figure 5: Script calculating the general area regarding double-sided ventilation. For single sided-ventilation, only the depth of the room must be checked.

Other aspects

Those conceptual tools are already working together within one script. Additional aspects must be considered such as the presence of technical shafts which would ensure the futureproofs of the building. Furthermore, the more aspects you add the most realistic vision you may have from the building but the trickier it is to interpret and combine them together.

Although the current tool is not sufficiently developed and tested to be presented as the solution to quantify generality and adaptability at a conceptual stage, it efficiently gathers data related to sustainable aspects, manage and process them to generate new insights either more quantitative one or more qualitative ones by showing potential weakness of a building (e.g. “Be careful this room might not have enough light”, “By having a central hallway you may improve the versatility of a space”).

4.2 Materialisation

In between, the conceptual design phase and the detailed design phase, designers have to develop the building permit. To do so, they encounter the materialisation phase when the concepts are translated into more practical solutions with materials, rough quantities and thus, the designs start to become more specific and the BIM model involves more data and increases in complexity.

While currently no specific and complete tool has been developed for this phase. We can already propose some approach which might be considered to materialise efficiently a building. Strategies such as pace-layering [26] and the sixth layers of brands (i.e. distinguish layers with different functions and thus, varying life span) or light elements that could be easily dismantled (with lower permeability rating for SAGA) may be interesting approaches to help the designer materialise the concepts into DfC compatible solutions.

After, this phase, the designer will have more reliable information (linked to real products) and also more information (more parameters) for every components but also for their interactions (the way they are connected). There, another tool helping the designer to assess a building at detailed-design phase is currently under development.

4.3 Detailed design phase Tool

In the literature, the importance of connections for reversible designs is very clear [6], [9], [27]. However, it is very time consuming and difficult to assess the building potential for disassembly

In (Durmisevic,2006) [11], the relational pattern approach is presented. This method is a graphical way of representing interaction between elements within a building. It is stated that interconnections between elements having different functions (bearing, servicing, partitioning and finishing) should be separated to avoid independencies leading to obsolescence and potential waste.

By investigating the potential of BIM for Design for Disassembly, an analogy between building’s components networks and social networks triggered our interest. Indeed, both buildings and social networks are structures relying on key elements making the connection between groups of object/people having different functions/hobbies/work. They both share the principle that the connection between them is a key feature of the whole structure and thus, it was decided to investigate the similarities of social networks and building’s components networks [28].

Design For Disassembly Network assessment

To do so, a script has been developed to extract from a BIM-model the intersections between components (it was decided to extract only the structure, the walls, the windows, the slabs, the curtain panels and the roofs). From experience we know, that elements connected linearly are more difficult to dismantle than elements connected around a more durable core. Indeed, if one element of the linear chain is weaker than the others and fails, the whole chain will probably need a replacement while if all elements are connected to a core which is durable and accessible, only the problematic element can be changed and reattached to the core.

Therefore, being able to identify potential weak points based on the way elements are connected (type of connection [dry vs wet], how they are connected [linearly or around a durable core]) will allow the designer to improve them faster.

Although, this tool can already map the elements’ intersection network, it needs to be further developed to automatically identify and provide useful feedback to the user.

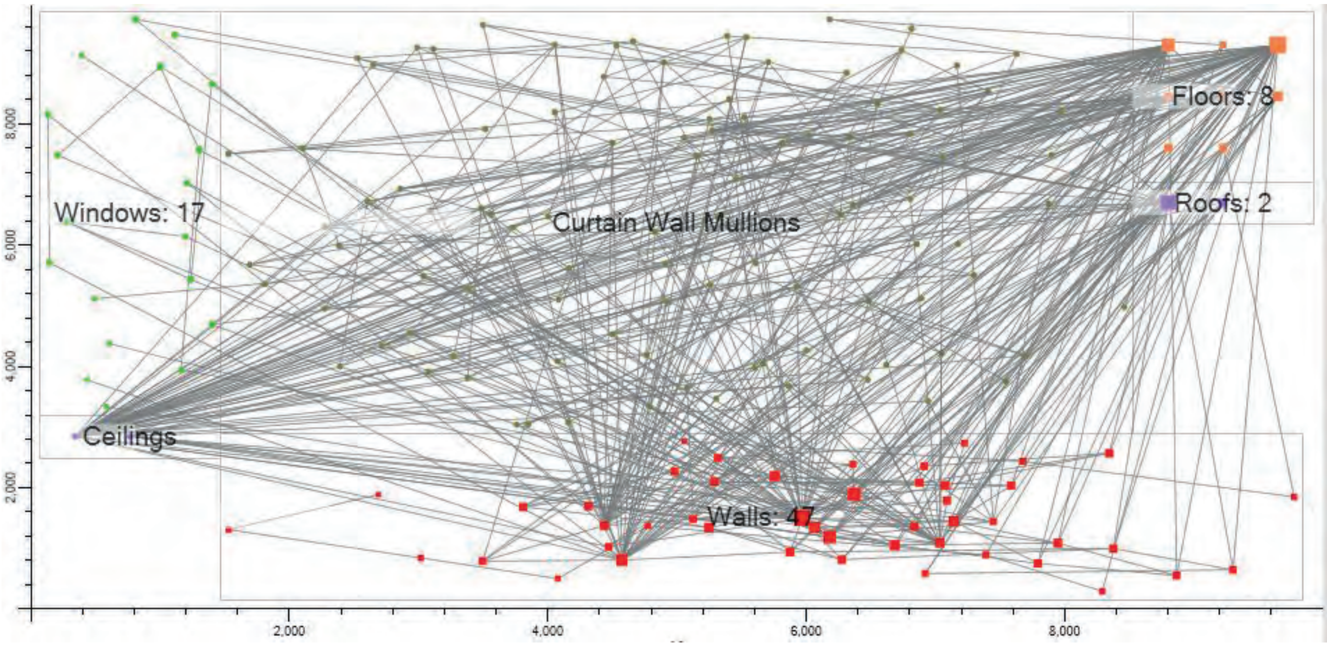

Figure 6: building's component network grouped by function

Currently, the current metrics used into social network analysis are studied and new conventions and practical rules to generate and display building networks are currently under development. Although, useful results are not generated yet it is already possible to extract such a network from a BIM model and analyse its structure with social network analysis tools such as NodeXL. Displaying the network in different ways (grouping by type), calculating the in-degree and out-degree value (object hosting the elements or being hosted by it).

Those, results already show potential to determine base elements (the core structure) but other aspects related to specific metrics for buildings must be investigated.

Limitations

The script does not consider real connections between elements (yet), it only considers geometrical intersection between elements. However, distinguishing point/linear/surface connections may also lead to new insights and results.

New metrics specific for buildings must be developed and determined through the study of exemplar building structures.

5 CONCLUSIONS

To designers interested in sustainable developments this research shows the added value of integrating sustainable approaches into a BIM process, by easing the processing and the management of information and allowing him to focus on the design. Although, a complete and objective assessment has been developed, BIM and DfC combination allows to initiate this process of quantifying and qualifying in comparable ways design alternatives.

To designers already using BIM to handle their data (mainly for the construction phase), it shows that the information is not only useful to construct the building but also to generate insights. The scope of sustainable development has been chosen voluntarily because it is believed to be a key aspect of the future job of designers; However, the demonstration goes beyond the field of DfC and clearly shows that information already available in the BIM allows designers to make better design decisions. This bold statement may change the way some designers seem BIM as it is often considered as a non-conceptual design tool. Indeed, by managing the information during the whole process (and thus, consider the amount of the reliability of information is evolving throughout the process), it is possible to generate phase-specific insights.

To governments (public owners), real estate agents and building owners, the ability to assess and analyse a building passive potential towards change (conceptual tool) or the ease of disassembly (detailed tool) allows them to identify buildings which are keener to be changed in function or easier to renovate or upgrade to fit the user's needs. Therefore, it will allow to give a value to this concept which were previously difficult to measure and therefore compare economically, environmentally and socially.

The following quote by *designtoproduction* in From Control to Design [2, p. 261] focusing mainly on design for production could be clearly extended towards sustainable development approaches:

> *"How translate the shape of the whole into parts made from standardized material? Here in fact, between the modeling tool and the fabrication tool, lies the complete architectural planning process including the breakdown into parts, the optimization according to various constraints, the detailing, and the preparation for fabrication"*

Indeed, to achieve a more circular economy and more sustainable buildings, designers must research "how to translate" their design principles into tools and methods. In the 21st century designers must also be able to design their tools to master the whole architectural process.

6 FUTURE DEVELOPMENTS

As stated during the whole paper, the proposed process and tools are not sufficient to ensure a full vision of buildings DfC potential. Therefore, developments of new methods and tools tackling specific issues should be done in the future. Please find here a preliminary list of potential tools/method and their interest:

- Assessing buildings elements in terms of waste generation with various end-of-life scenario
- Detecting and analysing the presence and the dimensions of technical shafts (increase generality and adaptability).
- Obsolescence detection tool (detects weakest elements and potential early failure in the maintenance of a building)
- Decision making tool showing the impact of choices money-and-environmentally-wise
- Tool managing scenario planning (e.g. social changes)

Additionally, several small tools that have been developed in the scope of this research as proof of concept (and slightly introduced and discussed in this paper or another paper of this conference entitled *"IDExAS, A Framework Supporting Designers in Creating Custom Data-Enabled Tools"* might be updated or further developed to be useful in real life and generate insights or decision supporting information.

7 ACKNOWLEDGMENTS

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Design for Disassembly as an Alternative Sustainable Construction Approach to Life-Cycle-Design of Concrete Buildings

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Abstract

Reviewing the previous attempts to dismantle and reuse concrete buildings indicate that only precast buildings have shown to be successful. The aim is to consider DfD of concrete buildings from an architectural point of view. The role of concrete technology in this context will be reviewed, assembly and disassembly, as well as DfD aspects and theories. A comprehensive analysis and evaluation of the common used precast conventional façade panel system will be carried out to highlight the aspects of weakness. Some concepts of development will be suggested to the conventional panel façade system to have higher disassembly potential.

Keywords:
Design for disassembly; precast concrete systems; reuse concrete; buildings lifecycle; transformation capacity

1. INTRODUCTION

The impact of the processes that accompanied building and construction on the environment becomes undeniable. These processes always consume resources in enormous amounts and produce CO_2 emissions. They also produce unavoidable waste. Buildings, for example, are responsible for more than 30% of the global greenhouse emissions CO_2 [1]. Despite the huge effort that has been made by all parties of the building sector regarding the sustainability of buildings, the developments in the design process have not been met with similar ones in the construction phase. Concrete buildings in specific, their materials and elements still have a linear model of life-cycle which increases the stress on the environment due to production and demolition of buildings. This linear life-cycle “cradle-to-grave” prevents from reuse of building elements and components and cause several environmental impacts. Also, concrete buildings in most cases end their function while their element can serve longer time, the Eurocode - Basis of structural design, for example, specify indicative design working lives for the design of various types of structures [2]. The conventional ways of dealing with concrete in the building are the major reason that prevents from reuse of concrete elements. On the other hand, concrete technologies are continuously developed. These developments open the door wide for new applications in architecture and building construction that could help in changing the linear model of life-cycle to a cyclic one. For that, the way of designing and constructing concrete building should be altered to allow access to component and elements with minimum damage for reuse and reconfiguration through Design for Disassembly (DfD). The previous attempts to reuse concrete elements showed that precast systems were to be successful [3]. Based on the previous facts this study aims to analyze the potential and limitations of the enclosure system of concrete buildings especially the facades regarding demountability as well as transformation capacity as an example and suggest some developments. This paper is a port of a wider Ph.D. Study at the faculty of architecture and landscape in Leibniz University, Hannover in Germany under the supervision of Prof. Alexander Furche.

2. METHODOLOGY

The study reviews two main fields: the available concrete systems and technologies and DfD aspects and theories. These theories are utilized for the analysis and evaluation of the concrete systems. The results are used to develop high disassembly potential systems.

3. CONSTRUCTION OF CONCRETE BUILDINGS

The construction method of a building decides its end-of-life scenario. Cast-in-situ construction produces monolithic entities that cannot be disassembled, while precast construction could allow demountability if other than wet connection methods are used. There are some aspects that affect the construction processes of concrete buildings and set some limitations such as gravity and technology [4]. Concrete as a building material passed through various types of developments and improvements during the last decades that made it more applicable in architecture and efficient in use. Various technologies and improvements are introduced to concrete to improve its performance and properties such as additives, fiber, and textile reinforcement, post-tensioning and prestressing. During the last decades, the end-of-life scenario has shown a dominance of demolition due to the use of cast-in-situ construction, at the same time some examples showed that when precast concrete is used demolition can be replaced by disassembly and reuse.

3.1. Concrete technology and types of concrete

A number of admixtures are used as improving agents to concrete or to increase workability. Some alternatives to cement could be used to reduce the cement content in concrete and decrease its environmental impact [5]. Many types of concrete could be obtained using improved mixes such as:

a- Ultra high-strength concrete
b- Self-healing concrete
c- Self-cleaning concrete
d- Light transmitting concrete
e- Self-compacting concrete. (See Figure 1)

Understanding the technical aspects of concrete and its development can help in defining the limitations and potentials of this material in producing more suitable elements for demountable structures and reuse potential.

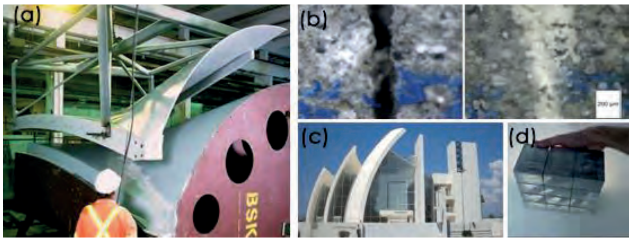

Figure 1: various types of concrete

Compared to other building materials, concrete has favorable characteristics that should encourage their use for demountable structures such fire resistant, durability, strength, ease of shaping, thermal mass and many others which bush toward considering it for demountability and reusability.

3.2. Life-cycle of concrete

In general, the production of building material is range from 30-50% of the total life-cycle energy of a building [7]. The use of clinker in concrete raises the embodied energy of concrete and the CO_2 emissions where the production of every ton of clinker release one ton of CO_2 [8] However, the production of a reinforced concrete beam compared to a steel I-beam could have less environmental impact and required energy as a study by Leslie Struble and Jonathan Godfrey showed [9]. Another study compared the environmental impact of steel and cast-in-situ concrete building and showed that the concrete frame required more energy and accompanied by CO2, CO, NO2, particulate matter, SO2 and hydrocarbon emissions but that was due to formwork and material transportation and long construction process. On the other hand, the steel frame was accompanied by more heavy metals Cr, Ni, Mu emissions, and VOC (see figure 2) [10].

Figure 2 clearly indicates that conventional construction methods of concrete buildings using the cast-in-situ system are the core of the problem and could be overcome by precast systems.

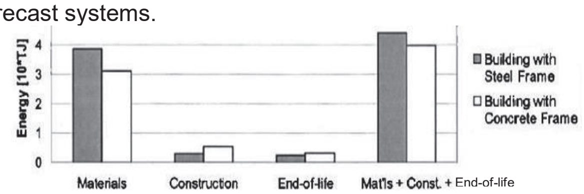

Figure 2: Comparison of energy use by life-cycle phase for steel and concrete frame buildings.

3.3. Ruse of concrete elements

A number of projects in which attempts have been made to reuse concrete elements showed to be successful such as Kummatti housing estate rehabilitation project in Raahe in Finland which resulted in 36% savings in construction costs [11]. Also the design project of new housing in Mehrow near Berlin where reuse of precast panels from old buildings that have been built using "Plattenbau" system occurred and resulted in 30% less construction cost [5]. The ministry of transport, building, and housing in Germany performed a project that aims to test the potential of dismantling and designing a house using reused components and showed that the cost of the reused building parts is 50% less than the new ones and the total cost could be 26% cheaper [12].

4. DESIGN OF BUILDINGS FOR DISASSEMBLY

The notion towards DfD in buildings considered relatively new and has environmental roots. One of the major basis behind DfD according to Crowther is to decrease the consumption of resources and to avoid the huge rates of waste due to demolition. DfD could also extend the service life of components and encourage reuse [13], [14]. Durmisevic believes that the dynamic and changing demands of users should be reflected in building design through reconfiguration, reuse, and easy maintenance as a result of disassembly potential [15]. According to Durmisevic all material levels that are accounted for the technical composition of the building should be designed for disassembly [15]. The concept of time-related building layers by Habraken and Brand in the middle of the 1990s was a vital concept that helps in DfD [16], [7].

4.1. How to design for disassembly

DfD aims to make the removal of layers possible for replacement, reconfiguration, maintenance and reuse without exposing other layers to damage [7]. Durmisevic made a considerable study that discusses most aspects that affect and being affected by DfD.

The technical composition of the building

When materials are being systematized according to a specific arrangement and integration into a specific physical level to provide a defined function then the technical composition could be recognized. Figure 3 shows the technical composition of a proposed concrete façade. The focus on the durability of material and interfaces as well as the arrangement in the technical composition is crucial to the life-cycle of the building as Durmisevic believes. In some cases some façade components end their use at a period of time while their technical life-cycle has a longer period, here a mismatch between the use and the technical life-cycles occur which require a kind of independence at the building level [7].

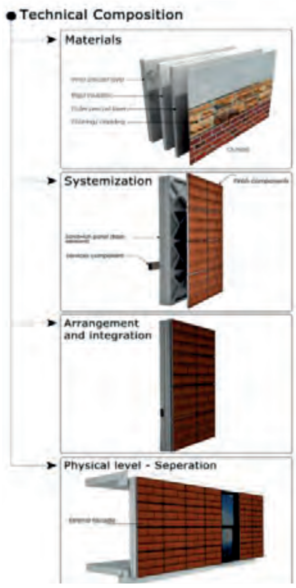

Figure 3: The technical composition of a proposed façade system

To identify the materials or elements that have a mismatch between the technical and the use life-cycles the life-cycle Durmisevic suggests using a life-cycle coordination matrix that specifies elements that have disproportion and treats them as disassembly sensitive elements [7].

Configuration design as a key to Disassembly

Yu believes that the relationships and arrangement whiten a design are the key factors that determine the type of configuration in a design process [17]. The future disassembly of a building is affected by these hierarchal arrangements. Durmisevic believes that three main domains are involved: functional, Physical and technical [7].

The independence and exchangeability of these configuration domains decide the level of transformation capacity of a building and its disassembly potential. The higher transformation capacity could be obtained through the specification of the material levels when independence between assembly and sub-assembly as well as function and sub-function exists. Furthermore, analysis of assembly relations, life-cycle relations and types of relations regarding connections helps in evaluating the actual transformation capacity. The last important factor is the independence and exchangeability of the physical integration which can be defined by the connection type, the geometry of element edge and the assembly sequence (Durmisevic, 2010).

Decomposition of buildings

A building can be decomposable when the independence of parts and the design of the interfaces of these parts for exchangeability occur. Eight aspects regarding the independence and exchangeability affect the decision-making processes during the design of decomposable structures:

1. Functional decomposition
2. Systematization and clustering,
3. Hierarchical relations between elements
4. Base element specification
5. Assembly sequences,
6. Interface geometry,
7. Type of the connections
8. Life-cycle co-ordination in assembly/disassembly

The evaluation of the disassembly potential

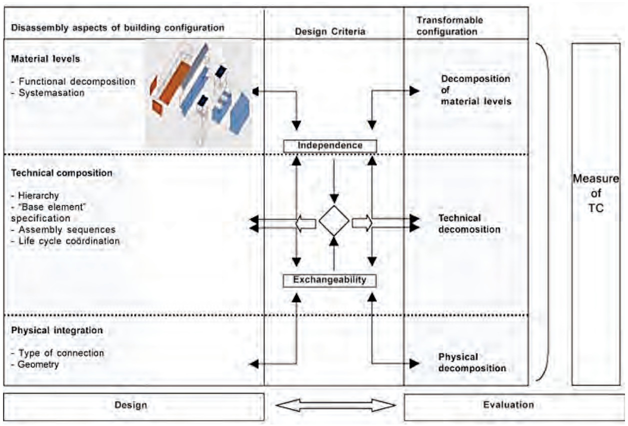

Figure 4: Various aspects of design for disassembly with relation to design criteria and transformable configuration

The disassembly potential of a building, a structure or a product could be evaluated using the knowledge model which has been developed by Durmisevic (see Figure 4). This model takes into consideration the eight aspects mentioned above. Despite the fact that it is not the only reference in this context but it is the most comprehensive.

5. DISASSEMBLY POTENTIAL EVALUATION OF PRECAST CONCRETE BUILDINGS

It has been previously indicated that the precast systems are the most suitable type of concrete systems that could provide the future concrete buildings with the required transformation capacity [3].

5.1. Building levels and technical composition

Durmisevic has previously shown how the emancipation of the independent physical levels has led to multiple spatial systems of the building and extension of some physical levels life. Figure 5 shows a suggested building levels and technical composition for the precast buildings based on the previous model of Durmisevic.

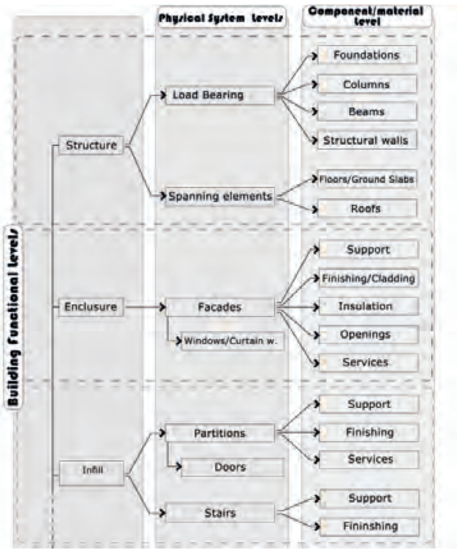

Figure 5: The technical composition of precast buildings

The following sections analyze and evaluate the conventional precast panel system as one of the most common precast façade systems regarding its disassembly potential and suggest developments.

5.2. Disassembly potential of the enclosure system: precast conventional panel as a case study

The conventional panel system is one of the most common precast facades used for the enclosure of concrete buildings.

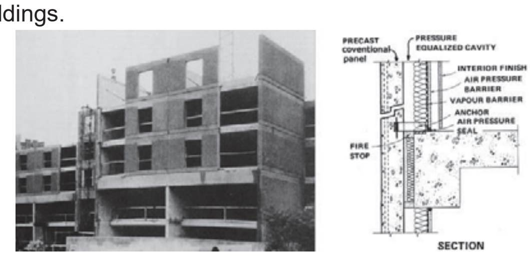

Figure 6: The use of conventional precast panel system

The conventional precast panels are the simplest form consisted of a single concrete layer either plain or with a desired finish, no insulation material is attached where it is being assembled at the site [18].

Connecting and jointing the façade panels

It should be distinguished between connecting the façade panels and jointing them. While connecting the panels means to anchor them to the load-bearing structure using console connections that transfer the loads, jointing them deal with sealing the gaps between the panels to ensure weather resistance.

Types of anchorage connections

The conventional panels are anchored to the load bearing frame or the slaps of the building using console connections. The design of the anchorage connection decides the successful application of the precast panels in construction. These anchorage systems are one or a combination of the following types (see Figure 7) [20]:

a) Direct bearing connections
b) Eccentric bearing connections
c) Alignment connections

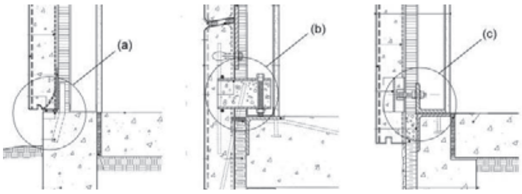

Figure 7: Various kinds of panel connections

Jointing the façade panels

Completing the function of the building envelope requires an effective jointing system that ensures weather resistant and air tightness, the design of the joints and the selection of the suitable jointing material play an important role.

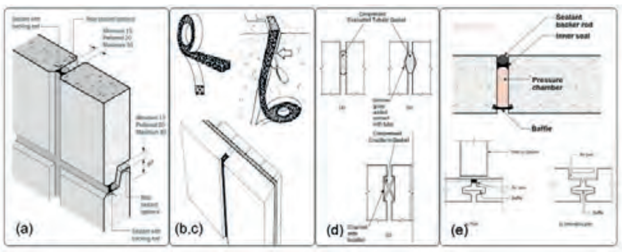

Figure 8: Various jointing techniques

There are several jointing materials and various techniques which can be easily disassembled such as:

a) Elastic sealant compounds
b) Waterproofing with adhesive strips
c) Joint waterproofing with pre-compressed sealing strips
d) Gaskets
e) Baffles (see Figure 8)

5.3. Levels of disassembly

The conventional panel system consisted of a number of materials and elements other than concrete to satisfy the required functionalities of the enclosure. Disassembly of the system and at what level the disassembly should be considered is determined by aspects that contribute to the extension of facades life. For example, the design of cladding for disassembly allows replacement and change in case of fashion obsolescence, also for insulation material which can be upgraded or replaced according to building codes requirements.

5.4. Analysis of the design for disassembly aspects for precast conventional panel

To evaluate the disassembly potential of the precast conventional panel system analysis of the typology of configuration regarding its dependence and exchangeability is required. Three aspects are included: material levels, technical composition, and physical integration.

Material levels

Facades that are made from precast conventional panels usually have the material levels shown in Figure 9.

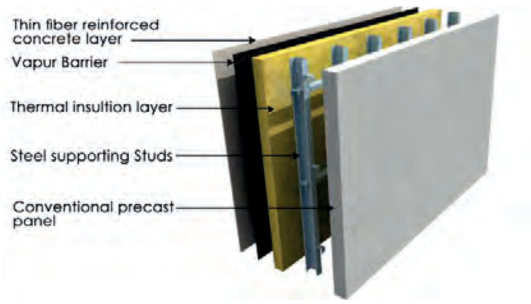

Figure 9: Material levels of the conventional panel system

These material levels provide the facades with four main functions: bearing, insulation, appearance and weather resistance. Independence and exchangeability of these functions provide the ability to change, replace and reuse of these materials.

Technical composition

The independence and exchangeability of the technical composition depend on hierarchal arrangements of materials and the relations between materials.

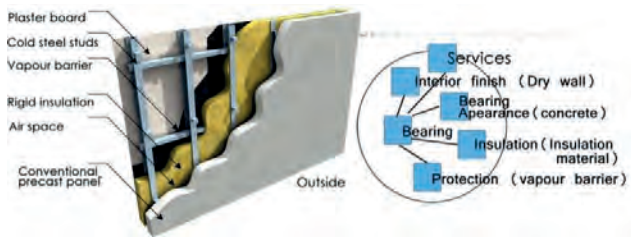

Figure 10: Arrangements and relations between materials

For the conventional precast panel system, the panel which is made of reinforced concrete provides bearing, protection and appearance and play as a base element (see Figure 10).

Physical integration

The physical integration of components and elements in a system has an important role in deciding the independence and exchangeability of its typology of configuration. Three main determining factors are included in a system physical integration: type of connection, the geometry of element edge and assembly sequence.

a) Assembly sequence

Precast conventional panels are usually anchored to the load-bearing structure it can be supported by steel or concrete console connections that transfer loads to the slab or beam. At the building level these panels assembled after the load bearing structure assembled, however, these panels can be assembled in a parallel manner to the structural system see Figure 11.

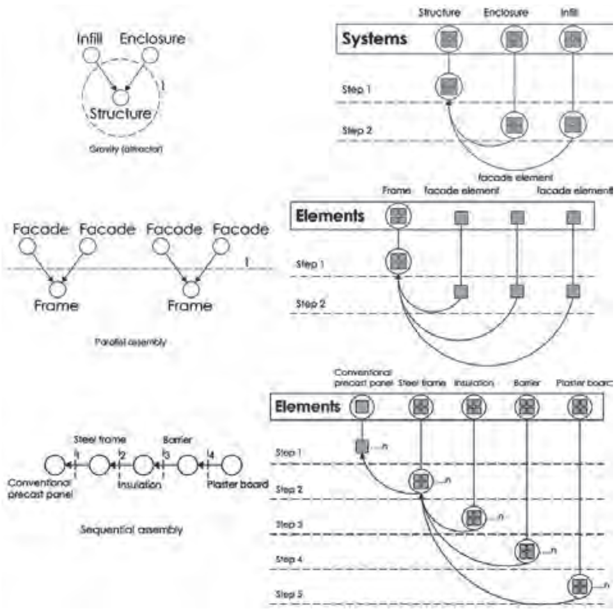

Figure 11: Assembly sequence of the conventional panel at the building and system level

b) Type of connection

Two common connections are used to anchor the conventional panels to the structural system: The eccentric bearing and the tie back the connection these types and their representation are indicated in Figure 12.

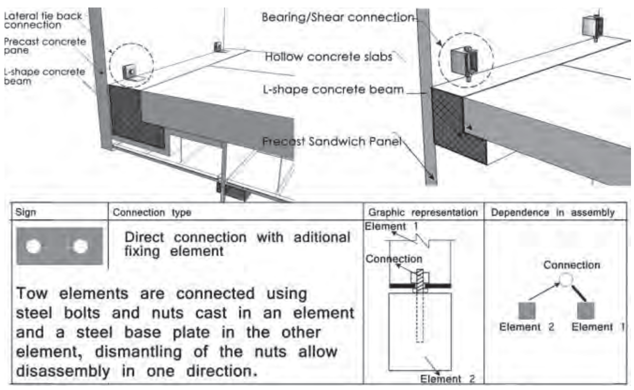

Figure 12: Connection types used for conventional panels

c) Geometry of element edge

Two types of the geometry of element edge can be distinguished in precast conventional panels: open liner and integral in two sides (see Figure 13).

5.5. Evaluation of the disassembly potential of precast conventional panel

The knowledge model of Durmisevic will be used to evaluate the disassembly potential of the precast conventional panel system, (values and determining factors could be found in appendix 1).

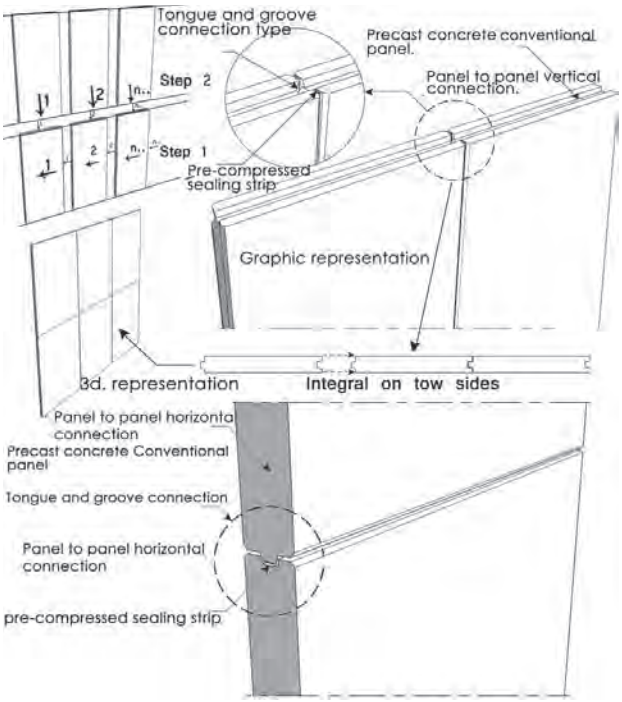

Figure 13: The use of integral on two sides geometry of element edge

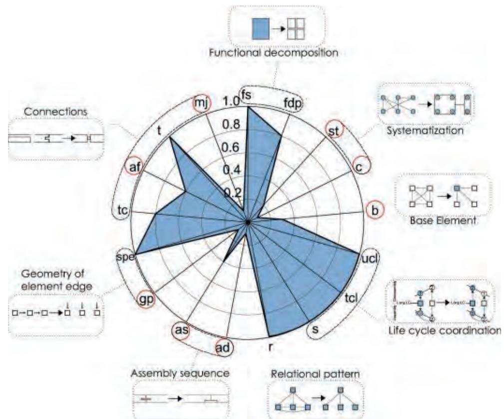

Figure 14: Radial diagram showing DfD aspects and their values for precast conventional panel based on the model of Durmisevic

Figure 14 indicates that some DfD aspects have shown low scores which mean that loss of time and material through assembly and disassembly processes could occur.

6. DEVELOPMENT OF THE CONVENTIONAL PANEL FAÇADE SYSTEM

Figure 14 has shown that, aspects of systematization, base element specification, assembly sequence, the geometry of element/product edge, accessibility to fixing and morphology of joint need to be considered to have higher values which will raise their transformation capacity.

6.1. Development of systematization aspects

For precast conventional panel system, a number of construction operations are required after the installation of a panel including the installation of the insulation materials, bearing studs, drywall. These operations occur at the site; they not only increase the assembly time but also complicate the future disassembly. By including components instead of individual materials and apply clustering of materials and elements according to functionality the systematization issues will be solved (see Figure 15).

6.2. Development of the base element specifications

A base element could be used to facilitate the gathering of elements and materials, in this case, a concrete frame could be used as a base element (see Figure 15).

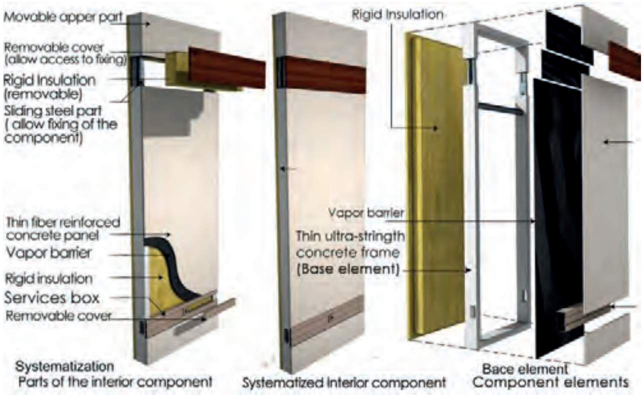

Figure 15: Developments of systematization and base element aspects.

6.3. Development of assembly aspect

Two determining factors can improve the assembly processes of the conventional panel facade system: assembly direction based on assembly type and assembly sequence regarding material levels. In this case, the ability to allow a parallel open assembly and the use of component assembly will help in improving the assembly aspects (see Figure 16).

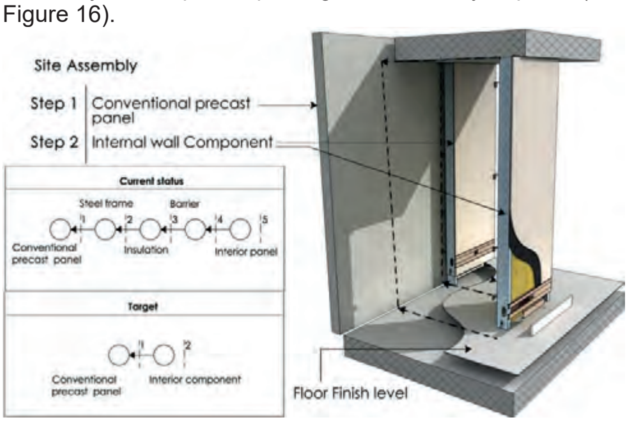

Figure 16: Development of assembly aspects

6.4. Development of geometry of element edge

It is possible to use open linear geometry for conventional precast panels instead of integration from two sides in this case various jointing methods and techniques could be used.

6.5. Connections

The evaluation chart showed that accessibility to fixing and morphology of joint have low scores and could be further developed by providing accessibility to fixing and using a 3d connection or point connection. The following details provide suggested solutions, where the interior component can be easily disassembled to provide access to the panel connections also the connection of the interior component, are accessible through the removable part (see Figure 15, Figure 17).

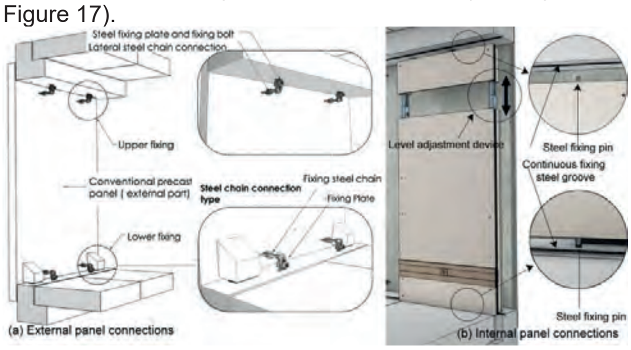

Figure 17: Development of connection aspect.

7. SUMMARY

The study discussed the aspects that affect the disassembly potential and transformation capacity of concrete buildings worked on finding the missing links between concrete technologies and the life-cycle-design of concrete buildings especially the end-of-life and considered development for precast conventional panel system to have higher disassembly potential.

8. ACKNOWLEDGMENT

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Appendix 1

List of design for disassembly aspects and corresponding sub-aspects

FD	functional separation	fs 01	Separation of functions	1
Functional decomposition		fs 02	Integration of functions with	0.6
		fs 03	integration of functions with	0.1
		fs= (fs1 + fs2+…… fs(n))/n		
	functional dependence	Fdp	Modular zoning	1
		Fdp	Planed interpenetrating for	0.8
		Fdp	Planed interpenetrating for	0.4
		Fdp	Unplanned interpenetrating	0.2
		Fdp	Total dependence	0.1
	fdp= (fdp1+fdp2+….fdp(n))/n			
	FD= Fuzzy calculation based on "fs" and "fdp" and their weighting			
SY	Structure and material levels	st 01	Components	1
Systematization		st 02	Elements/Components	0.8
		st 03	Elements	0.6
		st 04	Material/Element/Component	0.4
		st 05	Material/Element	0.2
		st 06	Material	0.1
		st=(St1+st2+…st(n))/n		
	Clustering	c 01	Clustering according to the	1
		c 02	Clustering according to the	0.6
		c 03	Clustering for fast assembly	0.3
		c 04	no clustering	0.1
	c=(c1+c2+…=c(n))/n			
	SY=fuzzy calculation based on "st" and "c" and their			
BE	Base element specification	b 01	Base element intermediary	1
Base element		b 02	Base element on two levels	0.6
		b 03	element with two functions	0.3
		b 04	No base element	0.1
	b=(b1+b2+…+b(n))n			
	b=fuzzy calculation based on "b"and its weighting factors			
LC	Use life-cycle coordination (1)- Assembles first (2)- Second	ulc 01	long LC (1)/ long LC (2) or	1
Life-cycle coordination		ulc 02	Long L.C. (1)/ short L.C. (2)	0.8
		ulc 03	Medium L.C. (1) / long L.C.	0.6
		ulc 04	Short L.C. (1) / medium L.C.	0.3
		ulc 05	Short L.C. (1) / long L.C. (2)	0.1
	ulc=(ulc1+ulc2+…ucl(n))/n			
	Technical life-cycle coordination	tcl 01	Long L.C. (1)/ long L.C. (2) or	1
		tcl 02	Medium L.C. (1) / long L.C.	0.5
		tcl 03	Short L.C. (1)/ medium (2)	0.3
		tcl 04	Short L.C.1/ short (2)	0.1
	tlc=(tcl1+tlc2+…+tlc(n))/n			
LCC	Life-cycle of components and elements in relation to the size (1) Assembled first	s 01	Small element (1)/ short L.C. or medium component (1)/ short LC	1
Life-cycle coordination		s 02	Big component (1)/ long L.C.	1
		s 03	Big (small element (1)/ long	0.8
		s 04	Big component (1)/short L.C.	0.4
		s 05	Material (1)/short L.C.	0.2
		s 06	Big element/ short L.C. or	0.1
	s=(s1+s2+…+s(n))/n			
	LCC= Fuzzy calculation based on "ulc"."tlc" and "s" and			
RP	Position of relations in relational diagram	r 01	Vertical	1
Relational pattern		r 02	Horizontal in lower zone in	0.6
		r 03	horizontal between upper and	0.4
		r 04	Horizontal in upper zone	0.1
	r=(r1+r2+…+r(n))/n			

	RP= Fuzzy calculation based on "r" and its weighting			
A	Assembly direction based on assembly type	ad 01	Parallel - open assembly	1
Assembly		ad 02	Stuck assembly	0.6
		ad 03	Base el. In stuck assembly	0.4
		ad 04	sequential seq. base el.	0.1
		ad=((ad1+ad2+…+ad(n))/n		
	Assembly sequence regarding material levels (1)- Assembled first (2)- Assembled second	as 01	Component (1)/ component	1
		as 02	Component (1)/ element (2)	0.8
		as 03	Element (1)/ component (2)	0.6
		as 04	Element (1)/ element (2)	0.5
		as 05	material (1)/ component (2)	0.3
		as 06	Component (1)/ material (2)	0.2
		as 07	Material (1)/ material (2)	0.1
	as=(as1+as2+…+as(n))/n			
	A= Fuzzy calculation based on"ad" and "as" and their weighting factors			
G	Geometry of product edge	gp 01	Open linear	1
Geometry		gp 02	Symmetrical overlapping	0.8
		gp 03	Overlapping on one side	0.7
		gp 04	Unsymmetrical overlapping	0.4
		gp 05	Insert on one side	0.2
		gp 06	Insert on two sides	0.1
		gp=(gp1+gp2+…+gp(n))/n		
	Standardization of product edge	spe	Premade geometry	1
		spe	Half standardized geometry	0.5
		spe	Geometry made on the	0.1
	spe=(spe1+spe2+…spe(n)/n			
	gG= Fuzzy calculation based on "gp" and"spe" and their			
C	Type of connection	tc 01	Accessory external	1
Connections		tc 02	Direct connection with	0.8
		tc 03	Direct integral connection	0.6
		tc 04	Direct integral connection	0.5
		tc 05	Accessory internal	0.4
		tc 06	Filled soft chemical	0.3
		tc 07	Filled hard chemical connection	0.2
		tc 08	Direct chemical connection	0.1
	tc=(tc1+tc2+…tc(n))/n			
	Accessibility to fixing and intermediary	af 01	Accessible	1
		af 02	Accessible with additional	0.8
		af 03	Accessible with additional	0.6
		af 04	Accessible with additional	0.4
		af 05	Not accessible total damage	0.1
	af=(af1+af2+…+af(n))/n			
	Tolerance	t 01	High tolerance	1
		t 02	Minimum tolerance	0.5
		t 03	No tolerance	0.1
	t=(t1+t2+…+t(n))/n			
	Morphology of joint	mj 01	Knot (3D connections)	1
		mj 02	Point	0.8
		mj 03	liner (1D connection)	0.6
		mj 04	service (2D connection	0.1
	mc=(mc1+mc2+…+mc(n))/n			
	C= Fuzzy calculation based on "tc", "af", "t" and "mc" and their			

INCREASING REUSE POTENTIAL BY TAKING A WHOLE LIFE-CYCLE PERSPECTIVE ON THE DIMENSIONAL COORDINATION OF BUILDING PRODUCTS

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Abstract
In the current design and construction practices, reuse and reconfiguration strategies are often not considered in building design, mostly preventing the building's life and its parts to be extended at end-of-life, resulting in enormous amounts of waste. In order to measure the reuse potential of building products the following three steps are essential, namely: 1) the ease of reclamation of building products, 2) the ease of re-applicability of reclaimed building products in new context, and 3) the ease of re-manufacturability and upgradability of reclaimed building products.

A significant barrier that restricts the re-applicability of reclaimed building products is the dimensional coordination and its compatibility in new building design. To give an example, it occurs that reclaimed building products are available but require a vast amount of costly re-work to dimensionally comply with the new design requirements, rendering the cost benefits of using reclaimed building products uncompetitive compared to new purchase. The optimization of dimensional coordination of building products, starting from the production line, is regarded as a way to overcome this barrier.

Therefore, the emphasis of this paper is put on how the dimensional coordination of building products can increase their applicability, which is regarded as having a direct effect on the reuse potential. In order to demonstrate the effect of an improved dimensional coordination of building products on the reuse potential, a case study approach will be used in which a whole life-cycle perspective will be adopted, taking in consideration; production measurement standards and production capacities, initial use and reconfiguration scenarios, direct- and indirect product reuse in different contexts.

Finally, this paper will provide a new perspective on the optimization of the dimensional coordination of building products based on its whole life-cycle, which will feed the development of an objective reuse potential measurement tool and guide designers in the dimensioning of building products that will generate a high reuse potential.

Keywords:
Reuse potential, dimensional coordination, application range, production standards and capacities, scenarios and configurations, direct- and indirect reuse.

1 INTRODUCTION

The reduction of waste and the depletion of non-renewable natural resources is one of the key issues to address in order to achieve a sustainable modern world. In Europe, the construction industry is responsible for more than 50% of the total resource extraction, 42% of the total energy use and its associated emissions and 35% of the total waste generation [1, 2]. In the current construction practice building products - the constituents of which a building is composed - are designed with a disregard to the end-of-first-life phase, leading to the loss of almost all applied energy and labour and contributing greatly to the waste generation. One way of addressing the aforementioned issue is by designing building products in such a way to allow the extension to a second and further life and, consequently, creating an incentive for future reuse. The reuse of building products enables the preservation of almost all of its embodied energy, labour and materials. Therefore, the design of building products with a high potential to be reused is considered to be 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.

The current construction industry relays heavily on readily available newly manufactured standard building products that are accessible at extremely low prices [3, 4, 5]. As stated by several researchers, the low prices of newly manufactured building products makes it extremely difficult for the reclaimed building product markets to become competitive in the current economic climate [4, 5, 6, 7, 8, 9, 10, 11]. Furthermore, the high labour costs in developed economies is one of the forces that renders environmental friendly behaviour un-economical and risky. The high labour costs are apparent in the labour-intensive processes that are required to acquire, recondition and recertify reclaimed building products, which potentially raises their price above their value [3, 12, 13], but also in primary production and construction phase the high labour costs have its effect. For manufacturers the high labour costs may lead to production decisions that are steered towards the need to reduce labour costs rather than the need for materials, which potentially results in an increased need of primary materials for the same quantity of final goods, which is termed as 'yieldloss' [3, 14]. Additionally, in the construction phase it has led to construction methods that are optimized for their assembly speed, these construction methods often make use of chemical connections that are irreversible [8, 9, 12, 13, 15, 16], rendering the potential of these building products to be reclaimed and reused obsolete.

In order to shift towards a construction industry in which building materials and products are continuously reused and reconfigured maintaining their value, the business-as-usual should be overcome to enable change. There are multiple barriers that can be identified, which can be of: technical, social, economic, environmental, organizational and political nature. In this paper design issues, which can be grouped as technical barriers will be discussed, since these are considered to be the facilitator that will enable the other barriers to be overcome. In order to guide designers and engineers in the design of buildings and building products that allow for continuous reuse and reconfiguration, it is considered to be necessary to develop a assessment method that identifies the capability and likeliness of a building product to have a second and further life after its primary life. This assessment method will be called the reuse potential tool. In order to measure the reuse potential of building products, three steps are considered to be essential, namely:

1. The ease of reclamation of building products (re-claim);
2. The ease of re-applicability of reclaimed building products in new context (re-apply), and;
3. The ease of re-manufacturability and upgradability of reclaimed building products (re-make)

To clarify the origin of these three steps, they are depicted in an abstract representation of the major life-cycle stage as shown in figure 1. The first step mainly focuses on how complicated it is to deconstruct the building products without damaging them, the second step focuses on the compatibility and adjustability of the reclaimed building product to its new context. And if the reuse of reclaimed building products requires physical adjustments and/ or upgrades to suit e.g. increased performance standards in their new context, the third step focusses on how complicated it is to perform these changes, without raising their costs above their value.

The aim of this paper is to explore how the dimensional coordination of building products can increase their re-applicability in new context. Since a major barrier that prevents building products to be compatible for reuse in new structures is their dimensional coordination [5, 14, 17, 18,]. Therefore, this paper will focus mainly on the second part, which is the ease of re-applicability of reclaimed building products and not so much on the ease of reclamation of building products.

Buildings are often seen as one-off bespoke structures requiring building products with unique dimensions [17, 18,]. Even when it is possible to easily reclaim these bespoke building products at the end of their first life, the potential that their unique dimensions will fit the new context is rather small. Multiple solutions could be thought of to overcome this barrier, namely:

1. The bespoke building product could be applied in a similar context. Although, a major setback of this approach is the potential to find a similar context, which could be limited and thus their potential to be reused decreases.
2. The bespoke building product could be adapted to their new use. Although, this could require a vast amount of costly re-work, potentially rendering the cost benefits of using reclaimed building products uncompetitive compared to new purchase in the current economic climate.
3. The new structure could be designed with the bespoke building products in mind. This would require a totally different approach for the architects and designers in their design process, in contrast to the current design approach, which relays on readily available newly manufactured building products.

This change in approach was also recognized by Gorgolewski [5] who stated that, the coordination of demand and supply of reusing building products can affect the whole design and construction process: “reclaimed materials do not show up at the right time, in the right amount or the right dimension” (p.179).

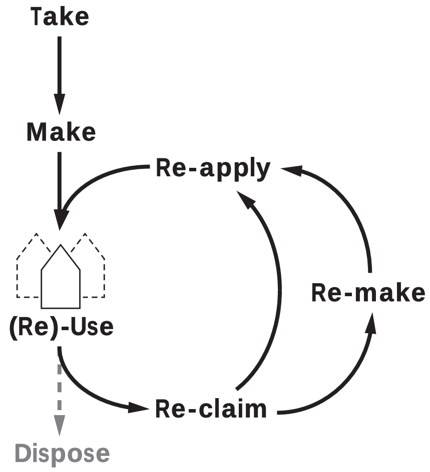

Figure 1: Conceptual model of major life-cycle stages, depicting the three essential steps for measuring the reuse potential of building products.

To improve the compatibility and re-applicability of building products in their new context, the standardization of dimensional coordination of building products is considered to be of big importance. Although, it is unclear what the preferred dimensional coordination for certain building products is and how it can be determined and integrated in the reuse potential tool.

2 METHODOLOGY

In order to explore and demonstrate the effect of a standardized dimensional coordination system of building products on its reuse potential a case study will be used. Since a change in the dimensional coordination of a building product could increase its potential to be reused but decrease the efficiency of material use during its production a whole life-cycle perspective will be adopted, taking in consideration; production standards and capacities, initial use and reconfiguration scenarios, direct- and indirect product reuse in different contexts.

To narrow the research scope, the study is limited to the dimensional coordination of facades, in specific curtain wall facades. In order to increase the re-applicability of curtain wall facades the factor application range is introduced, which will impact the dimensional coordination of curtain wall facades. Finally, the dimensional coordination will be related to the glass production efficiency and its yield rate, to complement to the whole life-cycle perspective on dimensional coordination. The glass dimensions are taken as the biggest restriction in the reuse of facades, because once produced it is not possible to change their dimensions, in contrast to steel profiles and window frames, which could be adapted in changing contexts.

The reuse potential of a building product is considered to increase if the amount of applications the building product has increases. As Habraken [19] stated, “We should not try to forecast what will happen, but try to make provisions for what cannot be foreseen” (p. 50). To enable the provisions of the unforeseen it can be argued that if a building façade is being designed to be easily disassembled and reused, it should be designed in such a way that it allows multiple applications to increase the potential to facilitate the unforeseen in its second and further use. In order to increase the application range, several factors are identified as relevant in the whole life-cycle perspective on the dimensional coordination, such as: functional design requirements, scenarios and configurations, direct- and indirect reuse and production standards and capacities.

In order to reveal the whole life-cycle perspective, the different aspects are related to the different life-cycle stage, as shown in figure 1: functional design requirements relate to the initial use *'(re)-use'*, direct-and indirect reuse, of which direct reuse is represented with the loop from *'re-claim'* to *'re-apply'* and indirect reuse with the loops from *'re-claim'* to *'re-make'* to *'re-apply'*, scenarios and configurations relate to the *'re-apply'* and production standards and capacities to *'re-make'*. Each aspect will be defined and clarified in the following sections.

2.1 Functional product requirements

The functional product requirements are defined in this study by the different type of functions a façade can perform and their related minimum requirements. The curtain wall can be filled in with three types of windows, namely fixed windows, movable windows, and doors. The fixed and movable windows are not restricted by any building code in their dimensional coordination. Although, for doors the Dutch building code defines a minimum opening size for new buildings, which requires them to have a minimum opening width of 850mm and minimum height of 2300mm, to ensure their accessibility [20]. By taking these minimum requirements into consideration it can be stated that the distance between the posts of a curtain wall should at least allow the placement of a door that fulfils these minimum opening requirements between them (see figure 2). If this minimum is taken into account in the design stage it will guarantee the possibility to replace a fixed window or movable window with a door that fulfils their minimum requirements, making the façade more versatile to changing demands. Therefore, it can be stated that if the distance between the posts is less than the minimum requirement the application range in its current and potential future configurations diminishes.

In order to translate this requirement into a quantifiable number, the following rule can be applied: If the distance between the posts and beams a curtain wall (distance x) allows a minimum door opening of 850 x 2300 mm the application range increases, if not, the application range decreases.

2.2 Scenarios and configurations

The application range of a façade can be increased by taking potential scenarios and configurations into account.

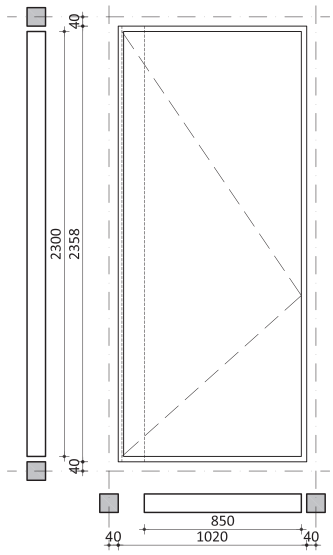

Figure 2: Example of a curtain wall door compliant with the minimum door requirements (type D-SS D1).

Therefore, it is important to define potential horizontal beam and vertical post arrangements. The potential horizontal and vertical arrangements are based on frequently occurring dimensions.

Horizontal beam arrangement

In order to approximate frequently occurring curtain wall heights and increase the application range of the curtain wall in different contexts, several scenarios and configurations are defined, based on: the current Dutch building code standards, frequently used floor- to ceiling heights in the past and floor to ceiling heights that increase spatial qualities and increases the ease of change of functions of buildings.

The Dutch building code requires all new buildings built after 2003 to have a minimum floor to ceiling height of 2,6m [20]. Furthermore, the Dutch government started in 2009 a program to increase the indoor qualities of educational buildings, which describes additional requirements on top of the building code requirements. In this program the floor to ceiling height is defined to be a minimum of 2,8m up to 3,5m as the most preferred dimension [21]. Additionally, it

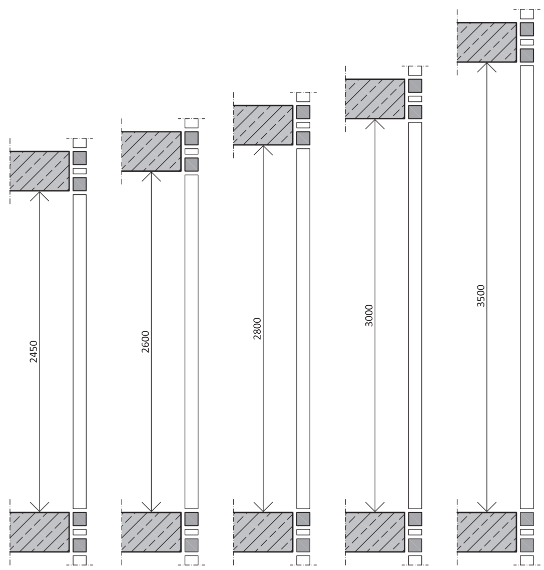

Figure 3: horizontal beam arrangement scenarios.

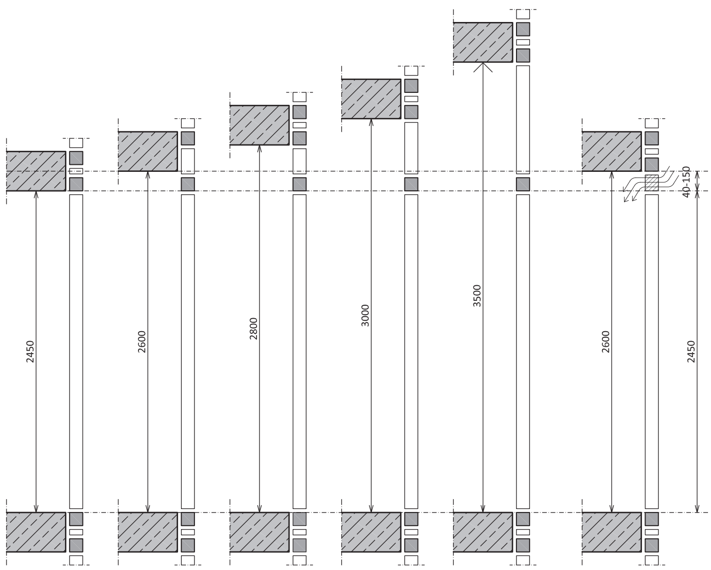

Figure 4: Horizontal arrangement scenarios to allow reuse in all scenarios. The scenario at the right depicts an arrangement scenario that includes the tolerance range.

is seen that if the internal height is 3,0m up to 3,5m it is considered to not only improve spatial qualities, but also the ability of a building to be transformed from function. Furthermore, it is seen that a large share of the existing built environment built in the 1970s and 1980s in the Netherlands has a floor to ceiling height of 2,45m. This results in the horizontal beam arrangement scenarios as shown in figure 3. The consideration of floor to ceiling heights of the existing built environment will enable the use of the curtain wall in renovation projects and thus increase their application range. It is argued that, the more scenarios the façade is compatible with the higher the applicability will be. As was already stated, the dimension of the glass in the façade is the factor that determines its applicability in other scenarios. If a curtain wall in a building with a floor to ceiling height of 3.5m is filled entirely with glass without any transom in-between, it would not be possible to reuse the glass windows on a building with a floor to ceiling height lower than 3,5m. Thus if a façade can be designed in such a way that it allows application in all situations its applicability would be the highest and result in the highest reuse potential.

In figure 4 a horizontal beam arrangement is shown that enables use in all scenarios without changing the window size. Although, as can be seen the scenarios of 2,8m and higher would require a fitting element to close the remaining height. It should be noted that figure 4 depicts an example that allows multiple scenarios, but is not the only option.

Horizontal beam tolerances

If a façade is considered to be reused on an existing building with a deviating floor to ceiling height, it is possible to deviate between 40-150mm with the use of ventilation grills. To give an example, this would allow the reuse of a curtain wall initially used in a building with a floor to ceiling height of 2,45m in a building with a floor to ceiling height between 2,49-2,6m, as shown in figure 4 at the right. The introduction of tolerance enables the application of irregular dimensions, increasing the application range and configuration options significantly.

Vertical post arrangement

The application range of the vertical post arrangement is considered to increase when the grid dimension is compatible with multiple scenarios. Furthermore, a building is considered easier to partition if the structural grid dimension aligns with the grid dimension of the façade. Therefore, the vertical arrangement scenarios will be based on frequently occurring structural grids, regardless the building function. The following grids dimensions are defined as base scenarios: 4,8m, 5,2m, 5,4m, 6m are frequently occurring in residential buildings. Additionally, 6m and 7,2m often occur in commercial buildings and in the 1970s and 1980s residential buildings often had a structural grid of 4,6m and 4,8m. The structural grid is often based on multiples of 0,6m or 1,2m, as shown in figure 5. Therefore, it would make sense to also use this grid for the vertical façade arrangement. Although, to comply with the functional product requirement of the minimum door requirements, a vertical post arrangement of 1,2m would be preferred, as shown in figure 5 at the bottom. If the new use does not correspond with a multiple of 1,2m it would require one fitting element, which would not be much of a hurdle if the rest of the building can make use of the reclaimed façade elements.

2.3 Direct and indirect product reuse

A building consists of many building products. At the end of their first life these building products, if possible could be disassembled and reused directly on a different structure in the same configuration. Although, it is more likely that it will be reused indirectly, in a different configuration or after modification to suit their new context. With indirect reuse it is more likely that components will be separated into their separate elements. In the case of glass windows, because they cannot be changed in dimension after they are produced, it is important to understand the dimensional coordination between the window frames and the dimensions of the glass inside the frames. In order to increase the applicability of the glass windows it can be argued that if the technical detailing of multiple window types with different aesthetics allow the same glass dimensions in the same grid, the applicability increases. In order to be able to match different technical detailing that allow similar glass dimensions a product inventory of frequently used products can be used.

Product inventory

Based on the product inventory of different types of technical details the relation between the glass dimension and the frame can be defined, as shown in figure 7. In figure 6 an example is given of a product inventory, which will be used to define the matches between different technical detailing and their glass dimensions. The product inventory as shown in figure 6 contains three curtain wall types: 1) standard steel curtain wall, 2) steel curtain wall with increased functionality, and 3) timber curtain wall with increased functionality. For each curtain wall type at least

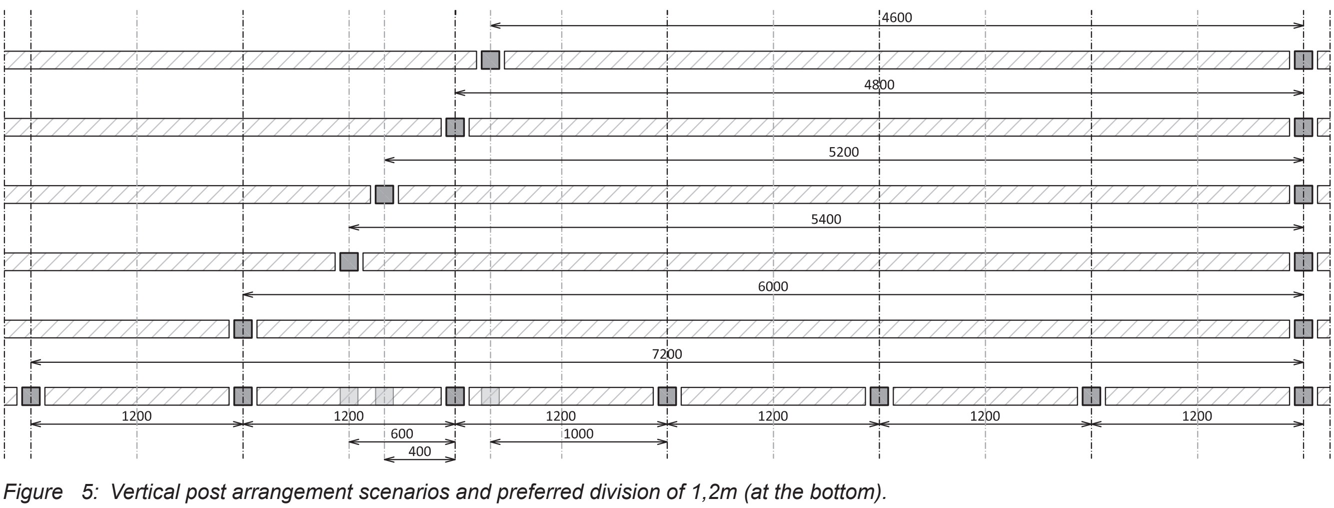

Figure 5: Vertical post arrangement scenarios and preferred division of 1,2m (at the bottom).

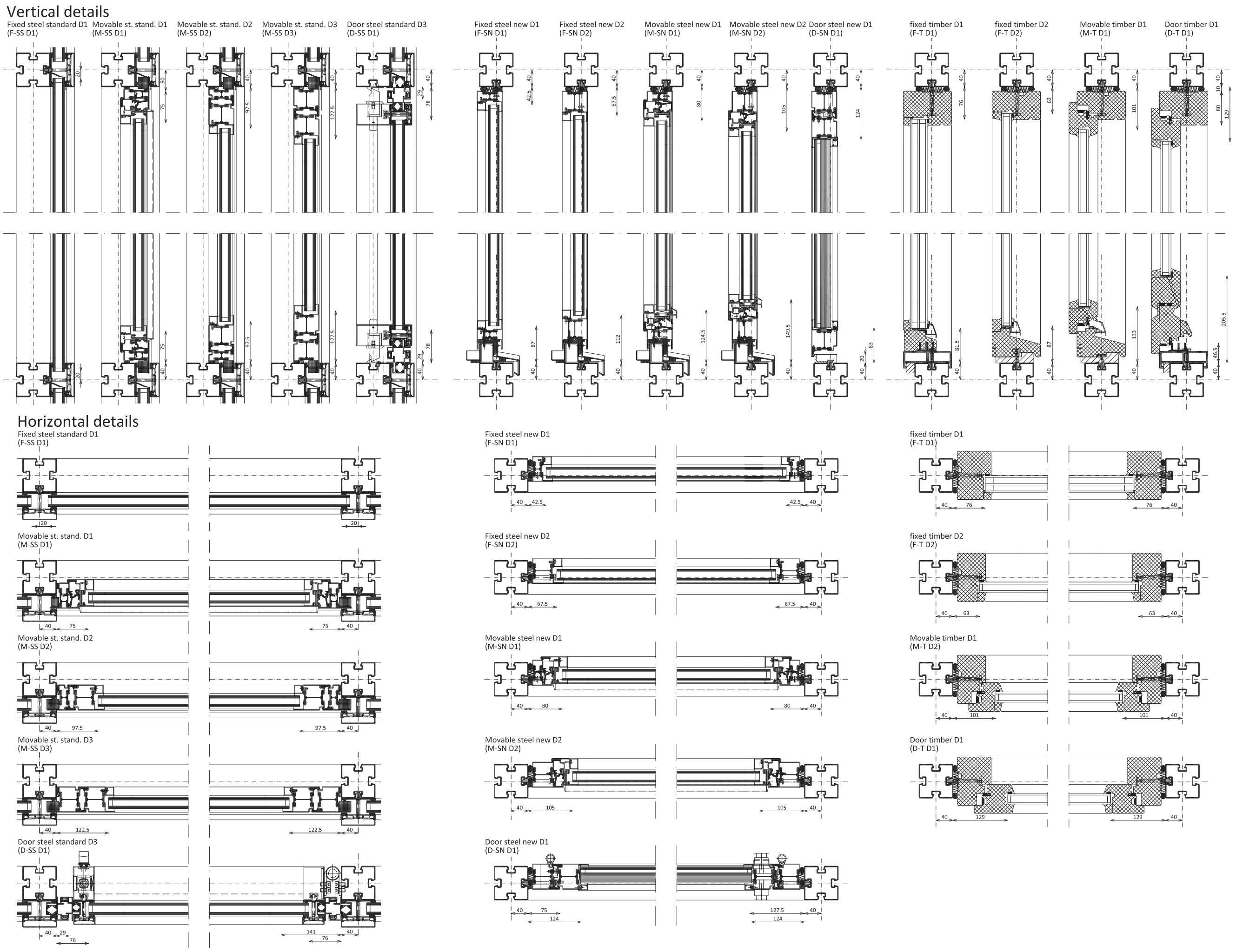

Figure 6: Product inventory with horizontal and vertical technical detailing of three types of curtain walls: standard steel curtain wall details (left), steel curtain wall with increased functionality (middle), and timber curtain wall with increased functionality (right) (technical details defined in collaboration with Kloeckner Metals ODS Nederland & Jansen AG).

Table 1: Window frame thicknesses and glass dimensions, based on the properties as described in the bottom.

Type of window	Frame thickness Horizontal	Frame thickness Vertical	Glass dimensions Width	Glass dimensions Height
D-T D1	270	350	850	2100
M-SS D3	270	250	850	2200
D-SN D1	270	200	850	2250
M-SN D2	220	250	900	2200
M-T D1	220	250	900	2200
M-SS D2	220	200	900	2250
M-SN D1	170	200	950	2250
F-SN D2	170	200	950	2250
D-SS D1	170	150	950	2300
F-T D1	170	150	950	2300
M-SS D1	170	150	950	2300
F-T D2	120	150	1000	2300
F-SN D1	70	150	1050	2300
F-SS D1	50	30	1150	2500

Used building properties

Floor to ceiling height	Grid dimension Horizontal	Grid dimension Vertical	Profile thickness Horizontal	Profile thickness Vertical
2450	1200	2530	80	80

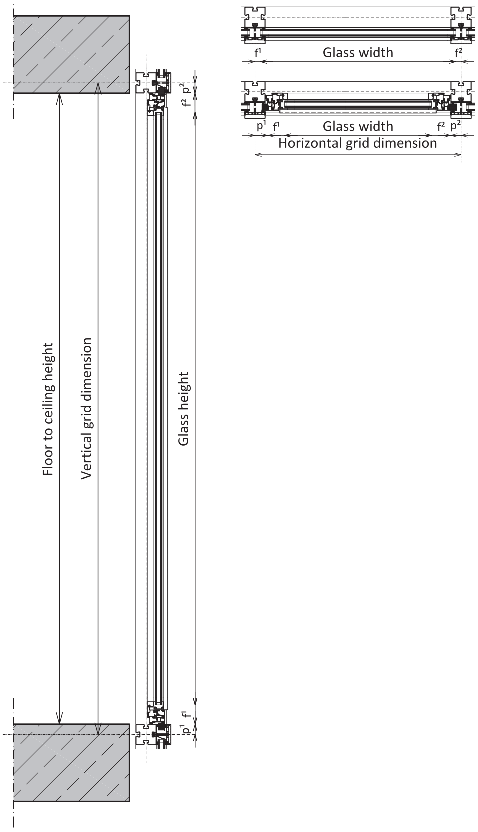

Figure 7: Glass dimension measurement.

[1] *The shown numbers at frame thickness and glass dimensions are rounded off, with a maximum allowable deviation of 35mm, to highlight matching sizes.*

one of the three functionalities (fixed window, movable windows, and doors) is represented, with a total of 14 different technical details. Finally, the product inventory is used to define the glass dimensions for each window type, as shown in table 1. As can be seen in table 1, the window types D-SS D1, F-T D1, M-SS D1 all have the same frame thickness, which allows the glass to be exchanged and reused between these three types and thus increases their application range.

Furthermore, the window types M-SN D1 and F-SN D2 can also be exchanged and reused with the previous three window types, when using a ventilation grill of 50mm, in order to match the dimension. The same accounts for the other windows that have a similar width and changing height up to 150mm. It can be stated that the glass dimensions of 950mm x 2250mm has with the use of a ventilation grill an application range of five types, making it the largest application range based on the limited product inventory.

As a side note, initially a curtain wall with structural glazing was also included in the product inventory. Although, since the glass used in a curtain wall as structural glazing is built up differently it was excluded from the product inventory, because the glass would be unable to be exchanged or reused with use of the other window frame types of the product inventory. This leaves the structural glazing to be only reusable in a similar situation and thus has a lower application range, in comparison to the other types shown in the product inventory.

2.4 Production standards and capacities

The final step takes in consideration the initial production process and its yield rate with its related cutting waste for different dimensions of glass windows, in order to complement to the whole life-cycle perspective. Based on this last step the designer is made aware of their design decisions and the related yield rate. This allows the designer to make a conscious decision between the application range and its yield rate.

To start it is important to understand the production process of glass windows. The production process of glass consists roughly of six distinct steps, namely: 1) melting and refining, 2) float bath, 3) coating, 4) annealing, 5) inspection, 6) cutting to order [22]. In the last step, cutting-to-order, an algorithm translates customers' requirements into patterns of cuts designed to minimize cutting waste.

The step cutting-to-order is considered to be the most important step, because this step determines the yield rate and its amount of cutting waste, based on the glass dimensions specified by the designer. The starting point of this step is the size of the un-cut glass coming out of the production line. The un-cut glass dimension is 6,0m x 3,21m [22, 23]. Based on these dimensions the cutting algorithm is reproduced by the authors to define the yield rate per glass dimension. The reproduced algorithm is based on the idea that one glass dimension is defined by the designer of which the algorithm determines the amount of glass windows that can be cut from one un-cut glass plate and calculates the yield rate of this particular dimension. In table 2, the yield rates are shown based on selected width and height of the glass window. By taking the factors that influence the application range into consideration, table 2 is limited to the glass dimensions that are considered to be relevant in this study. In table 2 it can be seen that the yield rate of glass windows drops enormously when using glass dimensions larger than 3210mm.

Table 2: Yield rate (percentage) per glass dimension. Representing the amount of glass, in percentage, which is used when cutting a plate of 6x3,21m in the specified size.

Length	Width														
	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
2050	85,2	81,4	76,6	80,9	85,2	78,2	82,0	85,7	63,9	66,5	69,2	71,8	74,5	77,2	79,8
2100	87,2	83,4	78,5	82,9	87,2	80,1	84,0	62,7	65,4	68,1	70,9	73,6	76,3	79,0	81,8
2150	89,3	85,4	80,4	84,8	89,3	82,0	61,4	64,2	67,0	69,8	72,6	75,4	78,1	80,9	83,7
2200	91,4	87,4	82,2	86,8	91,4	84,0	62,8	65,7	68,5	71,4	74,2	77,1	80,0	82,8	85,7
2250	84,1	89,4	84,1	88,8	81,8	85,9	64,3	67,2	70,1	73,0	75,9	78,9	81,8	84,7	70,1
2300	86,0	91,4	86,0	79,4	83,6	87,8	65,7	68,7	71,7	74,6	77,6	80,6	66,9	69,3	71,7
2350	87,9	93,3	76,9	81,1	85,4	89,7	67,1	70,2	73,2	76,3	63,4	65,9	68,3	70,8	73,2
2400	89,7	74,1	78,5	82,9	87,2	91,6	68,5	71,7	74,8	62,3	64,8	67,3	69,8	72,3	74,8
2450	91,6	75,7	80,1	84,6	89,0	93,5	70,0	73,1	76,3	63,6	66,1	68,7	71,2	73,8	76,3
2500	93,5	77,2	81,8	86,3	77,9	81,8	71,4	74,6	77,9	64,9	67,5	70,1	72,7	75,3	77,9
2550	95,3	78,8	71,5	75,5	79,4	83,4	72,8	76,1	79,4	66,2	68,8	71,5	74,1	76,8	79,4
2600	86,4	80,3	72,9	76,9	81,0	85,0	74,2	77,6	81,0	67,5	70,2	72,9	75,6	78,3	81,0
2650	88,1	81,9	74,3	78,4	82,6	86,7	75,7	79,1	82,6	68,8	71,5	74,3	77,1	79,8	82,6
2700	89,7	83,4	75,7	79,9	84,1	88,3	77,1	80,6	84,1	70,1	72,9	75,7	78,5	81,3	84,1
2750	91,4	85,0	77,1	81,4	85,7	90,0	78,5	82,1	85,7	71,4	74,2	77,1	80,0	82,8	85,7
2800	93,0	86,5	78,5	82,9	87,2	91,6	80,0	83,6	87,2	72,7	75,6	78,5	81,4	84,3	87,2
2850	94,7	88,0	79,9	84,3	88,8	93,2	81,4	85,1	88,8	74,0	76,9	79,9	82,9	85,8	88,8
2900	96,4	89,6	81,3	85,8	90,3	94,9	82,8	86,6	90,3	75,3	78,3	81,3	84,3	87,3	90,3
2950	98,0	91,1	82,7	87,3	91,9	96,5	84,2	88,1	91,9	76,6	79,6	82,7	85,8	88,8	91,9
3000	99,7	92,7	84,1	88,8	93,5	98,1	85,7	89,6	93,5	77,9	81,0	84,1	87,2	90,3	93,5
3050	88,7	94,2	85,5	90,3	95,0	83,1	87,1	91,1	95,0	79,2	82,3	85,5	88,7	91,8	95,0
3100	90,1	95,8	86,9	91,7	96,6	84,5	88,5	92,5	96,6	80,5	83,7	86,9	90,1	93,4	96,6
3150	91,6	97,3	88,3	93,2	98,1	85,9	90,0	94,0	98,1	81,8	85,0	88,3	91,6	94,9	98,1
3200	93,0	98,9	89,7	94,7	99,7	87,2	91,4	95,5	99,7	83,1	86,4	89,7	93,0	96,4	99,7
3210	93,3	99,2	90,0	95,0	100,0	87,5	91,7	95,8	100,0	83,3	86,7	90,0	93,3	96,7	100,0
3250	54,0	43,0	45,6	48,1	50,6	53,2	37,1	38,8	40,5	42,2	43,9	45,6	47,2	48,9	50,6
3300	54,8	43,7	46,3	48,8	51,4	54,0	37,7	39,4	41,1	42,8	44,5	46,3	48,0	49,7	51,4
3350	55,7	44,4	47,0	49,6	52,2	54,8	38,3	40,0	41,7	43,5	45,2	47,0	48,7	50,4	52,2

Legend

98-100%	90-95%	80-85%	60-70%
95-98%	85-90%	70-80%	0-60%

3 CASE STUDY REVERSIBLE EXTENSION UNIT

The reversible extension unit will be used as a case study and is derived based on the previously described methodology. The aim of the case study was to define a dimensional coordination that maximizes the reuse potential of their building products while keeping the whole life-cycle in mind, including initial production stage.

The reversible extension unit is part of the Green Transformable Building lab (GTB-lab), which is an experimental building acting as a showcase of Reversible Building Design and how a building can be developed as a material bank [24, 25]. The reversible extension unit is designed in such a way that it can easily be reconfigured, replaced and adapted to the changing needs and demands of the continuously changing users of the building. The versitality of the facade is enabled by the use of smart facade profiles that allows easy modification and additions of different functionalities.

The façade of the case study will be analyzed based on the methodology as described previously, in order to determine

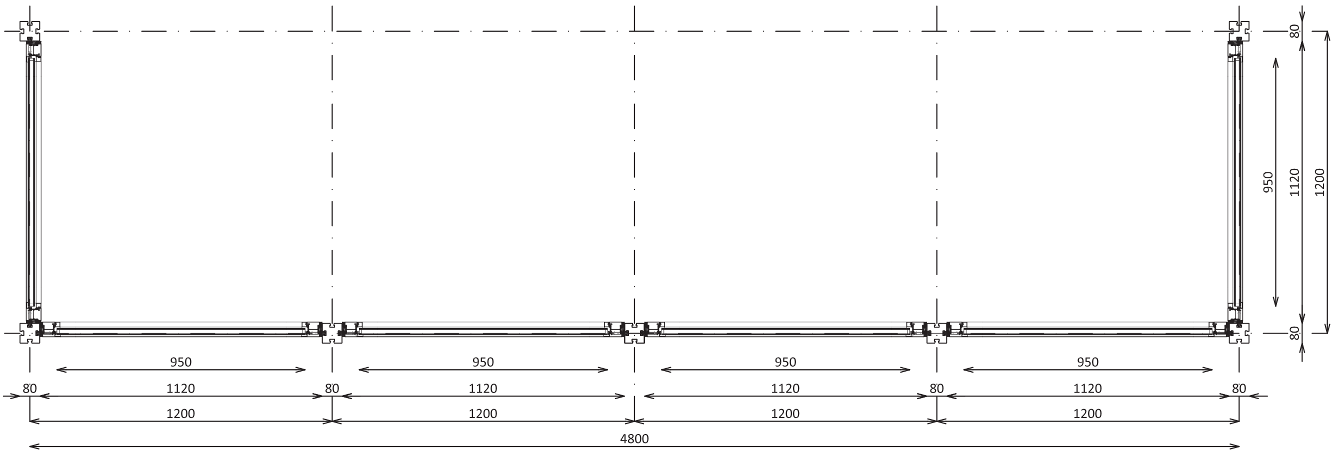

Figure 8: Floor plan reversible extension unit of the GTB-lab, with a steel curtain wall with improved functionality (type F-SN D2).

a dimensional coordination system that will increase the re-applicability and thus the reuse potential of its building products. Additionally, the production standards and capacities of the glass dimensions will be used to evaluate the yield rate of the derived dimensions.

As described in the methodology, the application range can be influenced based on the following factors: functional product requirements, horizontal beam arrangement scenarios, vertical post arrangement scenarios, tolerances and the product inventory. All these factors are taken into account in the design of the reversible extension unit (figure 8 and 9). In order to reveal the different application range and yield rates, multiple horizontal facade arrangement options are evaluated in table 3. The floor to ceiling height was chosen to be a total of 3,3m. In the current arrangement scenarios there has always been chosen to use an openable window as the top window and a fixed window for the larger bottom window.

Based on the amount of arrangement scenarios, product inventory options, functionalities the window dimension allow, the application range is being determined and rated from high to low in table 3. The determined values reveal that all yield rates are reasonably high, except for scenario three window size of 2600 x 950mm reveals a yield rate lower than 80%. Additionally, design option six was added to reveal the large impact a glass dimension larger than 3210mm in height or width has on the yield rate of these glass dimensions. Finally, design option one is being determined as the most preferred dimensional coordination, because it reveals the highest application range and a reasonably high yield rate.

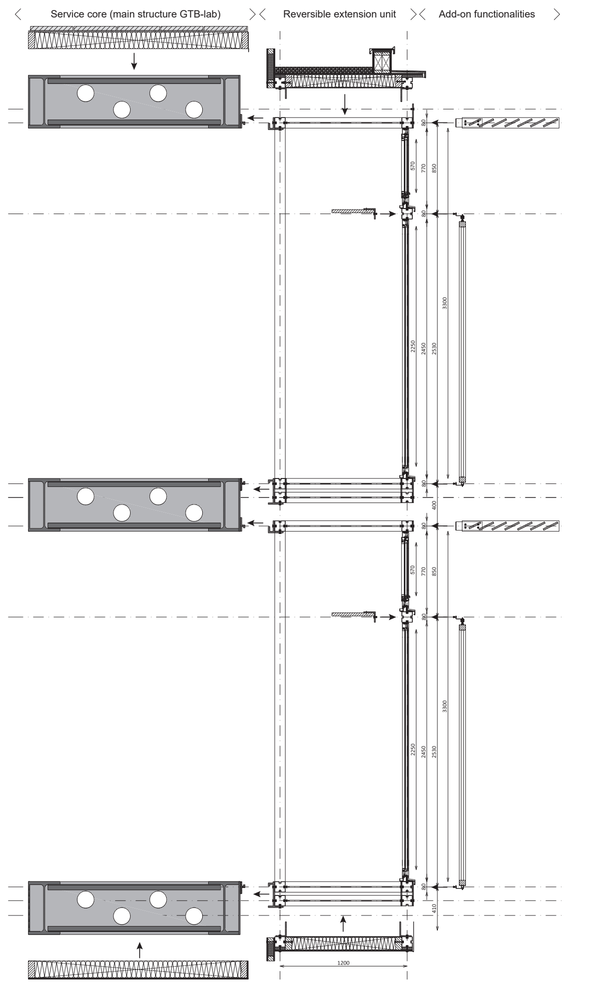

Figure 9: Exploded view, section reversible extension unit that will be connected to the service core of the GTB-lab.

Table 3: Six horizontal arrangement scenarios, all scenarios have a total floor to ceiling height of 3,3m divided in one or two glass windows.

Design option	Window type	Floor to ceiling height (Sum of)	Grid dimension Horizontal	Grid dimension Vertical	Glass dimensions Height	Glass dimensions width	Arrangement scenarios horizontal max = 5	Arrangement scenarios Vertical Max = 3	Product inventory options Max = 5	Functionalities Max = 3	Yield rate	Reuse potential – application range
1.	F-SN D2	**2450**	2530	1200	2250	950	5	3	5	3	88,8	High
	M-SN D1	850	850	1200	570	950	1	3	5	2	84,3	
2.	F-SN D2	**2600**	2680	1200	2400	950	4	3	5	3	82,9	High
	M-SN D1	700	700	1200	420	950	1	3	5	2	87,0	
3.	F-SN D2	**2800**	2880	1200	2600	950	3	3	5	3	76,9	Medium
	M-SN D1	500	500	1200	220	950	1	3	5	2	94,4	
4.	F-SN D2	**3000**	3080	1200	2800	950	2	3	5	3	82,9	Medium
	M-SN D1	300	300	1200	20	950	1	3	5	2	99,4	
5.	F-SN D2	**3300**	3380	1200	3100	950	1	3	5	3	91,7	Low
6.	F-SN D2	**3500**	3580	1200	3300	950	1	3	5	3	48,8	Low

** Window frame thickness is set at a thickness of 80mm vertical and 80mm horizontal.*

4 DISCUSSION & CONCLUSION

The aim of this paper was to define how the dimensional coordination of building products can increase their re-applicability, resulting in a higher reuse potential. Because a major barrier that restricts the re-applicability of reclaimed building products is the dimensional coordination and its compatibility to its new context. To define the dimensional coordination of building products that increase their reuse potential, a methodology was developed that provides guidance for designers in design decisions concerning the dimensional coordination of building products and evaluates the re-applicability of building products, in specific for facades. This is attained by taking a whole life-cycle perspective on the dimensional coordination, taking in consideration; functional product requirements, horizontal and vertical arrangement scenarios and configurations, direct- and indirect reuse in different contexts and production standards and capacities.

The methodology is based on the idea that it is better to make provisions that enable multiple applications to facilitate the unforeseen in its second and further use, than restricting it to one application.

To provide insight in the application of the methodology the development of the reversible extension unit as part of the Green Transformable Building lab was used as a case study. The green transformarble building lab is an experimental building as a proof of concept how Reversible Building Design enables the notion of a building as a material Bank. By taking a whole life perspective and the use of the methodology on the dimensioning of building products, the case study demonstrated that it allows the designer to make conscious decisions about the dimensioning of facades. With the result of the designer being able to increase the application range, allows conscious design decision regarding the yield rate of initial production and ultimately an increase of the reuse potential of the building products.

To increase the accuracy of the methodology at the reuse of glass windows it is seen that parameters such as glass thickness and their composition, glass coatings and insulation values should also be taken into account. Therefore, it is recommended to include these parameters in further development of the method, as they would influence the application range and thus the ease of re-application and the liklihood that the glass windows can and will be reused.

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BIM-based Integrated Project management for Reversible buildings

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Abstract
Due to the increasing need of non-conventional ways of construction to move the building sector towards a circular economy, reversible building design is now crucial to design buildings that have the ability of effective reuse of its systems, components or materials. Using these types of buildings could greatly lead to increasing the value of materials and reducing the wastes resulting from construction and deconstruction processes. This study discusses the integration of the trending technologies of building information modelling (BIM) and project management tools to give the decision makers and stakeholders realistic insights about the environmental and the economic impacts of reversible buildings. A case study of reusing different façade systems to construct a reversible model for a building module is investigated through analysing time and cost impacts of the deconstruction phase of the facade systems, testing phase, the transitional phase where the deconstructed components are prepared to be constructed in the building module and finally the construction of the building module. The analysis is then integrated with building information model to perform 4D and 5D simulations. Moreover, a probabilistic method of risk assessment using Monte Carlo simulation is then developed by giving probability distributions for uncertain activities instead of deterministic values. The results of the study illustrate how the current building information model and project management tools can be enhanced to be more efficient in Reversible buildings projects. Therefore, the approach of the study also helps in understanding the key factors in the case study affecting reversible buildings and their impacts.

Keywords:
Reversible Buildings, Building Information Modelling, Project Management, 5D Simulation, Risk Assessment.

1 INTRODUCTION

"Reversible Building are the buildings which can be easily deconstructed, or where parts can be removed and added easily without damaging the building or the products, components or materials. Reversible Building Design enables resource efficient repair, re-use and recovery of building materials, products and components since different layers like floors, windows, electric cords, ventilation, inner walls can be accessed without damaging other parts of the building and components can easily be removed or replaced" (BAMB) [1]. The flexibility of reusing or recycling its' components and minimizing the waste resulting from it is one of the main characteristics that differentiate these types of buildings. This concept which is the foundation of circular economy where the materials can sustain its value can greatly have a great impact in reducing the amount of waste in construction and the amount of carbon emissions resulting from the manufacture of construction materials. Since reversible buildings design is now crucial now to the construction industry, it is necessarily now to study the impact of using such concepts in terms of processes with determinate time, cost and risks to give the stakeholders and decision makers realistic insights about their impacts. One of the main challenges to achieve this is the availability of knowledge and information that can transfer from one phase to another taking into consideration that reversible building design is not limited to the initial design of buildings but it extends to deconstruction phase and studying the reuse options of the deconstructed parts and components.

That's why integrating Building Information Modelling (BIM) can be very beneficial for Design for Disassembly (DFD) and reversible building design. Building Information Model is defined by the original NBIMS document as: "The digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards" [2]. The main goal of this research is to investigate the integration of BIM tools with project management tools in reversible building design. After a literature review on the latest researches of BIM and project management for similar concepts to reversible buildings the methodology of the research will be discussed. In the next section, the work flow of the research which includes the formulation of the BIM model, preparing time and cost plan and probabilistic plan. Moreover, 4D and 5D simulations will be explained. At the end, the results and findings after implementing the research frame work on a case study will be discussed

2 LITERATURE REVIEW

Despite the rapid developments in researches related to BIM due to the great benefits of using BIM tools during the life cycle of buildings [3][4][5]. Yet, there are few of these tools that focus on the end of life considerations as deconstruction and waste management in terms of assessment or visual simulations. Akinade developed a mathematical model using BIM to assess deconstructability through evaluating a list of variables as the type of materials used, connections between elements, volume of materials and spacial position of elements [6]. A frame work was also proposed to evaluate different deconstruction strategies and their environmental and economic impacts [7] [9]. Several studies concentrated on the information needs to be provided by BIM models for deconstruction such as recyclability, reusability, structural, geographic, time and cost attributes … Moreover, many studies are done to include required information in BIM standards. COBie is one of these documents that targets more efficient BIM models for operation, maintenance and handing over [2] [8]. Yet, it is not enough for end-of-life scenarios as deconstruction and reversibility as it lacks some important information about structural elements and connections between elements. On the other hand, by investigating the project planning techniques implemented specially for deconstruction of buildings it was found that most of the techniques used depends on deterministic time and cost planning Moreover, most of them neglect risks and uncertainties.

3 RESEARCH METHODOLOGY

The research methodology is based on understanding each of the BIM tools and its capabilities in similar concepts, project management approaches in similar projects and developing new framework for integrating BIM and project management tools for reversible buildings. The research is based on an empirical approach on a case study which combines qualitative and quantitative data analysis. The qualitative data will depend on interviews and questionnaires from different disciplines to investigate the design and construction options which will be applied during the research that need experience in each discipline. On the other side, the quantitative data will be greatly based on using measurements and simulations using computerized tools. The process of collecting data about the time and cost of all the phases of the research was done on several stages and with several assumptions to ensure working with the most realistic information about the processes. Some studies about the connections between elements of the façade and their relationship with all other elements of the building through detailed sections of the façade systems. Data was collected through interviews of some construction engineers to estimate the durations of tasks on very high level of detail specially tasks of disassembly of façade timber frame ex. Removing nails of the timber wooden frame. Moreover, the costs of different materials, labour and equipment needed were estimated using similar projects done by the company.

4 BIM-BASED PROJECT MANAGEMENT WORK FLOW

This section presents the study that was performed on integrating the trending technologies of building information modelling (BIM) and project management tools to ensure an integrated project delivery for reversible buildings. This study was performed on four different stages where each stage is analysed solely and integrally with the other stages to reach the best approach in each

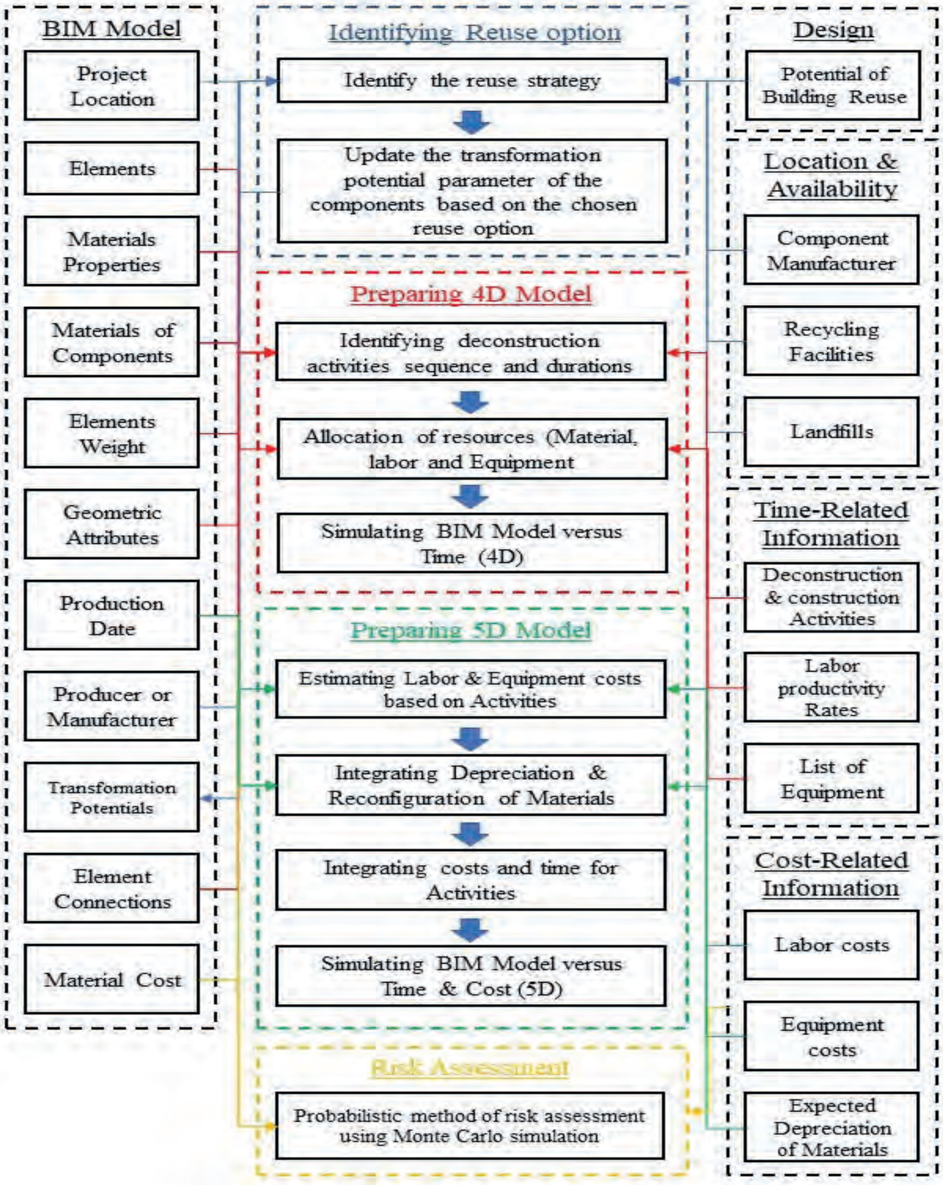

Figure 1: Research work flow

stage to ensure maximum integrity. The first stage discusses the formulation of BIM model that includes the modelling approaches that ensure better retrieve of information. Moreover, Finding the required information that should be embedded in the BIM model was also essential in this stage. The second stage discusses the processes of reversible buildings concept and transforming the different reuse options into tangible activities with deterministic durations and cost impact through scheduling using the critical path method. The third stage examines dealing with uncertainties in reversible buildings concepts through risk assessment using Monte Carlo simulation by giving probability distributions for uncertain activities instead of deterministic values. The last stage's main objective is integrating the parametric model with the deterministic and the probabilistic study to implement 4D and 5D simulation.

4.1 Formulation of Building Information Model

Based on the proposed information that is required to develop a useful BIM model for studying the process of deconstruction, reuse and reconstruction, several modelling approaches were tested to ensure the best retrieve of the required information during the study as stated in table 1.

Yet the information needed in the Building Information Model for studying reversible buildings can be classified into the following categories: -

	Modeling components directly in the Main model	Using Families using components	Using nested families
Advantages	• Better visualization for building components • Ability to view components parameters • Components materials and volumes can be easily scheduled in quantity takeoffs	• Lower modeling effort • Smaller model size	• Better visualization for building components • Ability to view components parameters • Components materials and volumes can be easily scheduled in quantity takeoffs
Disadvantages	• Higher modeling effort • Very Large model size	• Information about components of the families can't be easily attracted	• Higher modeling effort but it is done once • Large model size

Table 1: Comparison between different modelling approaches

1. **General Attributes**: - these attributes provide insights about the family and type of the element, materials of elements and manufacturer
2. **Geometric Attributes**: - these attributes provide insights about the dimension of the elements, thickness, area of elements, weights and volumes. These attributes are important to study the feasibility of reuse options in terms of handling, transportation and disassembly
3. **Structural Attributes**: - these attributes are very important to identify the reuse feasibility of elements specially if it will be reused as a structural element.
4. **Geographic Attributes**: - these attributes can be useful to study different options in terms of transportation to reuse facilities or recycling facilities or landfills.
5. **Condition-based Attributes**: - these attributes can include the year of assembly or manufacture or construction of the element and its initial cost. These attributes give insights about the condition of the element which is necessary to study the depreciation of elements and materials.
6. **Identification Attributes**: - these attributes include the IDs of the element, assembly or disassembly tags …. These attributes are necessary for mapping information from different disciplines and the interoperability between different platforms.
7. **Connections attributes**: - these attributes that can provide information about the connections between elements. The importance of this information is that it gives realistic vision on the process of construction or deconstruction, the feasibility of reuse and the risks undergoing these processes.

4.2 Deterministic Plan

The aim of the study is to investigate the whole process of the transformation and studying of the reuse options in terms of time and cost. That's why the planning and estimation were categorized under four phases. Operational planning using critical path method [11] was implemented through the study after using the BIM model to extract the needed information in this stage such as materials and components types, quantities, weight, transformation potential and the type of connections between elements which was easily exported as a schedule from BIM modelling tool. A detailed time and cost plan is then prepared through understanding the activities, durations and sequence. The next step is the allocation of the resources by planning the needed labour, materials and equipment to perform each task and the cost requirements of each task. Starting with the work breakdown structure we can break down reversible buildings projects into four consecutive phases. In the first phase (Deconstruction Phase) the target is to remove the connections between elements to reuse these elements in the new design or recycle it or even demolish it. The next phase (Inspection and testing phase) is testing and checking the condition of the elements after separating it from the other elements. The next phase which is the (Transitional Phase), the elements or components undergo different operations to be ready for the next state either to demolish it, recycle it or reuse it in the new design.

The last phase (Construction Phase) is the phase where the transitioned systems, elements or components are reused along with the new systems, elements or components that will be added in the new design.

In the first stage, it is found that one of the key factors that influence the processes of deconstruction is the connection between elements which can significantly affect the whole life cycle of reversible buildings from the conceptual design phase passing by the design phases, construction phase and even the operation and maintenance of these buildings [12]. These connections can have great implications on the project management

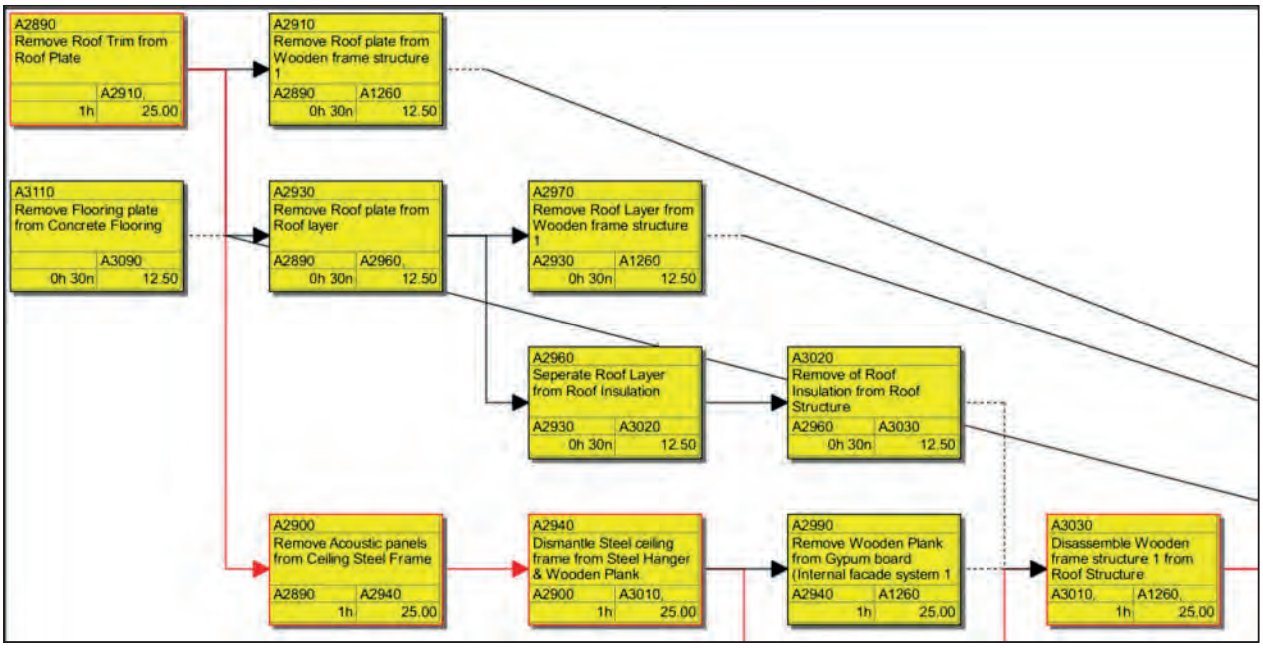

Figure 2: Disassembly Sequence

starting with its needed time and resources to remove these connections between elements, the cost of materials and equipment used to deal with these connections and the risks associated with these connections as using un experienced labour to disassemble these connections or failure of the materials due to difficulty in dealing with the connection as shown in figure 2. That's why understanding the type of connections between elements and the flexibility of these connections from highly flexible connections to highly fixed connection (Durmisevic, 2006) is the basic start by transforming this connections into tangible activities with determinate durations, resources and cost.

The second stage deals with the inspection and testing which is crucial in this type of projects due to the uncertainty about the condition of materials and components to detect whether these elements can be used again and the activities needed to be done for them to be reused again. This phase should be included in the time and cost plan as it can be time consuming and costly activities.

The next stage investigates the operations that is performed on the components as the subtraction of certain elements from the component, the reconfiguration of elements in a component, the substitution of some elements with another or the addition of new elements in a component. Moreover, some operations can be done on the element level such as the deformation or subtraction or addition on elements or destructive operations to extract materials for recycling. All these operations along with the transportation of the systems, elements or components is included in this phase.

The last stage is the new construction using the elements and components that was reused from the previous stages. Moreover, more new materials are expected to be added to the new building which should be taken into consideration.

By gathering these stages all together stake holders and decision makers can have a complete plan about the different reuse options of any building that starts with the disassembly of the components

4.3 Probabilistic Plan

One of the main challenges in reversible building design is dealing with uncertainties. These concepts mainly depend on the deconstruction process in a way that ensure the most efficient retrieve of the systems, elements and materials with the least damages to be reused again. Since these concepts are not very familiar in construction projects now, there is a difficulty to estimate deterministic information about the productivity rates of these activities, the condition of the materials and components extracted due to the huge amount of risks and uncertainties when dealing with such projects. That's why it is found that dealing with such projects neglects the risks of failure of some deconstruction tasks, the damage of fragile materials which is more probable to happen, the probabilistic productivity rates of labours due to not having enough experience with disassembly. All these factors greatly affect the insight of the project to the decision makers.

That's why the information in this research is collected in a way that is based on the probabilistic approach as most of these information is collected through personal estimations from experts who always give probabilistic ranges for these estimations due to uncertainty. So, the time and cost information gathered from the deterministic plan which is the most likely to happen is reformulated through including the minimum and maximum ranges to give a probabilistic more realistic indication of the processes. Moreover, testing activities is given a probability for success or failure which is followed by plan B in case of testing failure. For example, if an element failed to be used again, another plan to buy the new material of this element to be used.

4.4 4D and 5D Simulation

In this phase, the time and cost plan are extracted as activities and then linked to the BIM model through the identification ID's implemented in the model. Each phase in the plan should be visualised with a different colour. Elements which needs to be deconstructed is visualized as two connecting elements for each activity which gives the indication of the removal of the connection between these elements. The time and cost simulation along with

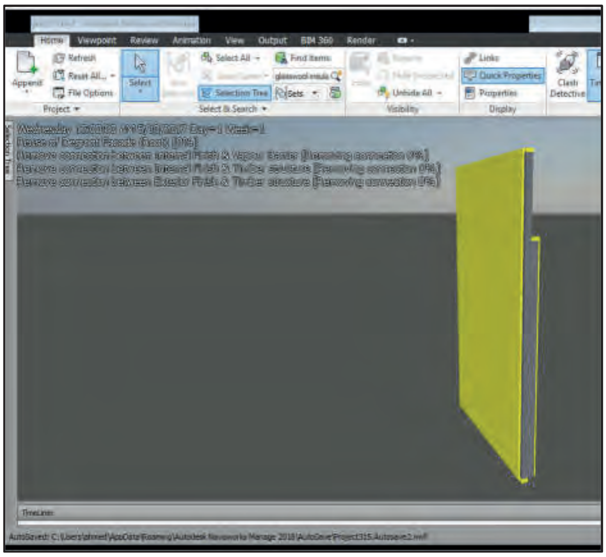

Figure 3: 5D Simulation for disassembly of a wooden facade

visualizing the sequence of work throughout the project is important to give the decision makers the time and cost at any instant along the project as shown in figure 3.

5 CASE STUDY

The case study aims to study the time and cost of processes of reuse options for different façade systems. Four façade systems as shown in figure 4 and an extrusion profile of a metal beam that can be cut into any length needed were chosen to be reused in new designed systems in the case study. The chosen facades in the case study were two typical closed timber façade systems. One of these facades needs to be used as one whole system and the other one can be disassembled into elements to reused separately. One more façade system which is an open timber frame façade that is meant to be disassembled into elements to be reused separately too. Moreover, a metal façade system (soap frame) will be used as disassembled elements or as a whole system beside a metal beam from the same company with unlimited length to be cut based on the needed length of beams in the new flexible design that can be easily reconfigured into a new module design.

5.1 Reuse options

The new design that was given in the case study was developed through many workshops that took place in different countries and included different engineers with different backgrounds (Architects - Civil engineers – Construction management engineers – Industrial engineers). The main purpose of the workshops was to develop different designs for building modules that take into consideration multi-criteria which included the maximum possible reuse of the façade elements with least waste, architectural quality, structural quality and design flexibility. Different designs were refined through consequent workshops until the best design were chosen.

5.2 Frame work implementation

The purpose of the implementation of the case study is to estimate the duration and cost of reusing the elements and the components of the façade systems and some extra materials to build a new building module. First, a 3D model of the façade systems and reused elements was formulated through different modelling techniques as stated in table 1. A detailed deterministic time schedule was then developed including the disassembly of the wooden frames which took about 50 working hours only for the disassembly of the frame from the building. The disassembly plan was done on a very high detail to be compatible with the BIM model in the 4D and 5D simulation. Then a probabilistic plan was implemented to know the degree of the uncertainty and the percentages of risk of overrun for the design which was found to be 15% probable increase in the budgeted total cost due to probable increase in the durations of disassembly due to using unskilled labour or risk of failure of the wooden studs during disassembly.

Figure 4: Open and Closed wooden frames

6 RESULTS AND DISCUSSION

This section is going to discuss the major findings, recommendations, challenges and future work. To summarize:

- It was found that labour in these kind of projects is the main driving factor that influence the time & cost of the projects. It was found during the case study that labour costs formed more than 70% of the total costs of the whole process as shown in figure 5. Since labours are the main driving factor, most costly and risky, some risk mitigation plans can be considered for example: Using high skilled labour specially in disassembly even it is more expensive but investing in this can reduce time and cost of the activities. Moreover, it mitigates the risk of failure of materials or disassembly errors. Documenting the assembly of the projects and up normal events that happened in construction to be a reference for labours while deconstruction.
- Improving project management tools for better and direct integration with BIM software. As there is always a need for a third platform to integrate between BIM models and these tools. There is no direct link between them in most of software on market specially for risk analysis tools.
- More research should be done on including and extracting all connections between elements from BIM models. As it is a key factor for the end-of-life scenarios, DFD and reversible buildings design.

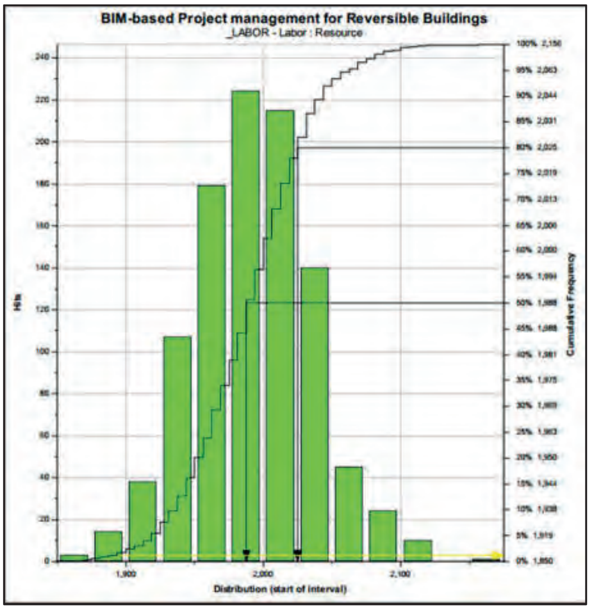

Figure 5: Probabilistic labour cost

CONCLUSION

Regarding the need for the reversible buildings design which will lead to the increase of the value of materials and reduction of wastes in construction. More concern should be directed to studying the impacts of using such concepts. As discussed throughout the paper BIM technology can be effectively used along with project management tools to provide insights about the time and cost impact of reusing the materials and components of buildings. The study which investigated some of the still needed information in BIM models and compared between different modelling approaches was followed by an examining scheduling and planning techniques that best suits the phases of the reversibility and the major risks facing it through the probabilistic approach. Moreover, BIM model, time and cost plans were integrated together to implement 4D and 5D simulations. All these steps which was applied on a case study lead to some findings as key factors affecting reversibility as labours and challenges such as the integration of BIM with project management tools.

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Design and Energy Analysis of Buildings Using BIM

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Abstract
The following article is a case study of the “Austrian house”, a sustainable building. The case study will present how such building can entirely be designed in Revit Architecture, software by Autodesk based on BIM. Furthermore, as one of the options Walter is offering to our clients is the energy analysis of the building by using Autodesk software called Green Building Studio (GBS). This case study presents the results obtained by applying the sustainable principles and using GBS and how they can be used in order to optimize the future building early in the design process.

Keywords:
Revit, BIM, Green Building Studio, energy analysis, design process

1 INTRODUCTION

Usual practice in building design is for the architects to first develop set of drawings and documents. This documentation is then taken over by structural, mechanical and electrical engineers who design their part of the project. And lastly, all of this material is then used to develop the energy analysis of the building. This process is time consuming and often times there is a lack of direct communication between different participants in the design process. Designing becomes an iterative/repetitive process and can take a lot of time, making the entire process costly. In addition to this, valuable information is being lost since it is stored in different locations and the investor or facility manager at the end never receives full information about the building. Additionally, this usual practice may force an aesthetic feature without considering performance impacts and it may not provide performance measurement/evaluation of a certain design solution [1].

The Building Information Modelling (BIM) is a systematic process of the management and dissemination of holistic information generated throughout building design development and operation [2]. The advantages of BIM design are many. BIM is a set of interrelating strategies, procedures and skills that creates a framework to monitor the vital building design and display data in digital layout throughout the building’s life-cycle [3]. Since one file is being used throughout the entire lifecycle of the building, no information is being lost and the building model becomes one large encyclopedia of information that can be easily accessed. There are no collisions in works, which is often the case in traditional design processes. Now, all the engineers work on one file and there is a clear digital communication between different participants in the project, which avoids mistakes. This saves time and money. In addition to this, by using BIM one can foresee and envisage the likely errors in design and subsequently adjust the designs early in order to reduce the possibility of project failure [4].

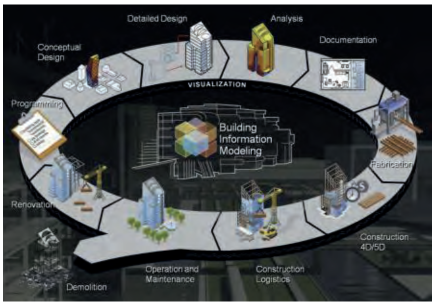

Figure 1: BIM throughout the life-cycle of the building

In order to evaluate and optimize the building performance, different analysis cycles by simulations should be part of an integrated design process, which is referred to as performance-based design method [1]. This enables the designers to conduct the simulations in order to validate the performance, improve and select the optimal design.

In particular, performance-based design method uses the software to predict the energy use of the building. It analyses different energy and mass flows inside the building in order to predict its future performance.

One such software is an Autodesk Green Building Studio (GBS). GBS is a flexible cloud-based service that allows the engineer to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality earlier in the design process [5]. It is compatible with Autodesk Revit Architecture, tool that allows the intelligent model-based process to plan, design, construct, and manage buildings and infrastructure [5]. Furthermore, GBS provides the ease of iterations between conceptualization and calculation stage [6]. BIM tools, such as GBS, have the ability to provide users with an opportunity to explore different energy saving alternatives at the early design stage by avoiding the time-consuming process of reentering all the building geometry and supporting information necessary for a complete energy analysis [7].

Walter is a company located in Sarajevo, Bosnia and Herzegovina, that offers solutions to building industry based on BIM technology. Founded in 2011, Walter employs over 70 highly-skilled individuals. Walter's team is comprised of developers, architects, structural, mechanical and electrical engineers and designers.

This paper presents a case study of the "Austrian house", designed in Walter in order to participate in the competition. The entire building is designed in Revit. Throughout the design process, GBS was continuously used in order to conduct the energy analysis of the building and optimize the future building early in the design process. Solar passive design techniques were implemented in order to minimize load on conventional systems. The proposal is made to use solar photovoltaic system on the roof as a renewable energy resource and to meet part of the load, but since this project is in its preliminary stage, no further calculations are made for the active systems.

BIM is a new topic in this region of the world and no such analysis has been made for buildings in Sarajevo. One of the goals of this paper is to convince the local participants in the construction process to start using tools like this in order to achieve energy efficient buildings.

2 DESIGN TOOLS AND ANALYSIS METHODS

2.1 The building design

Municipality Center in Sarajevo organized a public competition for design of „Austrian house" [8]. „Austrian house", as proposed in this paper, is a functional, innovative, original, practical, economical, healthy and pleasant urban space and is integral of park in which it is located. „Austrian house" is almost zero building mostly built of natural, local materials. This contributes to protection of planet Earth and encourages development of local economy while respecting the principles of circular economy.

Figure 2: "Austrian house"

Urban space is a platform for all human activity, creativity and occupation. People spend about 80% of their time inside. Often times, the common construction technologies don't place a human and his/her senses into focus, but rather economy and practicality. Synthetic materials are often used; they can be toxic and cold and lead to many diseases, such as allergies, depression, insomnia, anxiety, etc. Architecture is a science and art that has to have a holistic approach and give answers to many questions, not only practical, functional and economical, but environmental, social and health.

One of the goals of the competition was to create a space for healthy growing-up and education of the youth. The beginning of this is in construction of a healthy and educational building. The main lessons this house has to transfer to its future users are the following:

Urban space should be healthy and part of the nature

The goal was to create a space that is a logical continuation of the park in which it is located. Park combines nature and playground, this is why „Austrian house" exudes with greenery and playfulness. Building communicates and is connected with park on several levels.

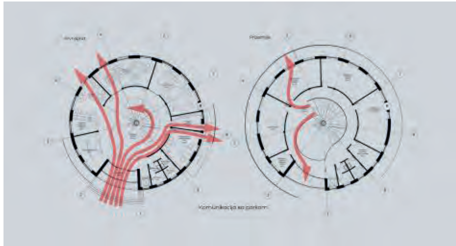

Figure 3: Communication with the park

Most of the building is constructed of natural materials. This creates even stronger feeling of belonging to nature. Structure is made out of wood, exterior walls of straw-bales covered with earthen plasters. Ground floor is made of earth in repute to Martin Rauh and his floor in Berlin chapel, while first floor is wooden. Roof is green. Friedensreich Hundertwasser considered trees and plants in his buildings as the most economical inhabitants. They pay the rent by improving the air quality in the building and in the city (greenery directly decreases the heat island effects) [9].

Biomimicry is reflected in circular layout surrounded by wooden structural elements and straw walls with central wooden staircase and gallery designed in golden mean. All of this reminds of wood trunk. Additional, central column that carries the perforated metal ceiling reminds of a tree making the visitor feel like he/she is protected from the sun by thick treetop.

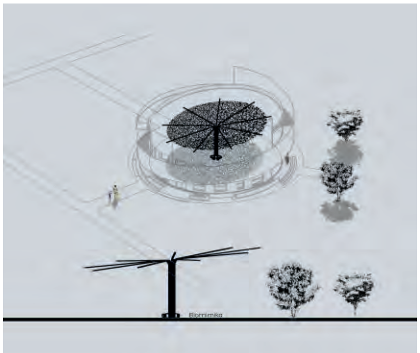

Figure 4: Biomimicry

Urban space should be functional, practical, sensible and pleasant. Its originality and innovation should inspire.

The main entrance leads the visitor into central exhibit space. Inside, the visitor is permeated with warmth of natural materials and silence they make, sun rays and shadows made by perforated suspended ceiling below the glass portion of the roof and carefully positioned plants. The visitor explores the ground floor exhibit space, wooden staircase (perfect for sitting) and gallery exhibit space. For visitors with special needs, the glass elevator is designed which enables sightseeing from the height of the total exhibit space as well as park on the outside. The entire exhibit space can also serve as amphitheater.

Figure 5: Interior exhibit space

Behind the exhibit space, the rooms are positioned respecting the need for appropriate light, silence and communication with exterior.

Structurally, the building is simple and logical both geometry wise as well as with the material selection. Wooden columns radially placed in combination with laminated beams carry the entire space. They transfer the load to reinforced concrete strip foundation .

One of the biggest threats to the straw buildings is moisture, so they need to be protected from rainfall and capillary action. This is why the entire building is raised above the ground. Additionally, upper part of the building, above the peripheral ramp is wooden facade, while the final layer of the lower part faced below the ramp is earth/lime plaster. Plinth is made of stone.

Originality and innovation is revealed through many aspects: material selection, central staircase, peripheral ramp that leads to green roof with the perforated fence which is „drilled“ with dancing children.

Architecture is sustainable and it encourages local economy

Sustainable architecture exploits site conditions, local construction materials, renewable energy resources, it spends water, air, earth and energy rationally and creates minimum maintenance, renovation, recycling and reuse of the building and location in the future.

The building is positioned to the South for solar heating during the winter. Earth ground floor is a thermal mass, which acts as natural stove. It is ideal for children's play and perfectly healthy (children should be in contact with earth as much as possible). Straw walls are perfect insulator. Additional insulation is placed in the floor and on the roof in order to create conditions for minimum energy spending and nearly zero house. Peripheral ramp saves the building from overheating during the summer.

63% of the territory of Bosnia and Herzegovina is covered with forest [10]. Energy necessary for construction, maintenance and recycling of wooden houses is the lowest when compared to all other construction materials [9]. Every cubic meter of used wood contributes to CO2 decrease in the atmosphere by 2 tons [11]. It is the most beautiful and warm construction material. These are just few reasons why wood is used in this building.

Bosnia and Herzegovina produces 200,000 tons of straw annually which can be used in the construction industry [9]. Today, most of this straw is waste. This means that 10,000 passive houses could be constructed annually in Bosnia and Herzegovina [9]. Straw buildings are referred to as „factor 10“, which means that they spend 10 times less energy than conventional houses.

The building is smartly open with glass portals in order to maximize the use of natural lighting. To make the space playful and additionally illuminate, central portion of the green roof is glazed and then covered with perforated metal from the inside. These perforations create the light and shadow game on the ground earth floor and wooden gallery floor. Additionally, they protect from overheating during the summer.

Central glazed roof can partially be open in order to ensure the natural ventilation (stack ventilation). Additionally, ventilation with recuperation is proposed in order to meet the guidelines for passive houses and ensure the clean, warm or cold air supply into the building. Green roof additionally saves energy.

The building is almost zero. Necessary energy is produced by diffuse solar panels placed on the roof.

Figure 6: Passive and active design

Architecture can only be sustainable if the construction takes over the circular process of planning instead of linear process that is often used today [12]. This means that the building configuration needs to be designed to ensure the disassembling. In respect to this, „Austrian house“ is designed to be somewhat flexible. Most of the interior partitions can be moved and space shaped in accordance to new trends. Since most of the construction materials are natural, they can be recycled down to compost.

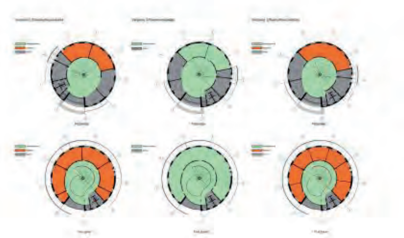

Figure 7: Flexibility of interior space

Construction costs of the houses built of natural materials are even cheaper than of the traditional building techniques and materials [13]. The biggest savings of this building are in its maintenance.

2.2 Analysis method

To develop building energy simulation in GBS, the following procedures are adopted:

- Developing a 3D BIM solid model using Autodesk Revit Architecture while respecting solar sustainable passive design techniques,
- Set the design parameters for different options analyzed in Autodesk GBS (refer to table below),
- Run the simulation in Autodesk GBS and evaluate the results.

In short, once when the building was initially designed in Revit Architecture, GBS was used in order to conduct the energy analysis. The building is virtually placed in Sarajevo. In addition to this and in order to present how this software can be used in the analysis, this building is first analyzed with walls made of straw, like it was in the design. Later on, it was analyzed for the walls made of brick with Styrofoam insulation with only double windows. And lastly, since it was discovered by the GBS analysis that most of the energy gets wasted through the windows, one building was made with half of the windows as original one, while the other one with half of the windows plus no window roof simply to demonstrate the savings. All these results are then evaluated in order to reach to valuable conclusions about the building and to come up with the final design which is the most effective when it comes to energy saving.

Location parameter	Sarajevo
Design parameters	
Building type 1	Straw-bale with earth/lime plaster, portion of the façade wooden, triple windows
Building type 2	Brick with Styrofoam insulation and cement plaster, double windows
Building type 3	Straw-bale with earth/lime plaster, portion of the facade wooden, triple windows, but only half of them as compared to „Building type 1“
Building type 4	Straw-bale with earth/lime plaster, portion of the facade wooden, triple windows, half of the windows as compared to “Building type 1” and no roof window

Table 1: Location and design parameters for the energy analysis

3 ENERGY ANALYSIS AND RESULTS

After the analysis, GBS produces the report, which contains lots of information, such as energy use intensity, renewable energy potential, annual carbon emissions, monthly heating and cooling loads, annual wind rose, humidity etc.

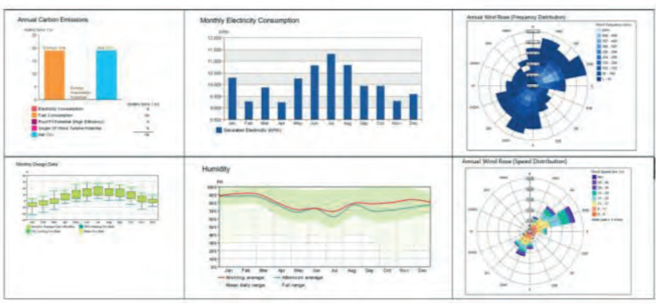

Figure 8: Examples of the information obtained by GBS

For presentation purposes, only monthly heating and cooling loads are compared.

The following are the monthly heating and cooling loads for the Building type 1:

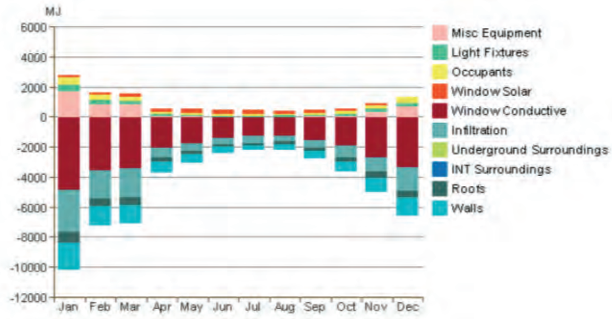

Figure 9: Monthly heating load / Building type 1

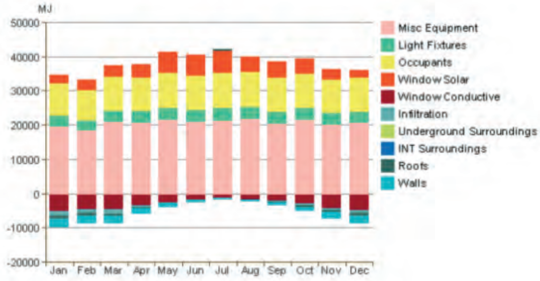

Figure 10: Monthly cooling load / Buidling type 1

As it can be seen, the highest heting load is around 10000 MJ for the month of January, while the maximum cooling load is 42000MJ for the month of July.

When compared to Building type 2 (refer to figure 11 and 12), it is visible that the Building type 1 is much more energy efficient: maximum heating load for the month of January is 15400 MJ and maximum cooling load for the month of July is 50000 MJ for Building type 2.

As it can be seen, the heating loads are above 10000 MJ. This is far from nearly zero or low energy building requirements. One reason is that GBS has predefined HVAC systems that can be analysed and there are not that many opetions [14]. Based on these systems, GBS generates energy data that is far from the realistic one. This is one of the weaknesses that GBS has. It would be much better if there was an option that no HVAC systems are to be used in the analysis or even better if the engineer can create his/her own HVAC system for the building. This is why the best use of GBS is for comparison purposes and for decision making in the early process of design.

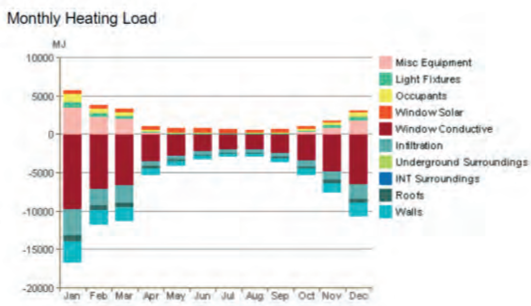

Figure 11: Monthly heating load / Building type 2

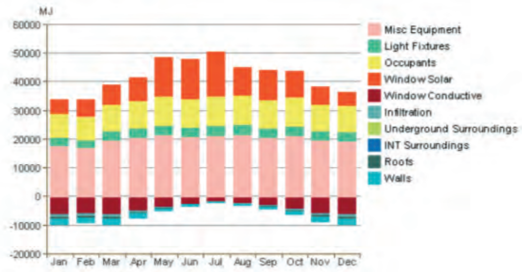

Figure 12: Monthly cooling load / Building type 2

The Building type 1 has lots of windows and it is visible on figures 8 and 9 that the windows loose the most energy. This is why two more modifications have been made in order to see if additional saving can be reached. Building type 3 has half of the windows when compared to Building type 1, while Building type 4 has half of the windows and no roof window and the following are the summary of all the results:

Building type no.	Max monthly heating load (MJ)	Max monthly cooling load (MJ)
1	10000	42000
2	15400	50000
3	6100	40000
4	4100	38000

Table 2: Maximum monthly heating and cooling loads for the differenty building types

As it can be seen, considerable savings could be made if roof window would be removed and number of windows in general decreased. The reason why the original building had the roof window is to provide extra light in the central protion and to assist with heating of the building. However, there is planty of natural daylight that comes trhough the windows (even if the number is decreased), so it would be quite resonable to implement this change in the original project.

4 CONCLUSIONS

Energy analysis is typically performed after the architectural/engineering design and related documents have been produced. This process does not consider the integration between the design and energy analysis processes during early stages and leads to an inefficient way of backtracking to modify the design in order to achieve a set of performance criteria [15].

BIM system can contribute to collaboration and communication between different participants of the project in early design phase to effectively provide the economic future building in every aspect. This paper concretely deals with collaboration between sustainability and passive design in architecture and energy analysis. It demonstrated the ease and the advantages of designing and analyzing when in particular Autodesk Revit Architecture and GBS are used. It showed how early in design stage, the designer can make selection of appropriate building elements in order to achieve greater energy savings during the facility management of the building.

However, there are some problems in using BIM for sustainable design that need to be overcome. Using BIM for energy analysis currently relies on estimated values for loads, air flows and heat transfer simulations which may result in unreliable estimates [16]. This can be resolved by using real data gathered from buildings. And this is why GBS is good for comparison purposes; just to see which building elements to use in the design, but not for final energy calculations. In addition to this, there is a slow uptake in adoption of new technologies throughout the AEC sector. Using BIM requires significant training and there are huge costs associated with purchasing, licensing and training. This can be resolved by hiring companies such as Walter that specialize in this type of work and can provide clients with fast and effective design solutions.

5 FUTURE WORK

This paper presents the work at the initial design of the building (architectural phase). Future work could involve the work of structural/mechanical/electrical engineers and the analysis of active design systems and how this can be altered in order to achieve greater energy savings.

6 ACKNOWLEDGMENTS

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BIM is Green

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Abstract
The use of BIM is on the rise in AEC industry, mainly in design and construction, facilitating green design and sustainability, but still far from reaching its peak. There are great unused potentials and benefits of BIM use in facility management. This paper will provide an overview of the advantages of BIM in synergy with green design on the example of projects from Walter's company portfolio. One of the goals of this paper is to raise the awareness on the fact that green design can accelerate BIM adoption.

Keywords:
BIM, green design, facility management, Revit

1 INTRODUCTION

Green design is continuously transforming AEC industry in its aim of achieving greater level of sustainability. Recognizing its benefits, industry practitioners are progressively embracing green design, realising that BIM is a game-changer on this journey.

1.1 Building Information Modelling

Building Information Modelling is a process of development of a digital information model of a building that is used by all the stakeholders in the building's lifecycle. By the use of technology and digital information, it improves AEC processes, their outcomes and building operation. It is a key facilitator of an improved decision-making process during the whole lifecycle [1].

Although it cannot be considered new, it represents a disruptive technology in the AEC industry, which is why it is being slowly accepted and implemented. Its full benefits are yet to be reaped, especially in the largest share of the sector – existing buildings.

1.2 Building stock

In today's world, new construction represents only a small percentage of the existing building stock. In the EU, this percentage is about 1% a year, while more than 40% of the existing stock was built before 1960 and 90% before 1990 [2].

According to the data of the Directorate-General for Energy of the European Commission, buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU [3], with significant potential of energy savings through renovations, retrofitting and improvement of energy efficiency.

In addition, it is estimated that on average, 60-85% of the total lifecycle costs of a building are incurred during its occupancy, after its construction [4]. Those costs are usually not considered during the design phase, most likely due to the fact that the design competitions decide the winners based on the on the capital costs of construction, and not on the long-term value of a building.

2 BIM FOR FACILITY MANAGEMENT

Out of the five distinct phases in a building's lifecycle (design, engineering, construction, maintenance and operation), currently the highest level of adoption and use of BIM is in the first three phases, utilizing the majority of 'BIM Dimensions' (3D - spatial, 4D – time and 5D - cost) [5]. BIM 6D refers to the post-construction phase (maintenance and operation) of the building and it is mostly identified with 'sustainability', being primarily aimed at improvement of the efficiency of FM practices that are directly linked to the lifecycle performance of the building. An example of the data used in 6D can be information about installed components: the manufacturer, installation dates, maintenance schedule, configuration to achieve optimal performance, energy performance, lifespan and decommissioning. Such comprehensive data facilitates better decision-making as early as during design phase, allowing designers to assess various options and scenarios and their effects across the building's lifecycle.

2.1 Benefits of BIM

The main advantage of a BIM model is easy access to information stored within and the ability to share that information with all the relevant parties – contractors, repairmen, inspectors, etc. Something that was previously stored, exchanged, hidden and lost in a multitude of paper files, folders and databases, is now contained in a visual, graphical representation of the queried element. It enables proactive facility management with regard to space assignments, planning of preventive maintenance activities, budgets, expenses and contingencies, warranty management, regulatory compliance and energy usage, resulting in maximum efficiency of operation, improved coordination, efficient facility documentation, and accessible energy audit information, something that this discipline struggled with in the past.

3 MODEL CREATION

Documentation used for creation of BIM models for facility management can include all kinds of sketches, blueprints and drawings, scanned documents, CAD files, PDFs, laser scans, photographs, aerial imaging, etc. The resulting BIM models can then be used in various applications, from FM systems to mobile applications and augmented reality.

3.1 BIM to FM

Facility managers are not commonly involved in the process of building design, which means that the BIM models created for construction do not satisfy the requirements of FM operations. After BIM to FM handover, information in such models needs to be shifted through for pieces of information that need to be passed forward, but more commonly gaps need to be identified and filled with FM information. This process can cause significant post-commissioning delays in achieving efficient operation [6].

3.2 BIM for FM

Advantages of BIM justify the BIM for FM process – creation of BIM models for the purpose of facility management. This process involves collecting all available documentation that is needed for the end purpose. The model is built with the level of development that enables placing any elements that are needed for asset management, analysis and simulation.

In order to maintain reaping these benefits, the BIM model needs to be constantly updated with the information about repairs, replacements, changes and renovations, as well as any other type of information that is essential for decision making.

4 CASE STUDIES

4.1 Company Background

Founded in 2011 in Sarajevo, Bosnia and Herzegovina, Walter is a company providing expert BIM services and solutions to clients from the AEC industry. It employs over 70 highly-skilled individuals organized in several business units that cover all areas of BIM application – from programming, content development, testing, modelling, design, reality capture, FM, BIM management. Through our partnership with Symetri from Sweden, the majority of our clients come from the Nordic countries, bringing with them their unique requirements and challenges.

Symetri is the foremost service provider in model and drawing-related IT. Their main task is to improve and develop the management and utilization of property data and information [7].

DoBIM, Digital Objectifying BIM, is one of Walter's business departments whose main task is to create, capture and store data in the form of BIM models. Providing services mainly to customers from Sweden, which is famous for its residential market and complex SIS standards covering building areas [8], specific tools needed to be developed to manipulate with different area types in a BIM model. Most commonly used software is Autodesk Revit, with Naviate addins for area manipulation and information extraction. After completion, BIM models with all the relevant information are exported in the form of xml files and raster images that are published into a FM system used by the customer (most commonly HyperDoc/HyperHouse and FM Access). The customer then accesses the information and the drawings through a web-based portal that is customized to their FM needs, and the models are kept in an archive service and updated upon request.

Through the process of objectification (creation of a model, based on building components – 'objects') using BIM software, an information-rich 3D model is created, enabling easy access and extrapolation of various information, such as room areas or rental information, and also allowing the end user to use it for designing renovations or add more features to the building component objects, such as flooring materials, fire/sound insulation class on doors etc.

4.2 AutoCAD as a BIM tool - Micasa

For some customers, switching to sophisticated BIM tools, such as Revit, is not an easy choice, especially when they have been basing their FM system on AutoCAD Architecture for decades. One of such customers is Micasa, a FM operator from Stockholm region. The images below show an example of a detailed site drawing (Figure 1) created from an aerial photo (Figure 2) and confirmed by site inspection, with information about landscape - vegetation (type and age of different plants), lawn areas (for grass-cutting contracts), lighting, street furniture etc. linked to AutoCAD objects via their specific layers. This information is then exported together with the raster image to the FM System (HyperDoc/HyperHouse – Figure 3). When compared with Revit, AutoCAD Architecture does not offer as many BIM analysis tools as Revit, but it is still sufficient for certain needs that enable proactive maintenance and more efficient decision making, thus not providing enough incentives to switch to true BIM.

Figure 1: Information-rich CAD drawing

Figure 2: Aerial photo used as reference

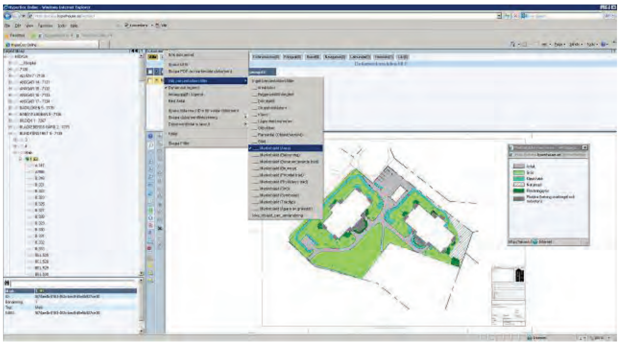


Figure 3: HyperHouse

4.3 Space Management - Botkyrkabyggen

Botkyrkabyggen is another client managing the building stock of social housing in Stockholm. Their buildings were built during the 'million programme' in late 1960s and have only recently decided to switch to a digital FM system, having a mostly scanned and incomplete archive of old drawings as a basis. Their building stock was also in need of serious renovation, being also a site of recent demonstrations, and their residents, mainly immigrants, are of a lower economic standard. All these factors influenced their decision to modernize their FM operations using BIM to create models that will also be used for design of massive renovations aimed at increasing the living standard of their residents and property value at the same time.

The first models were created from old scanned drawings in very poor condition, sometimes only electrical or plumbing drawings would be available, as illustrated by Figure 4.

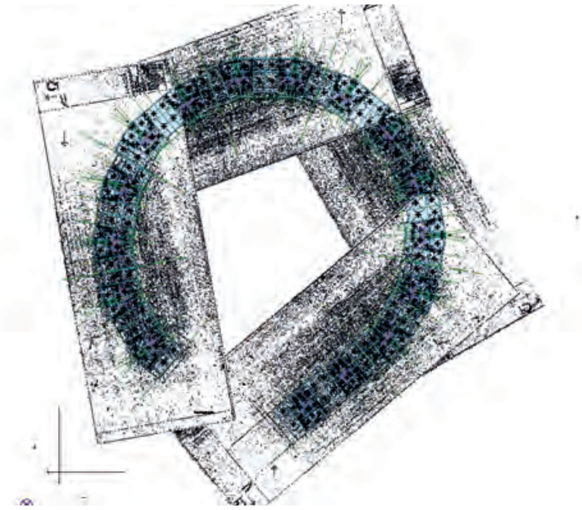


Figure 4: Scanned plans – used for creation of BIM

The resulting model (Figure 5) was clean, filled with necessary information about apartments and communal areas, with measurable elements that immediately proved its value for renovation works.

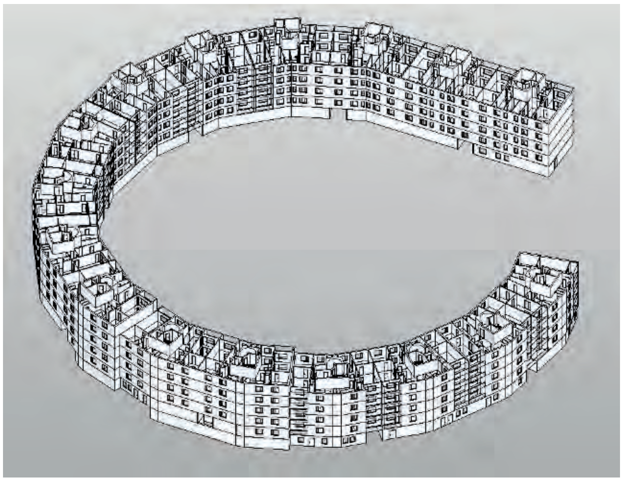


Figure 5: Completed Revit model

Figure 6: Google street view of the modelled building

The information that was entered in the Revit model was mainly concerning the areas, grouping rooms in apartments under their contract number, apartment type, etc. This comprehensive information was then exported into the FM System (HyperDoc/HyperHouse) (Figure 7), which provides various tools for quick extrapolation and visualization of different types of data

(a) (b)

Figure 7: (a) Revit – floor plan, (b) FM access

The client later decided to switch to the newest product in the FM software – FM Access, and the transition was very simple and straightforward, as the two application use the same export formats .xml and .cal. (Figure 8 and 9).

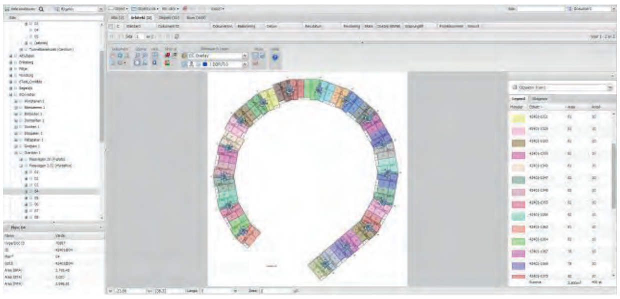
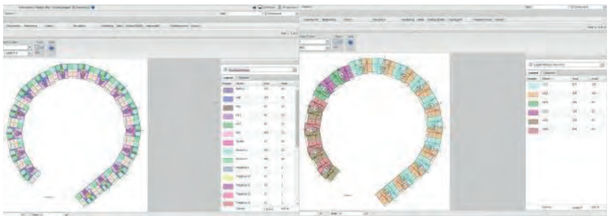


Figure 8: FM Access – object numbers, graphical review



(a) (b)

Figure 9: FM Access - (a) room names, (b) apartment type

This was only the first phase of the work with this client. After receiving the BIM model, and seeing the results in the FM system, having all the required data at their disposal, the client was quick to recognize the benefits and advantages and the next project stage followed, this time using laser scanning of the buildings they did not have accurate current drawings and BIM model construction based on point clouds, which also included more elements than before and higher level of development.

Figure 10 shows the end result of the first such project – model of a communal building owned by the customer.

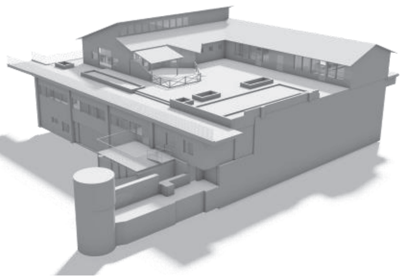


Figure 10: Revit 3D model

The work done for Botkyrkabyggen is an excellent example of the benefits BIM can provide for facility owners and managers, providing them accurate and accessible information and BIM models that can be reused for renovation works and subsequent updating of their FM system, saving time and money in the process.

4.4 Space Management - Signalisten

Signalisten is another company owning residential buildings in the Stockholm region. This example is interesting because of an added layer of information to the usual space management requirements. In addition to creation of BRA, BTA and NTA areas for every room in the buildings, contract numbers and apartment types, this client also required the information about Area Classes and Cleaning Classes, which was easily achieved in Revit, adding additional room parameters.

That way, rooms were also classified into:

- BOA (apartments, living area),
- BIA (building facility, service areas),
- ÖVA (vertical and horizontal circulation, areas for technical services and equipment),
- LOA - (business spaces).

Figure 11 shows the aerial photo of a building in a Stockholm suburb, whose model was created during this project. Reference drawings used were CAD drawings.

Figure 11: Google Maps aerial photo

The process of area manipulation – adjusting the usable (BRA), gross (BTA) and net (NTA) area of the rooms in the model – requires a special tool that creates the areas automatically and then enables manual editing of each area boundary, in order to correct possible errors, so that it would satisfy the SIS Standard requirements imposed on housing operators in Sweden. Revit creates a separate plan for each level and area type, as shown in Figure 12.

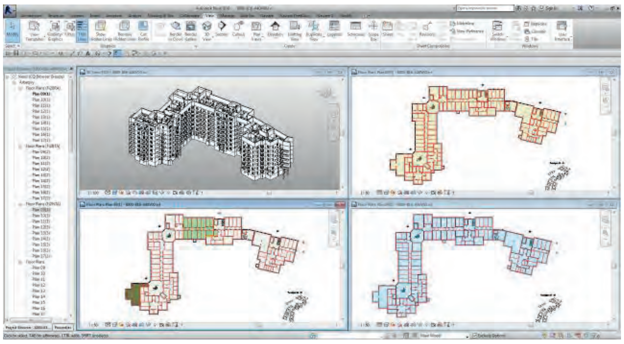


Figure 12: Revit - 3D model, BRA, NTA and BTA area

After the model is completed, the usual export files are created for integration into the FM System (HyperDoc/HyperHouse), which is also adjusted to the customer's special area requests and provides useful tools for filtering according to selected criteria to enable easier visualization and review of information. Figures 13, 14 and 15 show the examples of those visualization tools.

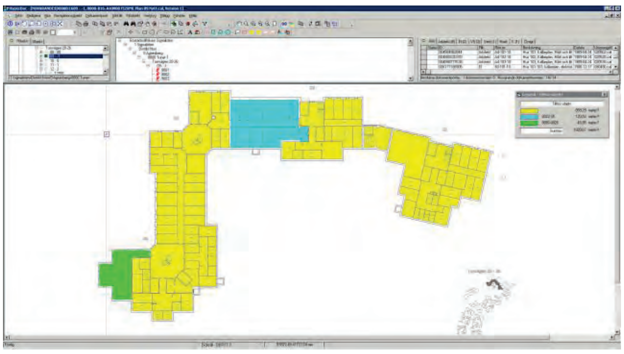


Figure 13: Hyper Doc - object numbers, graphical review

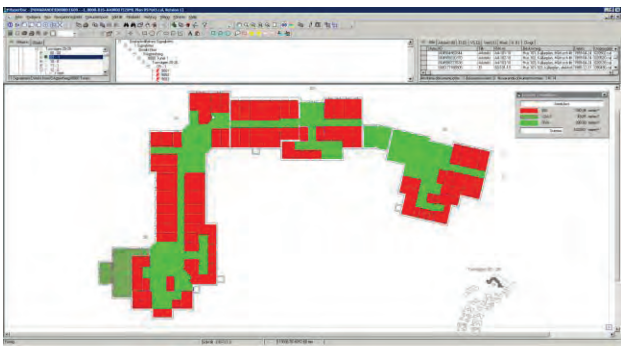


Figure 14: Hyper Doc – area class, graphical filters

(a) (b) (c)

Figure 15: HyperDoc –

(a) förråd, (b) städkategori, (c) teknik graphical filters

5 CONCLUSION

Judging by the results to date, BIM possesses a significant potential to improve the FM processes, by enabling proactive maintenance, enabling the use of the same performance analysis tools and following the green design guidelines in its operations. However, there are still some obstacles to its extensive adoption.

The end goal of BIM use in facility management is the integration of the BIM model with the existing FM software, which must enable a seamless flow of information back and forth. This integration needs to provide access to information without the complexity of going into the Revit model, as well as allow multiple people to see and use the live information, without strict control of rights to edit or modify data.

However, a single standard for this has not been established to date, and there are numerous independent software applications, web- or cloud-based, in existence today, often even custom-developed to satisfy very specific needs. This only creates confusion within the industry and emphasizes the need to develop a standard interchange format, as it will certainly hinder the wider adoption of BIM in facility management sector.

6 FUTURE WORK

Walter continues to provide services and solutions to the clients in AEC industry, including especially facility management sector. By continuously facing new challenges that provide us with additional layers of experience and BIM expertise, we will continue to promote the advantages of BIM and search for solutions to wider adoption of this technology, on the path to sustainability.

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IDE^{X}AS, A FRAMEWORK SUPPORTING DESIGNERS IN CREATING CUSTOM DATA-ENABLED TOOLS

How BIM and object-oriented technologies will also support designer during the design process?

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Abstract

In past times, the architects and the designers had their imagination and their line sketches as the only tools to create and represent their projects. While this allowed them to free their creativity, it also induced that most of their decisions were based either on their experience or on their personal vision but less frequently on objective and quantified parameters. With the development of digital 3D models, the idea of having a tool that uses objects instead of lines slowly came through, allowing the software to store data and "understand" the model as well as representing it. This is the beginning of Building Information Modelling (BIM), a kind of software as well as a process, strongly relying on data. Through that data, Building Information Modelling can represent physical and functional characteristics of a facility.

However, even though BIM proved its usefulness for plan production, some architects still discuss its added value at early stage design. Indeed, it is commonly accepted that BIM use generates high return on investments for contractors but many architects claim that BIM use at early stage require a tremendous amount of work, especially if the project is stopped before completion. What if digital object-oriented solutions in general and BIM was an opportunity for the designer to develop his/her own tools.

On one hand their core knowledge is in designing buildings not tools but on the other hand as users, they know exactly what they need and what is useful for them. This increasing need of specific tools lead to visual programming solutions such as Rhinoceros + Grasshopper or Revit + Dynamo which provide a simplified, user friendly and optimised interface allowing them to start designing tools. However, while only a few architectural schools teach programming skills to their students, all of them orient their learning around the architectural project.

This paper showcases the IDE^{x}AS framework which proposes to designers experienced with the architectural design process; key guidelines, rules and method to implement ideas and concepts within a digital script. While this method is completely software and language dependent, it will be showcased through scripts developed either in Grasshopper or in Dynamo. The structure of this method follows the general structure of the design process and is therefore divided in different phases with varying objectives. It proposes several ways to translate qualitative parameters – quite complex to handle for a computer - into quantitative ones depending on the designer's needs (threshold, ratio, fuzzy method) but also ways to display the result and ensure quick feedback to the user.

Keywords:
data driven architecture; scripting; design process; customized tools; design process

1 INTRODUCTION

The architect is the main actor at the core of the design, development and construction of buildings and infrastructure. His/her duty is to conceive a building in line with the requirements, the standards and other quantitative results but also, design, perceive and model a specific atmosphere, space, feeling or impression to the edifice.

To do so, the designer can count on their imagination and their ability to draw line sketches on paper. It is often said that the mind of an architect can visualize a space in three dimensions. However, a design must not only be conceived it also must be shared and understood by all the stakeholders. The question of the representation as always been a key issue and therefore the first tools and standards aimed at developing the representation rules for the different kind of objects, scales or drawings (e.g. structural, non-structural, cut, seen, hidden, above or the various types of materials and assemblies).

When the building industry started its digitalisation, the traditional drawing table transformed into a two-dimensional computer-aided-drafting (CAD) system. Later, the third dimension has been added in addition to other features such as renders or visualisation.

Today, the computers have evolved and the construction industry is also experiencing a paradigm change, the turn of the information era. Computers and software can handle a huge amount of data. The systems are becoming more complex because designers are now modelling with object-oriented software (such as BIM) instead of simple lines.

This might have an influence on designers. Indeed, before an architect had to be able to draw by hand or model within a CAD system, today, new questions occur such as "Should architects be trained as programmers?"[1]. With the appearances of new tools, new skills have been needed but also new ways of designing have been enabled such as generative designs or parametric designs. Furthermore, architecture per-se has always been a multidisciplinary field integrated many specialties such as HVAC, MEP, building performance or architectural quality and the current development in energy efficiency and the new standards induce that buildings are even more complex than before.

Therefore, as stated by Eastman [2], "*Until now, concept design has been a largely mental exercise of generating various spatial concepts and assessing them intuitively, based on the designer's knowledge and accumulated expertise. Reliance on such expertise is perhaps one reason why architectural success has traditionally come only to those with decades of experience who are able to bring to bear the wisdom required to assess and select design concepts worthy of being fully developed.*"

While this change in the work of an architect might be an extra load for some, it can also be a potential for the architect to design tools fitting his needs instead of buying a license and having to tweak the software to develop unconventional or specific tasks.

This led to the development and spreading of visual programming tools and interface first in three-dimensional modelling environment and later into building information modelling systems.

Many developments have been made to develop easier scripting languages such as Python or scripting interface such as Grasshopper (for Rhinoceros 3D) and Dynamo (for Revit). However, programming and developing tools is not only a question of language but also a way of structuring a problem and tackling it. In computer science, the use of algorithmic allows to develop logical methods and allows one to understand a software without having to learn the language.

In that perspective, the IDE^{x}AS framework [Figure 1] proposes a simplified approach allowing non-programmers and more specifically designers to develop small-application-scripts by helping them structuring their thoughts and their work process.

This framework has been initiated based on the analogy with the traditional design process of the architects. It has not the pretention of being exhaustive and neither, to be the most efficient in programming but is considered as a good approach towards solving architecture-related issues for non-programmers. The proposed framework was elaborated based on our personal experience with visual programming, scripting and coding [3] but also based from the acquired-experience of the Vrije Universiteit Brussel (VUB) Transform research group [4] in the framework of the course "Parametric Design of Transformable Structures" – a course guiding architectural and civil engineers in develop parametric designs and scripts to allow them to make better informed designs and decisions.

In the following part, the research hypothesis and the methodology is briefly presented and later, the analogy with the classical design process will be discussed and the different parts

2 RESEARCH HYPOTHESIS AND METHODOLOGY

This research is part of a larger framework in which the potential of combining Building Information Modelling (BIM) and Design for Change (DfC) principles together is investigated. While developing the combination of BIM and DfC, it appeared that guidelines for designers wanting to translate their knowledge into tools was missing or quite technical (e.g. programming language, syntax…). Therefore, we identified this lack of guidelines as an opportunity to contribute not only in BIM and DfC but also to all architecture-related topics needing or benefiting from the new object-oriented and information-oriented tools.

The IDExAS framework has been developed (and is still being updated) through a Research-by-design methodology. First the aim of this framework was to provide only guidelines and advices to designers by experimenting the translation of architectural concepts within programming environments. However, it appeared that the literature contained a gap between very technical sources related to tools and beginners books and tutorial. Therefore, it was proposed to build up from scratch a new method a) based on an analogy with the traditional design process and its phases, b) which proposes solutions and guide the designers decision-making during the elaboration of the tools and c) which ensure that the

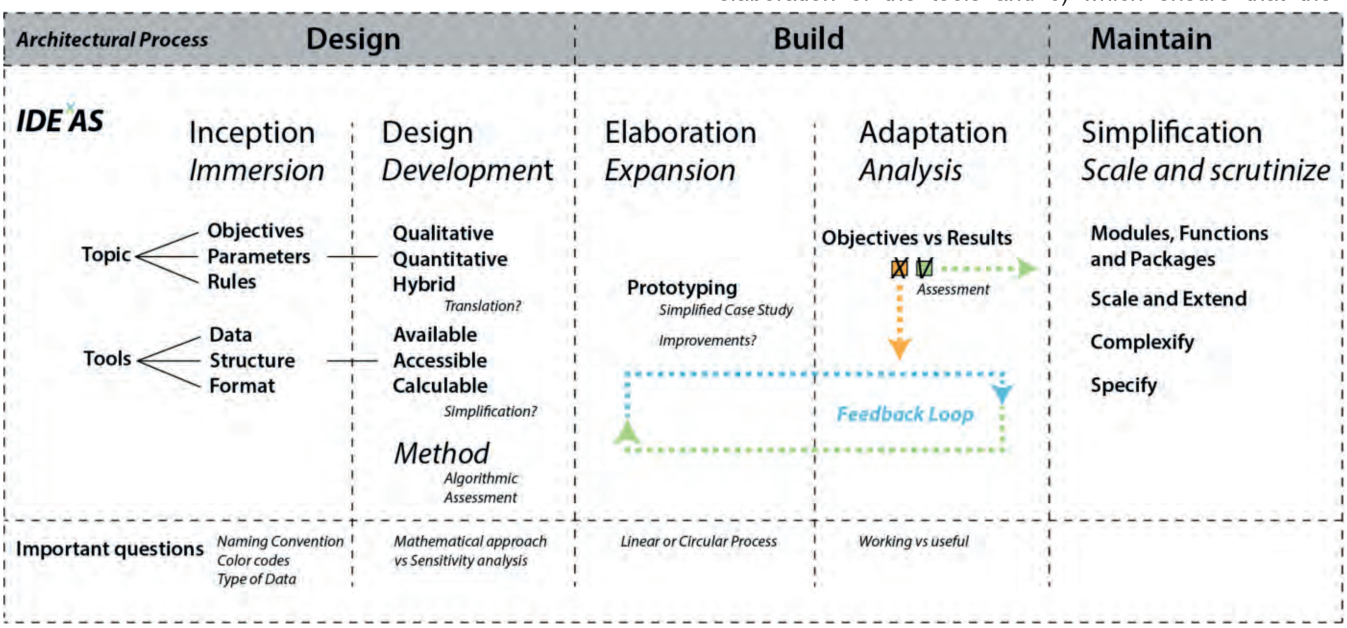

Figure 1: The IDE^{x}AS method guides the designers in developing their own tools

knowledge gained during the elaboration of the tool can be translated into a generic software independent method and therefore contributes in building up the knowledge of the field of architectural design.

To do so, three main tracks were developed. First, a literature review on either the architectural design process and the scripting/coding process has been done. Secondly, analogies between those two processes were highlighted to define potential gaps or key links. Then several scripts have been built by our research team and into the context of the Bruface Master 1 course *"Parametric Design of transformable structures"* [5]. This script development allowed to build up a list of strategies easing the translation of an architectural problem into a solving method and finally a specific tool. Several working and non-working strategies have been highlighted simply by comparing the results of the scripts and methods with the expected results during the definition of the project.

In other words, this research combines on one hand insights from the literature and cases studies developed specifically for this research by the author but also on experience learned from students' projects at master level.

Although, the rules and strategies presented in this paper proved their efficiency and their usefulness in developing software solutions for architects, it is never assumed that they are the only ones. Therefore, if one wants to contribute in testing, deepening, updating and extending this framework we would be glad to share our knowledge. Consequently, the following chapters introduce the IDE^{x}AS framework and presents the key steps and important questions to answer or investigate during the method and tool development.

3 THE IDE^{x}AS FRAMEWORK, AN ANALOGY WITH THE ARCHITECTURAL DESIGN PROCESS

Depending on the sources in the scientific literature or professionals websites and blogs, the amount of steps between the start of an architectural design and its construction varies [6], [7, pp. 44–45], [8]. In "Parametric Design Thinking" [8, p. 25], Chockhachian compares 12 Design Process Theories. However, the authors states "When we compare all different stage in the same column it's understandable that they are repeating the same language in different words which means that the root of all is a linear process". He highlights the limitation of such linear approach arguing that in reality the boundaries between the stage are not that strict. Furthermore, he adds that the design process is "a cooperation between problem and solution by means of analysis, synthesis and evaluation".

The proposed framework, although presented - for the sake of simplification and analogy with the traditional view of the design process - as a linear step-by-step approach - considers the various design loops and guides the architect into prototyping his own method and tool to answer a specific and defined question. To do so, we also take into account the increasing amount of information and its varying reliability throughout the different phases.

We propose three main steps – Design, Building and Maintain - with a possible iteration with feedback loops in between. Each step represents either in increase in terms of the amount of information or of the reliability of the information (e.g. from conceptual geometry towards real objects, from generic values to specific and reliable ones).

3.1 From a method towards a tool

Before entering in the core of the IDE^{x}AS framework [Figure 3], it is need to clearly define some terms used during this paper. While discussing the elaboration and creation of a script the Transform Research Group [5] makes the distinction between a method and a tool. According to "Oxford Living Dictionaries" [9].

A ***method*** is *"A particular procedure for accomplishing or approaching something, especially a systematic or established one"*. Therefore, we consider that a method should be generic and software and syntax independent. Thus, it could be represented as an algorithm or a flow chart.

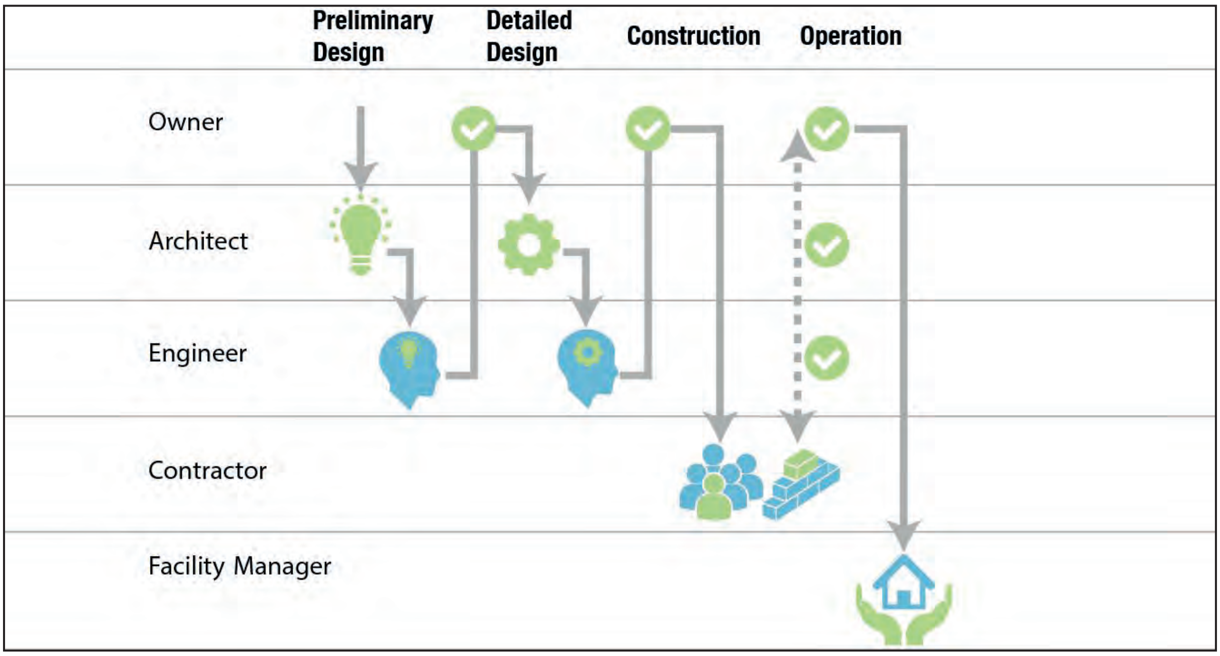

Figure 2: Simplified view of the traditional design process

While a ***tool*** is the *practical application or translation of a method into a specific software*. While the method is rather general but do not necessary provides real answers, the tool needs a clear set of inputs and outputs but also functions or mathematical operations.

Ideally, the translation of a method into a tool is rather smooth. However, due to software limitations, proprietary file formats, closed API or other practical reasons, it occurs that a very simple method is rather difficult to translate into a tool. Some of these problems are discussed into the following parts of this paper, respectively in the phase they have a higher chance of occurring.

3.2 Inception

Similarly, to a building design, the first phase of the tool design process is to gather the information, requirements and documents related to the task to run.

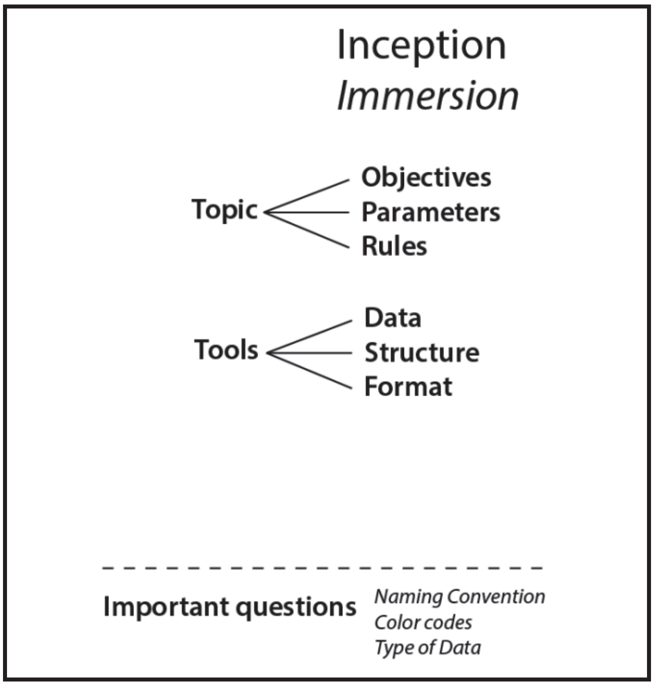

Figure 3 : The Inception phase focuses proposes to deepen the knowledge in a) the topic and b) the tools/programming language used to create the method.

A good **method** combines a good understanding of the topic and a vision on the logical links between the different variables or parameters. Suppose you want to create a method helping a designer in placing buildings oriented towards a set of very qualitative views. It makes no sense to orient a building towards a view if the walls are completely opaque. The designer must establish the logical link between a) placing a building facing a view and b) select the right skin to allow the inhabitants to actually benefit from the view. Later, when trying to translate this method into a tool, the designer must think about practical ways to represent geometrically a view. For example, a view could be represented as a conical surface starting from the location of the inhabitants or a line between the attraction point and the building skin.

To do so, the designer must understand and research how the **tool/scripting environment/programming language,** he uses work.

In other words, during the Inception phase, the designers must research and elaborate a kind of state-of-the-art for the **topic** (e.g. views, energy performance, acoustic…) and the **programming environment** (e.g. tools, software, language) he wants to use. Hopefully, the researches made on the programming environment will benefit also to the further projects.

Now that the two key parts of the inception phase - topic and programming environment – their needs and requirements will be introduced respectively.

Topic

As we stated earlier, before entering the method or the tool creation: One must research and deepen the knowledge in the field he wants to propose a solution. To do so, we identified three key aspects: a) the objectives, b) the parameters definitions and c) the rules.

The objectives are the first formulation of the questions that would ideally be solved by the tool. While an aim is rather general and touches a large topic (e.g. contribute towards more sustainable buildings), objectives must be rather practical and linked to clear deliverables (e.g. measure and reduce waste after buildings' demolition). Later, by considering the programming environment they will be translated into requirements (e.g. buildings elements must be modelled in 3D with their material density given in metric tons as a parameter).

To translate objectives into clear requirements for the tool, we must list the potential parameters or variables that might have an impact or an interest to reach our objective. To continue our previous example, the weight, toxicity, technical and service life span of buildings elements as well as the connection types might be good parameters to study the generated waste in a building end-of-life scenario.

Once the general ideas have been clarified on the topic side, it is necessary to investigate the potential provided by the programming environment tool.

Tools

We already stated earlier that the aim is a) to develop a software independent method and b) create a software specific tool following this method. To do so, one must know the possibilities and limitations of the scripting interface.

As this framework is specially oriented towards beginners in programming but having a designer's background. We advise them to start with simplified visual programming interfaces such as Rhino3D + Grasshopper or Revit + Dynamo. Although, they already provide a rather large spectrum of use, having a basic knowledge in a "High-level" programming language such as Python.

The major advantage of using visual programming interfaces is that many functions rather specific for architects/buildings are already implemented, the programming interface is rather simple and well-structured, the community is large and many online resources are available.

While investigating, the tool used to develop the application. One must at least consider and investigate the kind of *data* between imported, exported or generated by the tool (e.g. text, geometry, objects [geometry + text]), the data *structure* (e.g. lists, tables...) and the file *format* (e.g. proprietary, open…)

3.3 Design

This stage, similar in an architectural project with the early stage design is also separated into two main paths.

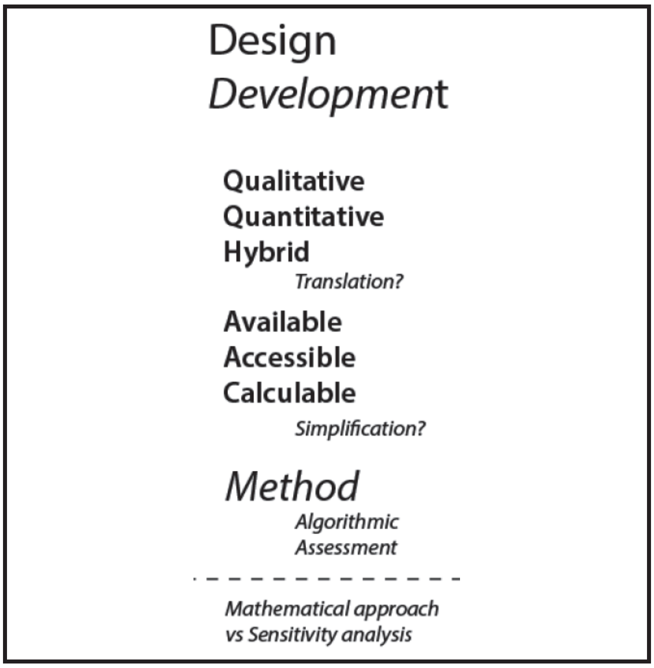

Figure 4: The main concepts under the design development phase.

The first one focuses on the algorithmic and the development of the method. It is rather "field/discipline" specific as the aim is to determine a logical process within the expected tasks and subtasks of the tool. Usually, programmers use flow charts to represent the algorithms. One box being an operation and an edge between two block being the information being transferred from one to the other.

The second part, which is the one mainly covered by the IDE^{x}AS framework concerns the translation of the parameters, rules and objectives developed in the Inception phase into practical variables useful into a digital environment.

Parameters can be Qualitative, Quantitative or Hybrids. Quantitative parameters are related directly to a quantity or a number. It could be a room surface, the number of windows in a building or the energy consumption of the building. The advantage of such type of parameter is that the translation into a digital environment is rather easy because they can be measure, processed and compared easily – by comparing the numbers together.

However, although architecture has a lot of quantitative parameters it appears that some aspects such as comfort, sustainability, view, space connectivity are not directly translatable into number. As an example, a reversible connection potentially reduces the amount of waste in an end-of-life scenario but how can you translate that into a computer-compliant parameter?

How to measure the unmeasurable?

In order to translate qualities into valid parameters, several methods can be used. We will briefly list several six strategies helping to make the link between qualities and digital calculations: a) Use of threshold value, b) Fuzzy logic, c) Ratio, d) Analogy/comparison, e) Mathematical approach and f) Object-oriented approach

a) Threshold value: Defining a limit value under which the objective is not reached (e.g.: at least one window to have a bedroom);
b) Fuzzy logic: In contradiction with Boolean logic where it is either true (1) or false (0), fuzzy logic allows to discuss a range of solutions between 0 and 1 (e.g.: room temperature may be ranged from too cold to too hot; cold and hot ranges in °C may be defined by the users)[1];
c) Ratio: using a unitless ratio has the advantages of having comparable results why are not case dependent. Instead of stating that five rooms (out of 10) within a building are rather versatile; it may be easier to consider that 50% of the rooms are versatile. That way, it is easier to compare with other cases.
d) Physical value: this proposition of parameter is very specific to architecture. Considering parameters with a clear physical interpretation might also help developing the method (e.g. considering an amount of m^2 responding to certain qualities
e) Mathematical approach: using mathematical theories that have been proven such as graph theories or networks might allow you to translate a real problem into clear, defined and proven metrics.[2]
f) Object-oriented approach: Typical added value from BIM integration. As the models are now object-oriented logical links between different objects can be considered. (e.g.: distinction between bearing walls and non-bearing walls can be easily done within the model and propose different alternatives. While removing a bearing wall will lead to the creation of a new column/beam, the removal of non-bearing wall does not induce this king of change).

3.4 Elaboration & Adaptation

Once the general design objectives and the major logical process (method) have been developed. One can start prototyping the method within a tool. To do so, starting with a simplified case study to check if an "optimal scenario" works and if any "parameter" considered as

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[1] While for some rather general questions such as the "comfort" temperature in a room you do not need to select a specific audience for your survey, for more specific questions such as "What is the minimum dimension of a generic space?" considering questioning only experts in the field will increase the reliability of the developed scale.

[2] Although, the mathematical results might be correct, the interpretation of these results and thus, potential conclusions may not be easy to elaborate. Therefore, elaborating a large panel of case study (to be able to interpret and compare results) might be a necessary step of this process.

available can actually be reached[3] (technically within the tool). This key phase is the start of the iterative process in which the tool and the method will be iteratively improved and updated [Figure 5]. To do so, it is interesting to set clear objectives for the script

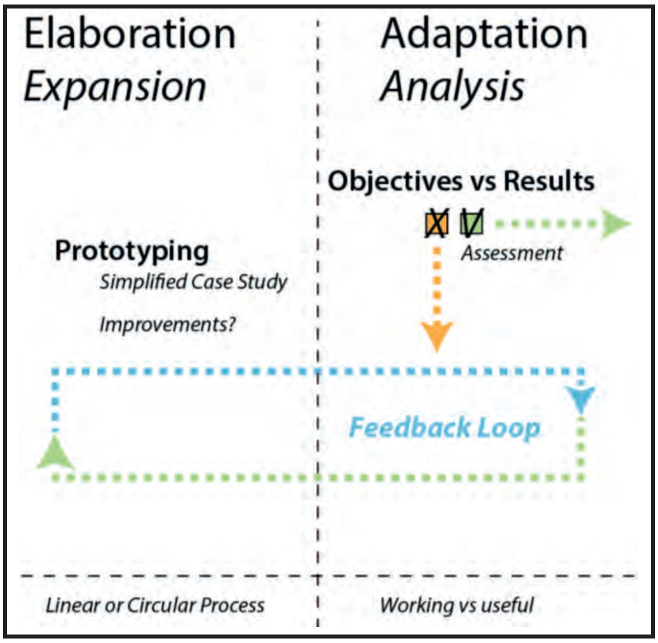


Figure 5 : Elaboration and Adaptation, an iterative loop improving the tool progressively.

3.5 Simplification, scaling and scrutinizing

Once the script has been developed and works effectively it is possible to either:

a) Create clusters of modules, functions and packages for future use or to allow their future update (modular scripting)

b) Adjust the tool towards several scales (e.g. material level, component level, building level or city…) and their specificity or extend the script by adding new features.

c) Increase the complexity of the script by adding more detailed calculations (e.g. precise model instead of rule of thumbs).

d) Specify the script towards a particular use and deepen its development to make it a specialised tool.

4 APPLICATION ON SMALL SCALE CASE STUDIES

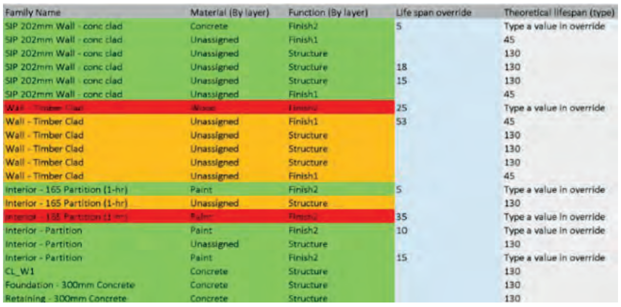
To show that these principles have been applied within actual scripts, the following part proposes to showcase some very small and specific scripts developed during this research. The two showcases are presented with a table summarising briefly the key parts of their elaboration while the two other cases are shown to show the possibilities, proof-of-concept (this framework has been used to develop them and therefore their existence proves its usefulness) or inspiration for future works.

4.1 Walls/panel composition analysis

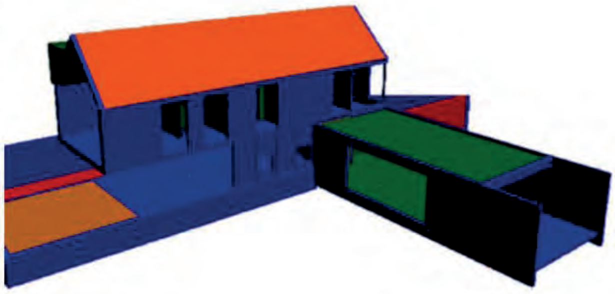
Table 1: Key elements and features of the wall.panel composition analysis tool

Inception	
Topic	The six layers of Brand; pace-layering *Objective:* Determine if an layered element (wall, floor, roof) could be easily dismantled without having to destroy and waste materials with longer expected lifespan. *Parameters:* technical life span *Rules:* connection between different layers might reduce technical lifespan
Tool	Dynamo and Revit; *Data:* life span per element + lifespan per layer [had to be added] *Structure:* each element is a table; each line represents a layer. *Format:* Excel sheet; script either in Python and Visual programming
Development [Figure 6, 7 & 8]	
Quantitative	Lifespan
Qualitative	Connection type: Reversible or Not
Method	If the connection type between two layers is not reversible; the final lifespan of the bundle is the lowest – the layers cannot be separated leading to quicker obsolescence of one of the layers [object-oriented approach]
Elaboration and Adaptation	
Prototype	First only with one element (modelled by the designer): a given slab; Then with various elements (modelled by the designer). Finally, working on a generic file (basic showcase file provided by the software) to show the versatility of the tool
Objectives	The tool can extract the needed information (life span), process it (calculate the influence of a layer over another) and display it to the user (green: easy to dismantle; red: hard to dismantle)
Simplification	
Further developments	The life span profile could be used to check if the principles of pace layering are respected -> the slope of the chart, changes its sign after reaching a maximum; Therefore, to respect pace-layering the wall profile shouldn't have more than one local maximum and the minimum should be at the extremities. Additional developments regarding visual feedback should also be encountered
Complexify	Curtain panels are not considered as layered elements within Revit; this functionality could be added

[3] Sometimes, parameters are considered as easy to get in the method but are very difficult to access within either the software or the scripting interface chosen (e.g. limitations of the scripting language, protected information…)



Family Name	Material (By layer)	Function (By layer)	Life span override	Theoretical lifespan (type)
SIP 202mm Wall - conc clad	Concrete	Finish2	5	Type a value in override
SIP 202mm Wall - conc clad	Unassigned	Finish1		45
SIP 202mm Wall - conc clad	Unassigned	Structure		130
SIP 202mm Wall - conc clad	Unassigned	Structure	18	130
SIP 202mm Wall - conc clad	Unassigned	Structure	15	130
SIP 202mm Wall - conc clad	Unassigned	Finish1		45
Wall - Timber Clad	[illegible]	[illegible]	25	Type a value in override
Wall - Timber Clad	Unassigned	Finish1	53	45
Wall - Timber Clad	Unassigned	Structure		130
Wall - Timber Clad	Unassigned	Structure		130
Wall - Timber Clad	Unassigned	Structure		130
Wall - Timber Clad	Unassigned	Finish1		45
Interior - 165 Partition (1-hr)	Paint	Finish2	5	Type a value in override
Interior - 165 Partition (1-hr)	Unassigned	Structure		130
[illegible]	[illegible]	[illegible]	35	Type a value in override
Interior - Partition	Paint	Finish2	10	Type a value in override
Interior - Partition	Unassigned	Structure		130
Interior - Partition	Paint	Finish2	15	Type a value in override
CL_W1	Concrete	Structure		130
Foundation - 300mm Concrete	Concrete	Structure		130
Retaining - 300mm Concrete	Concrete	Structure		130



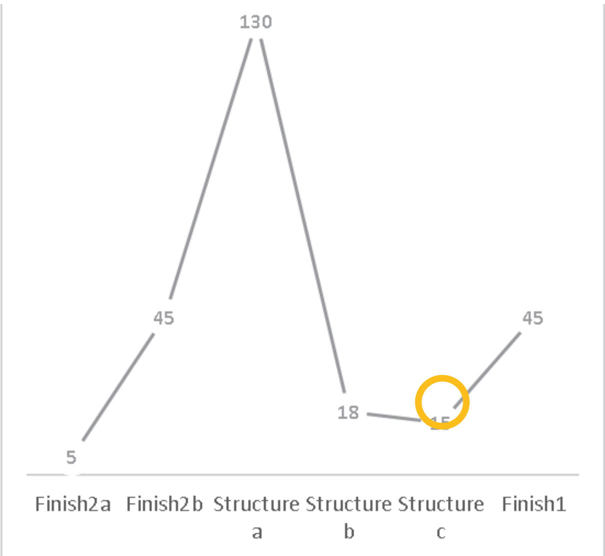


Figure 6, 7& 8: Three major kinds of feedback provided by the wall/panel composition analysis tool: a) a datasheet with the expected life span per layer and their influence on each other; b) a three-dimensional model displaying the ease of separating layers of elements and c) for each component the life span profile allowing to highlight potential weaknesses.

4.2 SAGA implementation into BIM

Table 2 : Key elements and features of SAGA BIM tool

Inception	
Topic	SAGA is a Grasshopper tool developed by Pieter Herthogs [10]. It uses the theory of space syntax to assess buildings generality and adaptability through space connectivity.
Tool	Dynamo and Revit; *Data:* In the original tool, the designer uses convex spaces however, within a BIM interface we can directly extract rooms from the model. *Structure:* list of [from /to] rooms *Format:* data is processed within the software and only the calculated metrics are displayed with a graphical representation of the connectivity maps.
Development	
Quantitative	The original method is mainly quantitative. It is based either on mathematical background (space syntax) or on coefficient attributed through fuzzy logic (permeability rating)
Qualitative	Permeability rating; Load bearing walls or walls containing plumbing are considered as non-permeable while
Method	In the original version, a Line was drawn between two spaces. However, as the BIM model can use metadata to connect join elements, it has been decided to connect spaces through doors (horizontal connexion) or stairs (vertical connexions).
Elaboration and Adaptation	
Prototype	First, only with doors (actual doors and only generality). Then, analytical doors were added for the adaptability. Permeability ratings which contributes to the weighting of the saga method have been added later to allow a fully automated process. Finally, the addition of the three-dimensional feature has been made using stair connections.
Objectives	The tool can calculate the same metrics as the original one using an automated method. The tool expands the use to Three-dimensional analysis by considering stairs. Additionally, it relates more to the architectural vision of a space by not considering only convex spaces but also functional spaces.
Simplification	
Further developments	Additional features can be developed easily through the modular scripting used. Automatic determination of the permeability ratings depending on wall families can be extended. Further analysis of the justified plan graph could also help the designer to design buildings that could be divided later in smaller ones (e.g. transforming easily a house into two apartments).
Complexify	Having a complete database per building typologies would allow to compare buildings and optimise them.

4.3 Host/hosted relation

In Denis (2014) [3], the importance of connections between elements was shown as a key factor for transformable buildings. Indeed, elements connected using dry joints are allowing the disassembly of the building. The following tool was made to analyse the connection between two elements. The host is the element that bears the other. In this case, the host is the wall and the hosted element is a window.

Depending on the type of connection between two elements (i.e. reversible or non-reversible) and depending on their comparative life span (e.g. wall more durable or window more durable), the tool colours them to provide a visual feedback to the user [Figure 9 & 10].

Figure 9 & 10: Colour feedback outputted by the host/hosted relation tool. By comparing the life span of walls and windows the tool can sort them into four different categories and change their displayed colours (b)

5 CONCLUSION

Although, it is difficult to assess the efficiency of design methods, our framework contributes to documenting and facilitating the development of custom made solutions. It proved its usefulness in the development of the three cases study briefly introduced.

These examples which are all depending vastly on information already within the models (without extensive additional work) already trigger the interest of using parametric design and scripting approach in order to allow designers to make better informed decisions but also show their experience and knowledge through a tangible method/tool which can be deepened and improved throughout the years.

6 FURTHER RESEARCH AND POTENTIAL IMPROVEMENTS

While this paper presents briefly the main steps and concepts within the IDE^{x}AS framework, and although several small tools have been developed during the elaboration of the method, another publication showing the actual implementation of such a method into a practical case would be useful to illustrate extensively the different steps proposed earlier.

The method is also developed in an iterative manner and may be completed or updated several times through the light of new tools development within our research team, guiding sessions with students or feedback from either designers or external researchers.

Providing the designers with template documents might also contribute in increasing their *ability* [11] to use and develop BIM tools, ensuring an democratization of assessment and analysis tools and method made by and for designers within information models.

7 AVAILABILITY OF THE DATA

The researchers involved in this paper, are willing to share more information concerning the tools and their developing process. However, as it is the first time this framework is presented and shared within a conference, it has been decided to focus more on the explanation/description/structure of the framework rather than its application within case studies.

8 ACKNOWLEDGMENTS

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Building DNA for a Circular Future

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Abstract
The objectives of the BAMB (Buildings as Materials Banks) project is to support a transition from the linear building life cycle to a circular one. This will be greatly assisted through providing support to key decision makers and stakeholders on how the design & specification, product selection and business models attached to products, materials and systems influence the economic and environmental outcomes of a built asset. Providing such support requires superior data provision and analytics, where complex assessment is undertaken through software programming, rather than expecting the user to spend much time and effort to do so.

Keywords:
Circular economy; design for disassembly; Building information modelling; environmental assessment; economic assessment

1 INTRODUCTION

Currently, there is little consideration given to the future reuse and recovery potential of building related products and materials when they are no longer required in their first use cycle. This can be enhanced through designing for disassembly, constructing to those design intentions, maintaining product value throughout the use cycle, and finally removing in line with optimal disassembly techniques to minimize damage. Conversely, the future value of products and materials can be significantly reduced through lack of such considerations throughout the first use cycle. This needs to be combined with improved data collection, retention and transfer. Accurate information on the products and materials in a built asset, along with design details on how they are assembled and connected is crucial to converting design for disassembly intentions into a reality.

2 BUILDINGS AS MATERIAL BANKS

The aims of BAMB (Buildings as Material Banks) are the prevention of construction and demolition waste, the reduction of virgin resource consumption and the development towards a circular economy. This builds upon many years of resource efficiency in the construction sector, where high levels of recycling are now commonplace in many European countries. As is often the case with a linear use of resources, much of this recycling is not at high levels of application and the amount of reuse is minimal. BAMB, therefore, seeks to develop a circular approach to the use of building, systems, products and materials.

However, the challenges faced in achieving this paradigm shift are many, including:

- A complex and multifaceted supply chain, from commissioning to decommissioning
- Buildings and infrastructure tend to last a long time, compared to other products, and can have multiple ownership and occupation profiles over their life cycle
- There is a general lack of standardisation of design and component use compared to other sectors
- There are many priorities in terms of delivering our built environment, including affordability, health and safety, and reducing energy consumption

To deal with the complexities outlined above, research is underway on multiple fronts in the BAMB project, with crucial interaction between them.

This paper focusses on one aspect of the BAMB project - to create and test a decision support methodology, integrating input on materials, reversible design, reuse potential and transformation potential of buildings, systems and components. Having such information readily available, at key stages of design, product selection & procurement, operation, maintenance, refurbishment and deconstruction of a building's life cycle, will enable better decisions to be made in ensuring the value of buildings, and their constituent parts are enhanced, rather than deteriorated..

3 BUILDING DNA

3.1 Building Information Modelling

A significant element of the work being undertaken in this aspect of the BAMB project is to more fully understand the composition and design details of a building and its systems. Having such information in a readily usable form would facilitate easier comparison of building and system level alternative scenarios, with the objective of supporting a more resource efficient (circular) built environment.

Data and information is already captured at design, build and operational stages of the building life cycle, and a great deal of progress has been made to standardise and co-ordinate this to promote collaborative working in creating and managing buildings.

Collaborative working is assisted through a **Common Data Environment**, as supported through Building Information Models (Graphical) and Building Information (Non Graphical).

Building Information Modelling (BIM), is the overall process of creating a three dimensional database, in the form of a model of information that pertains to the design of a building. Stakeholders involved generate and manage asset's data over its life cycle using model-based technologies linked to a database of reliable information [1].

As illustrated in Figure 1, the 3 main components of the information model are:

- Graphical Model
- Non-graphical Model
- Documentation

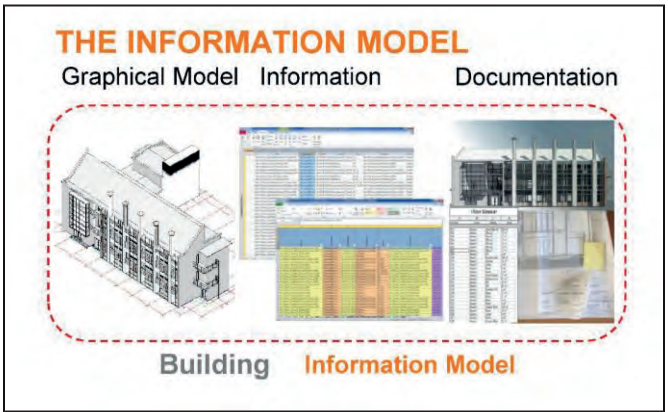

Figure 1 BIM overview

In summary, BIM is a collection of data and information generated for various strands of issues to be addressed in delivering a scheme. This information flow in each stage of an asset's lifecycle needs to be carefully planned and managed as per the operational requirements of the building owner client. These developments in the digitisation of construction information are fundamental steps in establishing a building's DNA.

3.2 Product and material information

Within BIM, such data is already captured in generic form and proprietary product form. The generic form includes system families, such as walls, floors and roofs. Systems such as Revit (software for BIM) have pre-defined family types that exist within each system family, and within each family type are sets of pre-defined construction specifications. These can then be broken down into materials, such as the layers comprising a certain wall type. This approach enables pre-populating of material information.

Users of BIM software can add further detail to pre-populated data, such as specific product URL, cost, thermal performance, life cycle assessment and life cycle costing related information.

Product specific information should be available where a specific product URL has been included and the supplier of the product has made data available in a standardised and accessible format. This can include environmental information, such as the product's EPD (Environmental Product Declaration).

The combination of the dimensional information with the material/product information enables automatic calculation of the amount of different products and materials at a building level. Such information can then be used to carry out additional analyses, such as life cycle assessment, for which there are BIM compatible software 'Add-ins'.

3.3 Design information

The graphical model and non-graphical information contain much design information. However, for the purposes of reversible building design, this is difficult to access in an automated way. This is due to the lack of data input, either by the pre-populated datasets or being invited as user input, in relation to assessing reversibility. The various aspects of design information required to assess reversibility include connection types, assembly sequencing and dependencies between systems.

4 USER REQUIREMENTS

In order to produce decision making support for various potential users of the BAMB related outputs, a series of stakeholder workshops and interviews were conducted as part of the project work. This task is not yet concluded, and the final results have not been published, but initial results are being used to steer the development of the decision making methodology. Stakeholders consulted included designers, BIM software producers/users, suppliers, contractors, facility managers, consultants and academics.

Generally speaking, it was thought that there were data and/or reporting deficiencies in the current tools and methodologies to enable better decision making where there are 'circular economy' objectives. There were also thought to be gaps in reporting/decision making in other areas that could be encompassed by the approach being developed to improve information relating to the design and composition of new and existing buildings.

Throughout the workshops, a number of key areas for consideration (in terms of improved reporting) were consistently identified. These included:

- Understanding the whole life value/ cost of a building. This included social, economic and environmental aspects
- The ability to carry out a virtual pre-demolition or pre-refurbishment audit, which would also support safer & improved deconstruction practices
- Improved asset tracking across building life cycle – of products and systems, which would also support alternative business models such as leasing or sell-back schemes.
- Linking of warranties and maintenance to enhance asset value during multiple service lives
- Facilitating future reuse through providing an audit trail and provenance record, such as a Material Passport
- Identifying interface and connectivity issues that could prevent future reuse

Across the spectrum of BAMB outputs, including Material Passports, Reversible Building Design assessment and the integration into a decision making support methodology, all the items on this 'wish list' should be achievable.

5 DECISION MAKING METHODOLOGYT

Within the BAMB project, work is currently underway to develop an adapted approach to collecting, collating and analysing data and information to support improved decision making. The performance assessments that are being focussed on relate to the likely drivers of the decision makers across the procurement, design, build, operate and decommissioning phases. These are grouped into environmental, economic and social assessment, with consideration of integrated assessment once the individual elements have been developed.

Development of the methodology is following a process of unpicking the current methods and approaches (baseline), flagging areas where there are gaps or inconsistencies, and developing solutions (BAMB proposed method) or recommendations for an improved approach. The proposed solutions will be trialled on a number of real-life building scenarios to illustrate the differences between the baseline approach vs. the BAMB proposed method.

In terms of the baseline situation, the following areas have been evaluated for life cycle assessment, life cycle costing, BIM and social value/impact:

- Underpinning standards, assessment boundaries and classifications
- Where and how data is input, or and scenarios/choices are selected
- How the results are used and what are the drivers behind these assessments
- Where does data typically come from
- What are the assumptions/default data used to minimise user input
- How does the user input information
- What reports/ KPIs (Key Performance indicators) are typically produced

For BIM there are additional aspects such as the product information normally available from the supplier URL and the structure of data.

The flagging of issues includes where: default data is not sufficiently refined to influence the results, there is lack of guidance or clarity; the boundaries or assessment rules do not adequately consider circular building approaches; or the data is missing to support Reversible Building Design (RBD) type assessment.

The recommended BAMB approach will detail the following aspects:

- Data input (where, what, how and when)
- Environmental assessment – explaining any deviations from the current life cycle assessment approaches
- Economic assessment - explaining any deviations from the current life cycle costing approaches and providing guidance where appropriate
- Proposed social value assessment of circular buildings
- BIM – what extra information could be included by the user and/or software provider to support improved resource productivity
- Underpinning databases to reduce user input requirements and support the assessment process
- User input – guidance and specific data that has to be input to run the revised assessments
- Transferability issues i.e. differences in approach/data that might be needed across EU

The methodological development will also consider how the information and decision making intentions will be transferred and updated throughout the first building life cycle and into future service life cycles.

A final aspect will be the adaptation of the recommended method to existing buildings, focussing on refurbishment scenarios.

6 BIM RESOURCE PRODUCTIVITY PROTOTYPE

BIM is the ideal vehicle upon which a more user friendly and scenario specific evaluation of product and design choices can be made. With some adaptation of the user interface with additional datasets and revised assumptions it is anticipated that a BIM compatible software add-in can be developed. This will effectively illustrate the potential to software providers who may be interested in providing such a product commercially. Final users are considered to be the professionals and decision makers wanting to create a built environment based upon circular economy or resource efficiency/productivity objectives.

7 SUMMARY

In summary, the development of building DNA is well underway with the progression of building information modelling & management, and the digitisation of construction product information. However, the systematic and automated evaluation of circular economy scenarios is an emerging application for such information, resulting in a number of data and methodological gaps and/or inconsistencies.

It is important to build upon the rapid developments in both BIM and circular economy to create an approach and supporting datasets to optimise decision making throughout a building and product life cycle. This is a key development area within the BAMB R&D project, with initial results due to be published in Spring 2018.

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BIM uses for reversible building design: Identification, classification & elaboration

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Abstract

The construction industry urgently needs new approaches to design buildings that can be incorporated in the circular economy. Buildings are still predominantly conceived as static structures with one end-of-life option, demolition, which typically results in excessive amounts of waste. To cut waste, buildings need to be designed as reversible structures that enable transformations, disassembly and reuse of building elements. This may be complex in practice due to the significant information processing capabilities it requires, but previous research has suggested that Building Information Modeling (BIM) could be valuable in the additional gathering, interpreting and synthesizing of information needed. This paper aims to explore how BIM can support reversible building design through an in-depth case-study of the reversible building design practices of a Dutch system builder. Eight BIM uses were systematically identified, classified and elaborated on according to the extent they can support reversible building design. It is concluded that three 'key' BIM uses can fully support reversible building design (design authoring, 3D coordination and drawing production), two 'viable' BIM uses partially (quantity take-off and design review) and three 'negligible' BIM uses deficiently (phase planning, code validation and engineering analyses). The insights and recommendations derived from this paper hopefully assist in selecting BIM uses to design and study tomorrow's reversible buildings.

Keywords:

Building Information Modeling, BIM use, Case-study, Reversible building

1 INTRODUCTION

The construction industry urgently needs new approaches to design buildings that can be incorporated in the circular economy. Buildings are still predominantly conceived as static structures with one end-of-life option: demolition. On one hand, this typically results in excessive amounts of waste being generated [1]. Construction and demolition (C&D) waste contributes about 40% of all solid waste in developed countries [2, 3], with the largest part of C&D waste over the life-cycle of a building being generated during demolition [4]. On the other hand, buildings consume large volumes of virgin resources, which are extracted with considerable environmental damage, in this linear economic system [5, 6]. Moreover, the demand for those resources is likely to increase substantially due to ever-expanding economies and populations [7]. This increasingly critical socio-environmental problem is forcing the construction industry to adopt design guidelines for reversible (rather than static) buildings.

A reversible building is a type of building that is specifically designed to enable transformations, disassembly and reuse of building elements. Transformations involve the change from one building form into another through eliminating, adding, relocating or substituting parts. They are the result of the need to adjust physical surroundings to human activities and may occur on the spatial, structural or material level of a building [8]. Disassembly is the careful dismantling of a building structure to maximize the recovery of its elements for reuse. Reuse is the process during which discarded building elements are recirculated (and sometimes upgraded according to the material structure) and used for the same function without destruction [9]. This preserves the invested embodied energy of deconstructed building parts, extends their service life and significantly reduces the cost, energy use and carbon emissions resulting from demolition, processing for recycling and transportation to landfill and recycling facilities [10]. Through enabling transformations and reuse, the theoretical goal of reversible building design is to design-out waste. In other words, it aims to close the loop of material usage and to achieve upgrading rather than downgrading/down-cycling of building materials. That is not easy to achieve in practice though due to the significant information processing capabilities it requires [11].

Building Information Modeling (BIM) has the potential to support the gathering, interpreting and synthesizing of information needed to design reversible buildings. BIM has frequently been defined as a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle [12, 13]. It is centered around the deployment of a digital representation of a building, the building information model (also abbreviated with BIM). A wide range of methods of applying that model (with one or more specific objectives) have been developed over the years, including quantity take-off (cost estimation), phase planning (4D simulation) and 3D coordination (clash detection). However, little is known about how such BIM uses may assist in dealing with the additional complexities of designing reversible buildings described in earlier studies [5].

This paper therefore explores how BIM can support reversible building design. The upcoming section identifies possible BIM uses and describes their potential benefits. The section thereafter discusses the case-study method that was used to investigate which uses were implemented and how. The paper then continues with presenting and discussing the findings and concludes with a classification and elaboration on how BIM can be leveraged for reversible building design.

2 THEORETICAL FRAMEWORK

Building Information Modeling is the result of a long series of computer-integrated construction research for interactive 3D design since the 1970s. Turk [14] argues that designers have always used information models to describe buildings, but that those models became digital with the adoption of information technology and that they have since then become increasingly well structured. Computer-aided design (CAD) evolved from 2D geometry via 3D geometry towards 3D parametric objects. Where in a geometric CAD system, the human needs to interpret, for example, a cylinder as a structural column, in BIM software this is explicitly stated in the resulting database. Specialized engineering software has been based on engineering objects rather than geometry. Current BIM software represents building parts as objects that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion [15].

In that way, BIM enables the creation, development and use of semantically rich information models. Ongoing research and software development has led to a wide variety of BIM tools and technologies. The potential uses of those tools and technologies have been documented extensively [16-18]. In an attempt to classify those uses, a BIM use was defined as "a method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives" [19]. Other categorizations of BIM uses (or "functionalities") are found in the studies of Won and Cheng [20], Sacks, Koskela [21] and Eastman, Teicholz [15]. Here, based on these sources, eight BIM uses that can contribute to the (reversible) design process are identified and discussed.

1. *Design authoring:* a process in which a BIM model is developed based on previously established criteria. BIM authoring tools can make designing more productive through eliminating rework, providing consistency between different views of the same model and powerful design visualizations [15].
2. *Quantity take-off (cost estimation):* a process that can produce a list of quantity information of materials and building elements from a BIM model. This makes it possible to quickly generate a bill of quantities and to make cost estimates [22]. Precisely and accurately quantifying modeled materials can be particularly useful to measure the effects of additions and modifications to the model.
3. *Phase planning (4D simulation):* a process in which an information model is integrated with a project schedule to visualize phased occupancy, construction sequences and space requirements on a construction site. 4D modeling can support the coordination of various construction activities [23, 24].
4. *3D coordination (clash detection):* a process to identify field conflicts by comparing 3D models of building systems and to eliminate the conflicts prior to installation. This may lead to cost savings of up to 10% of the contract value [22].
5. *Design review:* a process in which a design solution is evaluated by relevant stakeholders to detect any possible failures with respect to program, function of spaces or overall performance [25-27]. The feedback may help in resolving design and constructability issues.
6. *Code validation:* a process in which code validation software is utilized to check the parameters of a BIM model against project specific codes [15, 19]. This reduces the chance of code design errors and automatization has the potential to save time on multiple checking for code compliance.
7. *Drawing production:* a process in which drawings and drawings sets are automatically generated from a BIM model. This includes Schematic Design, Design Development, Construction and Shop Drawings [15]. The same model can be used to create all drawings, reports and analysis datasets, thereby eliminating the need to manually update each drawing for each design change.
8. *Engineering analyses (structural, lighting, energy, mechanical, other):* a process in which the BIM model is used to determine the most effective engineering method based on design specifications. BIM provides several advantages over traditional 2D or 3D models due to the richness of object information necessary for analyses. BIM analysis tools have been developed for structural, lighting, energy, mechanical and other engineering analyses [15, 28].

Other well-documented BIM uses, such as Record modeling, Asset management and Supply chain management, deal more with project phases other than the design phase – which is the focus here. Designing reversible buildings explicitly considers the configuration of building elements, their functions and relationships in a way that satisfies requirements and constraints for disassembly, reuse and transformation. Durmisevic [8] has suggested that this can be achieved by systematically considering independence and exchangeability of building systems/components in three design domains: the functional (material levels), technical (hierarchy) and physical (interfaces) domain. As such, reversible building design can be seen as an activity concerned with different relationships and interdependencies. Previous works have studied above BIM uses for (traditional, static) building design, but implementations for reversible building design have not been well-documented.

3 RESEARCH METHODOLOGY

The aim of this research is to explore how BIM can support reversible building design through identifying, classifying and elaborating on BIM use implementations. A case-study was here chosen as method as it enables to gain in-depth insights about real-world events [29]. This type of research is particularly useful to answer how/why questions about a contemporary set of events over which the researchers have little or no control [30] – like here. The unit of analysis in this case-study is the design practice of a Dutch system builder. This company successfully designs, constructs (and, together with a partnering firm, often disassembles) buildings with mostly temporary or semi-permanent functions. For the main structure, the firm therefore uses modular, prefabricated building elements that match with each other, such as foundation, column, façade and roof elements with standardized sizes. The use life-cycle of most of the firm's buildings is relatively short, so a unique yet key design consideration is that these can be disassembled easily and that the aforementioned elements can be reused elsewhere. For the context of this study, their designs are therefore seen as 'reversible.'

Data about BIM uses in reversible building design practice is collected from multiple sources as to enable data triangulation. The most important data source concerns two rounds of semi-structured interviews with knowledgeable practitioners from the focal company, such as a designer, project leader and expedition/logistics manager. The first round of interviews dealt with information management practices within the firm. This round was followed by a second round in which an in-depth interview was held with one of the designers. Questions included if and how the eight BIM uses (derived from literature) were implemented in the firm's design practices. The first mentioned author conducted and recorded all (seven) interviews and transcribed them verbatim. A summary of the transcriptions was then sent to the interviewees for verification purposes. Other data that was collected includes a BIM model, 2D and 3D drawings, schedules, cost estimations, e-mail correspondence and contract documents.

Data analysis involved systematically examining, categorizing and comparing the collected data. The aforementioned BIM uses were identified *a priori* and guided the analysis – which is the "most preferred strategy" in case-study research [30]. The transcriptions were examined for BIM uses within the context of reversible building design. Relevant excerpts were marked and later categorized in a table with BIM uses. All other evidence was assessed and the interpretations were recombined with this table, thereby considering alternative interpretations of the theoretical relations that were emerging. It was then also decided to further specify the findings of the BIM use 'design authoring' in a distinct appendix, since this use turned out to be the most dominant of all uses (but those specifics were not the main focus here). Hence, comparing the evidence from practice with the *identified* BIM uses made it possible to *classify* and *elaborate on* each of the eight theoretical BIM uses for reversible building design.

4 RESULTS

The case-study's focal firm has implemented some, but not all, BIM uses in their reversible building design processes. BIM is mainly comprehended as a way to draw in three dimensions, rather than as a way to organize relevant project information in a database. Design authoring, the BIM use that is concerned with the creation of the actual model of a building, is seen as the most important use (and specified in more detail in Appendix I).

1. *Design authoring:* In their project work, the focal firm's designers use BIM to efficiently create representations of buildings. All standardized, prefabricated building elements that the firm uses to (re)construct a building are available as object families in the BIM software platform used. Instances of these objects can be inserted in a project template and set to different levels of detail (ranging from coarse to fine), corresponding with the relevant design stage. The parametric object behavior reduces repetitive design work (and rework), since modifications to one object in one view automatically propagate to other objects and views. Product data, like available materials for façade elements, is received from sub-contractors or, mainly, suppliers and is stored in an extensive library. Rendering, the process of creating 2D images with 3D (photo)realistic effects, is not always yielding satisfying results and is therefore sometimes outsourced.
2. *Quantity take-off (cost estimation):* Cost estimations are based on the BIM model. The parametric objects in the model contain data that makes it possible to identify and count them. Designers can use that to generate a bill of quantities (take-off), which serves as a basis for cost estimations (but not for work preparation). These cost estimations are complemented by (or replaced with) manual calculations, since the cost estimators typically find that less time-consuming and also expect the latter to be more accurate.
3. *Phase planning (4D simulation):* No 4D simulations are conducted to inform the building design. The planning of a construction project is graphically represented with Gantt charts in which the activities are represented as horizontal bars that have certain relations with each other. Such schedules are not integrated or linked with a BIM model, even though the firm has the necessary software licenses. Planning the construction works is seen as a task for the project leaders (who also do not deploy 4D simulations) rather than an activity to inform or optimize a building's design.
4. *3D coordination (clash detection):* The firm performs clash detections to identify and resolve design issues. Different aspect models, representing design work from different design disciplines, subcontractors or suppliers, are therefore compared with each other in specific software. The firm pursues an 'open BIM' policy, requesting the IFC file format for importing and exchanging data models. Spatial conflicts that are being detected by the software are visually evaluated by a designer, who then makes screenshots and annotations about those conflicts that need to be resolved. Subsequently, potential solutions are discussed between the different designers in order to decide what solution is most preferable.
5. *Design review:* BIM is used to evaluate a design proposal with a client and to receive feedback. This is typically done by designers who make cross-sections, floor plans and 3D images from the BIM model to show relevant design details; the 3D model itself is only sometimes shared with a client. During a review, it is discussed whether the designed solution complies with the intent of the client. Such review meetings are primarily conducted by a project leader rather than a designer. Project leaders do not use walkthroughs or other functionalities from 3D viewing software to demonstrate aspects of a design proposal. They mainly rely on the designers' visuals generated from the BIM model.
6. *Code validation:* BIM is not (yet) used to validate whether the model complies with the building code. Designers perform a variety of checks against existing rules and regulations, for example related to the quantity of daylight available in rooms or the necessary ventilation capacity. These checks are done by hand with the help of simple spreadsheet software. However, the firm recently purchased a license for new software that also turned out to have the ability to validate a model against the building code. At the time of this research, it was decided to investigate the potential of this BIM use for the firm's design practices.
7. *Drawing production:* All drawings are generated from a BIM model. Designers do this by determining from which perspective they want to view the model and with which settings (for example color usages and levels of details). Relevant views include elevation plans, cross-sections and 3D visualizations. One or more views are then put in a framework and complemented with a legend and relevant textual elements (like information on the assembly sequences). In producing a drawing, a designer essentially creates a PDF file or print job from a framework with BIM view(s). No other drawing software is used for making a 2D or 3D drawing from a building design.
8. *Engineering analyses (structural, lighting, energy, mechanical, other):* The firm does not analyze building engineering aspects with BIM. Most of the engineering

analyses, for example related to fire loading or energy performance, are outsourced to other consultancy or engineering firms. Those firms typically request a (simpler) geometric 2D or 3D model rather than a BIM model. Shadow analyses are conducted by the focal firm itself though, but those are only rarely requested.

The data do not reveal any other BIM use implementations for the reversible building design practices of this case-study's focal firm.

5 DISCUSSION

This study explored how BIM can support reversible building design. Eight potential BIM uses were first identified through a review of recent literature. An in-depth case-study was then conducted to examine which of these BIM uses were implemented – and how – in the reversible building design practices of a Dutch system builder. Through contrasting the actual BIM use implementations with the theorized ones, this paper contributes with novel insights and recommendations on leveraging BIM for reversible building design.

5.1 Theoretical and practical contributions

First, the implementation of three BIM uses can *fully* support reversible building design: design authoring, 3D coordination (clash detection) and drawing production. The findings demonstrate that designers use BIM to efficiently develop three-dimensional representations of a reversible building, although rendering may be tedious (design authoring). Spatial conflicts in the design proposals are identified and collaboratively resolved with clash detection software (3D coordination). Drawings of a building project are generated from a BIM model through defining perspectives and applying desired viewing settings (drawing production). The potentials of these three BIM uses are exploited in the case-study's focal firm. The authors therefore classify these as 'key' BIM uses for reversible building design.

Second, the implementation of two BIM uses can *partially* support reversible building design: quantity take-off (cost estimation) and design review. It was found that the BIM model can be used to generate a bill of quantities (quantity take-off). However, cost estimations are still predominantly based on (additional) manual calculations of quantities of materials. The BIM model can be used to evaluate a building design with a client and to receive feedback on the design intent (design review). Designers nevertheless provide mostly static visuals to the firm's project leaders and have little or no contact with a client themselves. The potentials of these two BIM uses are only partially exploited in the design practices studied. The authors therefore classify these as 'viable' BIM uses for reversible building design.

Third, the implementation of three BIM uses can *deficiently* support reversible building design: phase planning (4D simulation), code validation and engineering analyses (structural, energy, mechanical, other). In the case-study, no evidence was found of 4D simulations to inform the building design (phase planning). The BIM model was also not used to validate the design against the relevant building code (code validation). Simulations and calculations of engineering aspects are not based on BIM (engineering analyses). The potentials of these three BIM uses are deficiently exploited by the designers in this case-study. The authors therefore classify these as 'negligible' BIM uses for reversible building design.

This study also offers practical contributions to designers who aim to design reversible buildings. It has identified eight BIM uses for reversible building design. The authors' empirically-based classifications of these uses helps designers in prioritizing and implementing BIM uses. They should start with selecting the key BIM uses (design authoring, 3D coordination and drawing production), followed by the viable BIM uses (quantity take-off and design review). The potentials of the negligible BIM uses (phase planning, code validation and engineering analyses) remain unclear. In implementing these uses, designers can expect similar contributions as the ones described in this study when the contexts of their design work are more proximally similar to the one here.

5.2 Limitations and further research

This study has several limitations, from which the authors suggest new directions for research. It is firstly based on a single case-study. The rationale behind that is that the focal firm uncommonly designs buildings that can be disassembled and of which the elements can be reused elsewhere. In terms of Yin [30], this offered a "unique" case. The downside of the single case is that it is unclear to what extent the findings are generalizable beyond the immediate settings of this study. Similar studies as this one, but in varying times and places, can help in answering that question. Another problem concerns the limited insights into the relative benefits of using BIM to design reversible buildings. This study elaborated on how BIM uses are implemented in the context of reversible building design, but cannot accurately answer how much better those design practices are compared to the absence of BIM. Previous work has, for example, suggested that the design process can be more effective if the firm has a higher BIM 'maturity' [31]. More research is therefore needed that relates perceived benefits of BIM uses with the BIM maturity levels within the context of reversible building design.

6 CONCLUSION

This paper has explored how BIM can support reversible building design through an in-depth case-study. Eight BIM uses were systematically identified, classified and elaborated on – according to the extent they can support reversible building design. Based on that, three main conclusions are drawn. First, it is concluded that design authoring, 3D coordination (clash detection) and drawing production – classified as key BIM uses – can fully support reversible building design. Second, it is concluded that quantity take-off (cost estimation) and design review – classified as viable BIM uses – can partially support reversible building design. Third, it is concluded that phase planning (4D simulation), code validation and engineering analyses (structural, lighting, energy, mechanical, other) – classified as negligible BIM uses – can deficiently support reversible building design. It is hoped that the insights and recommendations this paper provides can assist in selecting BIM uses to design and study tomorrow's reversible buildings.

ACKNOWLEDGEMENTS

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APPENDIX I: IMPLEMENTATION OF REVERSIBLE BUILDING DESIGN GUIDELINES WITH BIM IN CASE-STUDY

Reversible building design guideline[1]	Implementation with BIM
1. Functional decomposition	Different design disciplines (e.g. structural, MEP) add data to one main (i.e. architectural) model. A distinction is made between structural and non-structural elements. No conscious functional separation for other elements.
2. Systematization and clustering	Buildings are systematized to a great extent: they are all made of modular, prefabricated elements from the following categories: foundation, floor, column, wall, façade and roof elements. All of these are available as parametric object families within the BIM software used.
3. Hierarchical relations between elements	The most important hierarchical distinction between building elements is whether an element has a structural function (or not). Parametric objects therefore have a parameter that indicates this. Similarly, walls can be room bounding (or not), which is also indicated with a parameter which value can be changed.
4. Base element specification	Snap points are used within the BIM software to define how building elements are connected with each other. These snap points are linked to the regular building grid. Some parametric families have their own snap points (e.g. piping needs to be connected to the sanitary system). No conscious specification of base elements.
5. Assembly sequences	The BIM software enables the creation of an exploded view of the building design, which can be used to communicate assembly sequences. An exploded view is typically accompanied with some (manually inserted) texts. No design optimizations regarding (dis)assembly sequences.
6. Interface geometry	The geometry of interfaces is standardized to a large extent. This is a core part of the building system applied in all projects. It is represented in a simplified way in the BIM model. At the highest level of detail, the location of bolts is modeled (yet manufacturing information is missing).
7. Type of connections	Connections between elements are mostly mechanical (rather than chemical), being bolts and screws. That knowledge is primarily implicit and modeled limitedly to make sure the model becomes not too heavy (in terms of processing power).
8. Life-cycle coordination	Data about the expected life-cycle duration is not linked to the model. Information about warrantees is shared with a client through other project documentation (such as contracts). Within the BIM software, a phasing functionality is used to define whether building elements are new or reused.

[1] Guidelines are based on the design for disassembly aspects of Durmisevic [8]

Sarajevo Green Capital

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Abstract
This paper was inspired by the European Green Capital Award, which is awarded annually within the EU. The main message that this award aims to send is that European cities and citizens have the right to healthy living in urban areas. Cities should strive to improve quality of life while at the same time reducing the impact on the global environment.
This article aims to analyze some of those cities, that are similar to Sarajevo and that have received this prestigious award, and look for ways and steps that Sarajevo should take in the future in order to be able to become the candidate for this award.

Keywords:
Sarajevo, green capital, green City

1 INTRODUCTION

The aim of this paper is to find ways to make Sarajevo a green city. The best examples of changes made by European cities in order to create green cities are reflected in the European Green Capital Award. Therefore, part of this paper deals with the analysis of this award and its application to Sarajevo. This award is given annually to the city that is leading environmentally friendly. So far, 15 European cities have decided to create this type of competition in 2006 in order to make it clear how important it is to improve urban spaces in order to make them healthier and sustainable.
The progress in this direction is a reward for itself, but these cities considered it important to appreciate their work with such a reward. Also in this way they will work on promoting and encouraging other cities to move in direction of sustainable and environmentally friendly urban environments.
The main message that these awards want to send is that European cities and citizens have a right on a healthy urban life. Cities should strive to improve the quality of life while at the same time reducing the impact on the global environment. The slogan of this award is: "Green Cities - Great for Life". [1]
The choice is estimated on the basis of 12 environmental indicators: climate change, local transport, green urban areas, nature and biodiversity, air quality, acoustical environment quality, waste production, and its management, water management, waste water treatment, eco-innovations and sustainable employment, energy efficiency, integrated environmental management.
The aim of this paper was to examine the situation in the city of Sarajevo regarding several areas that are important for winning the European Green Cities Award in order to determine if there is a possibility for Sarajevo to run for this prestigious award in the future and, if so, where improvements need to be made.
This paper deals with the following topics: local transport, green urban areas, nature and biodiversity, air quality, waste management, energy efficiency. Other important topics, which are not part of this paper, are planned to be analyzed in the future.
Cities that have already won this award were taken as examples and they are Copenhagen, Nantes and Vitoria-Gesteitz. This paper attempts to analyze the current situation in Sarajevo, and what has been done so far. In comparison to the above cities, it also attempts to come up with some recommendations that should be applied in order for Sarajevo to become a candidate for a green city capital.

2 LOCAL TRANSPORT

During the analysis of local transport, the proposed solutions from Copenhagen were analyzed, because it had most similar problems as Sarajevo from awarded cites. The transport enhancement plan in Copenhagen has been divided into 4 areas and 13 concrete measurable targets. Areas of action are the creation of a city adapted to cyclists, improved public transport, traffic calming and parking restriction, and measures to reduce emissions of harmful gases from vehicles. [2]
They recognized that 50% of the population was going to work or to school by bicycle in 2013 compared to 35% when they started applying the program when that percentage was 35%. In order to achieve this goal, the city spent 67 million euros, the most of which went to improving the cycling infrastructure. [2]
Regarding the improvement of public transport, the city has implemented the system so that at least a certain type of traffic is available to 98% of the population in the radius up to 350m from the place of residence. Especially, suburban trains are promoted as the most environmentally acceptable mode of transport. [2]
Regarding traffic calming, the application of different methods has been applied, primarily in pricing of parking in the city centers and parking restrictions. This enabled parking exclusively for residents of certain city zones.

During the survey, the data has been obtained for number of registered vehicles in Sarajevo Canton, which showed an enormous increase. It has grown from 92 062 vehicles from 2003 to 133 948 registered vehicles in 2015. This means that number of vehicles has grown by 45% in the last 12 years. [3]

The biggest reasons for this increase are poorly organized public transport and changes in the regulations for the import of used vehicles, since EU customs duties in 2009 have been abolished.

There are 95 trams 95 trams, 130 buses, 47 minibuses and 19 trolleybuses and 908 registered taxi vehicles in Canton Sarajevo. On the basis of this data and the analysis of cities with a similar number of inhabitants, it can be concluded that this number of vehicles is not adequate. [4] [5]

Considering that the exact data on fuel types used by motor vehicles in Canton Sarajevo could not be obtained, an estimate based on fuel sales was made, according to which 69% of the vehicles go on diesel fuel, and 26% on petrol, while only 5% use alternative fuels. It was also not possible to find the correct exhaust gas standard in vehicles, but the estimate was based on the age of the registered vehicles.

It was also not possible to obtain accurate data on the number of parking spaces in the city of Sarajevo, since public utility company "Rad" has only data on its parking spaces. In addition, there is a large number of private parking lots, and an estimate has been made that the city in total has 30 000 parking spaces, which is inadequate in view of the number of registered vehicles. [6]

Measures that could improve local transport are the following: promotion of a bicycle as a mode of transport, improving cycling infrastructure, improving public transport services (increasing number of lines and number of vehicles), development of new modes of transport that the City of Sarajevo currently does not have, such as city cable cars and suburban trains, zoning of the city in terms of parking, so that public parking can be used only by residents of the settlement, increase parking fee in the city center, increase in the number of parking spaces in suburban areas, making new roads that will change the transit traffic outside the city center, payment for entering the city, subsidizing vehicles to alternative fuels, prohibition of registration of vehicles that do not meet the EURO 3 standard of exhaust gases and etc.

3 GREEN URBAN AREAS

Copenhagen was analyzed in relation to the urban greenhouse. About 25% of the city area is covered with greenery, which amounts to 42.4 m2 of green area per inhabitant. The city planned redistribution of green areas in order for 80% to be available at a distance of 300m from the place of residence. [2]

Plans for the future development of the city envision that the city expands into the areas of former industrial zones and be converted into residential and business leaves larger green areas to form the "green lungs" of the city. The city has divided the parks into two types: small (pocket parks) and large (over 5000m2). They have decided that the pocket parks should be equally distributed in the structure of the city, while larger ones should become places of meeting and be richly equipped with play areas, sports grounds, pleasures, skate parks and the like.

In addition, they make a unique register of parks and natural landscapes within the city and it is decided not to reduce their area, but it is only possible to do a counter-process to turn other zones into parks. In addition to green areas, the city recognized swimming as an important sport, so the city made several swimming pools and beaches that have become a magnet for the public. In addition to this, a special aspect of the city was the promotion of active use of parks in terms of recreation and sports activities. The ultimate goal of all the listed activities is to improve the climate conditions in the city and to increase the quality of life.

Sarajevo is lacking adequate data on this matter. The data that exists is not systematized. In other countries, the recreation zone and urban greenery are classified into the same groups; however, they can still be stratified, which is not possible in Sarajevo records. According to the latest available data on urban greenery in Sarajevo there is only 4,0m2 per inhabitant, which is far from the minimum required greenery of 9,0m2 per inhabitant according to the World Health Organization. [7] [8]

In addition to the above-mentioned astonishing small green spaces in the city, the second problem is reflected in sports and recreation zones that are true in the city's tissue and are not equally accessible to the population. Their maintenance and organization is very limited and primarily rely on the initiative of the authorities without the possibility of a private initiative. Recommendations for Sarajevo regarding urban greenery are the following: introduce a single register of green areas, limit the spread of the urban zone to the urban greenhouse, increase the number of mini parks (under 1000m2) and make them relatively uniformly distributed in the city structure, transforming former industrial zones into parks, formerly military facilities, increase the green areas of urban greenery to at least a minimum by the World Health Organization, promote active life, modernize parks as recreation areas, increase the number and equalize the distribution of sports grounds in the city.

4 NATURE AND BIODIVERSITY

Copenhagen created a register of protected natural landscapes and recognized vulnerable and protected natural entities and decided to protect them. In order to protect these types of parks, the parks are divided by types, so the city recognized: urban parks and urban areas close to nature. Two approaches emerged from this division, with parks called "urban areas close to nature" minimally protected and human intervention in them reduced to a minimum. In addition, the city has worked to promote pastures in the vicinity of urban areas in order to make these spaces into family picnics, especially taking into account the children and their familiarity with domestic animals.

Given the lack of an adequate systemic approach to the issue of parks and green areas, biodiversity cannot be seen on the example of Sarajevo. The very concept and importance of biodiversity in Bosnia and Herzegovina is relatively new, it was only introduced in 1995. If these concepts at the level of Bosnia and Herzegovina are analyzed, the vast diversity of plant and life species owned cannot be recognized. What is lacking is a systemic relationship to the inherited natural wealth both in collection, analysis, systematization and in preservation. [9]

Recommendations for action in this aspect for Canton Sarajevo are the following: introduction of a register of protected plant and animal species, protection and promotion of plant and animal species from the register, promotion of urban pastures, promotion of urban farms, biodiversity is an integral part of all planning processes for improving the quality of life in the city, and it is difficult to see and apply it as an isolated one.

5 AIR QUALITY

Of the award winning cities for Green Capital, the most complete analysis was done for the city of Copenhagen. Air in this city is mostly polluted due to traffic. Car traffic makes up 90% of the city's pollution [2]. The largest air pollutants, such as lead, sulfur dioxide and PM10 particles, are below the limiting values. In 2010, only measurements of NO2 exceeded the boundaries on several roads in Copenhagen. In order to reduce NO2 emissions, the Danish Environmental Protection Agency has defined several actions that must be taken: to promote energy-efficient cars, taxi vehicles must be minimum energy class C, the requirements for establishing a zone in a city limited to low emissions vehicles, it is necessary to reduce tax for electric vehicles, it is necessary to establish a special tax on the use of fossil fuel for cars and vans.

The situation in Sarajevo is quite alarming. A study by CETEOR compared the level of carbon monoxide, nitrogen oxide, particulate matter and sulfur dioxide in the last 30 years [10]. The levels of particulate matter and nitrogen oxide have been found to increase significantly. Furthermore, the measurements showed that the level of SO2 is decreasing. Black smoke (soot) increases during winter, and the reason is incomplete combustion of fuel for heating [11].

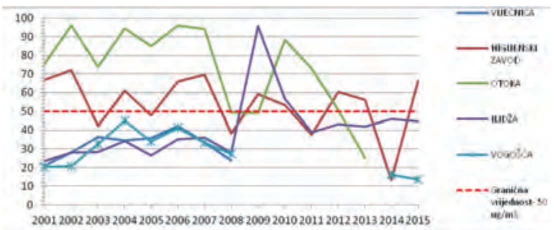

Figure 1: Concentration of soot at manual stations

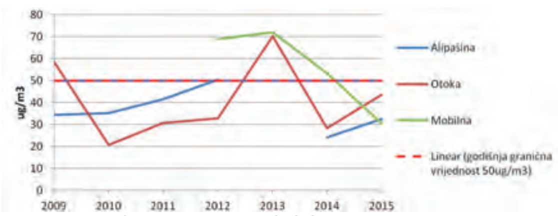

Figure 2: Concentration of SO_2 at automatic stations

Figure 3: PM10 concentration at automatic stations

As can be seen, soot, nitrogen dioxide and PM10 particles in most of the city of Sarajevo exceed the limiting values as they are defined by the standards on air quality of the European Union. Air in Sarajevo is polluted for several reasons, and they can be divided into industrial, residential and traffic [10]. If the industrial sector is considered, the most common causes of pollution are: poor maintenance of energy and industrial plants and the use of inappropriate fuel. The most common reasons for air pollution occurring in the housing sector are the following: large heat losses, and houses that are not energy efficient and insufficient use of biomass for small fires. Most of the coal is of poor quality. Finally, the reasons for pollution in the traffic sector are: a large number of cars, the regulation of automobile control is not applied or missing, public transport is inefficient.

The following is a list of priority actions to be undertaken in the city of Sarajevo in order to improve air quality: it is important to work on raising citizens' awareness. Cantonal institutions, municipalities and industry representatives need to be involved and educated in order for everyone to understand that air protection is a shared responsibility. When it comes to heating houses and public buildings, there is plenty of room for improvement. First, we need to work on improving the energy efficiency of all facilities. The Sarajevo Canton should ensure the availability of natural gas for heating, so that citizens use natural gas for heating more than coal. It would be good to introduce district heating for residential areas in a city that currently use coal for individually heating the buildings.

Finally, improvements should also occur in the field of urban planning. When planning a city, the natural environment must be respected. The appropriate area of green space is crucial for one city due to natural air purification, and these principles must be respected especially when it comes to building new facilities. The floors of new buildings must be clearly defined, and respect the climate of Sarajevo. Namely, during the winter in Sarajevo there is no direct wind, and the air cannot be cleaned in this way. This is aggravated by the construction of high-rise buildings and large facade surfaces, and this construction trend should be stopped.

6 WASTE MANAGEMENT

In Copenhagen, 57.4% of waste was recycled in 2009 [1]. In the residential sector, 27% of waste was recycled, and 71% of waste was sent to incineration for energy recovery. These incineration plants are connected to boiler houses for district heating, and electrical systems, and in this way waste is used for heating and electricity production. 86.9% of the waste from the construction industry is recycled.

In total, only 1.8% of waste is taken to urban landfills, and this waste is mostly asbestos, insulation or other inert materials. It is completely prohibited to deposit organic waste in Denmark. The priority of the city of Copenhagen has been to reduce waste production for a long time and increase reuse [2].

The information that follows in figure below is the data from "Waste Management Plan of Canton Sarajevo 2013-2018. Draft" [12]. When comparing the amount of waste produced (totaling 201,684 tons per year) in Sarajevo compared to some other world cities, it can be seen that Sarajevo produces more waste than most cities.

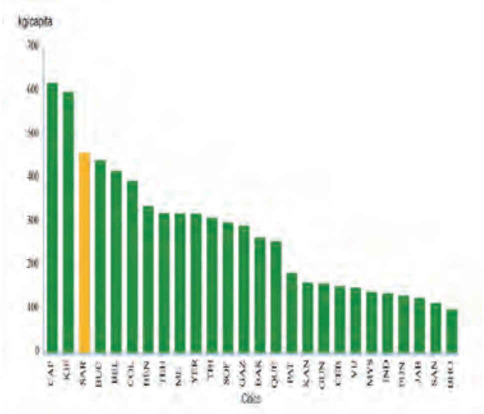

Figure 4: Amount of waste per resident

Therefore, these volumes are potentials that could be used in the recycling process, but they are deposited in the city of Sarajevo on city landfills.
Figure 5 shows the goals for recycling paper, plastic and glass in Sarajevo Canton [12]:

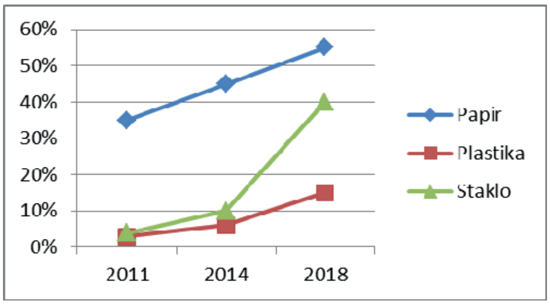

Figure 5: Aims of recycle by Canton Sarajevo

Generally, there are no accurate data on types of waste and their quantities in the Sarajevo Canton. Cut-off estimates found that in 2012, 29% of paper, 1.8% plastic, and 4.8% glass were recycled [12]. Therefore, the targets set in 2012 have not been achieved. Iron is recycled in sufficient quantities, and there is a strong market for this material. There is no organized collection of waste oils and oily waste. Measurement of waste batteries was not performed, but the analysis showed that it is approx. 36% of the total amount of waste batteries recycles [12]. There are no data on the actual amount of waste tires. There are a number of companies registered in the Canton for the collection of waste tires, but it is certain that it is not actively involved, because there is no recycling market for waste tires. There is no detailed analysis of the construction waste, and its quantity, or species, has not been determined, but the following data is available at the Smiljevići landfill [12]:

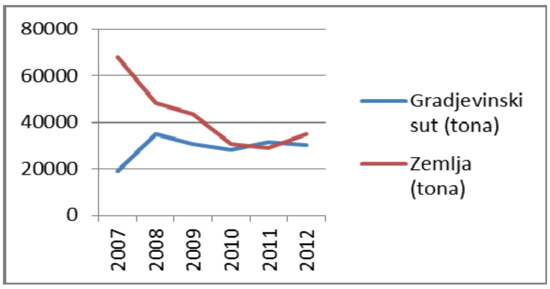

Figure 6: Amount of waste at Smiljevći land fill from construction industry

There is no sorting of construction waste, nor recycling. Almost everything ends up in urban landfills. Furthermore, it was estimated that Canton Sarajevo generates over 30,000 tons of biodegradable waste per year, but it is not collected separately, and ends up in a landfill with residual municipal waste [12]. There are no data on the collected amount of asbestos, or special landfills, nor the regulations on how to treat this toxic waste.
Ultimately, in Canton Sarajevo there is no adequate system of organized selective collection of waste through a public operator. Because of this, the Canton has no way to profit from the reuse of raw materials, while at the same time city dumps are filled with unnecessary materials, which could otherwise be reused.
In order to improve the situation in Sarajevo, the following are urgent measures to be taken:

- Make a detailed analysis of waste, and clearly define what type of waste is generated by the city and in what quantities.
- Establish by measuring the amount of recycled material, and work on capacity building in this field. Strengthen existing capacity or create new recycling facilities. Work to establish a market for such materials.
- Establish a recycling system that functions throughout the city.
- Work on informing citizens about the importance of recycling.

7 ENERGY EFFICIENCY

Copenhagen reduced the emissions of greenhouse gases by 20% compared to 2005, and it managed to do so by 75% of the reduction realized by the basket of changes in energy production, and 10% come from energy savings. In particular, the production of energy from renewable sources for district heating of residential units has increased. These units were pre-heated on coal, and now mostly on biomass. Geothermal energy plants and winds are increasingly used, and some of the plants are based on the use of waste and sewage sludge. It is planned that by 2025 heating of residential areas is completely based on renewable sources. Also, one of the important items is that, with the improvement of the isolation of public buildings, 1000 m2 of photovoltaic panels are installed on these facilities.
The Law on Energy Efficiency in Bosnia and Herzegovina was recently adopted in February 2017, so it can be safely stated that there was no systemic approach to this area. Most projects to improve in this area are the result of various initiatives. Most local communities have opted for energy efficiency projects that will go towards the infliction of public buildings, primarily kindergartens and schools, and very few housing facilities. However, in addition to extinguishing, not much has been done on solving and obtaining some other alternative energy sources, so these processes can be called partial problem solving.
It can be noted that the largest energy consumers in Canton Sarajevo are housing units with a share of 44%. The reasons for this are the fact that most buildings built before 1970 have no thermal insulation, and that a total of 85% of residential buildings do not have a satisfactory thermal insulation. The average energy consumption for heating purposes in FBiH is 180KWh / m2, while 95KWk / m2 is permitted.
Given that there are no official data on the types of fuels used by citizens in heating, we estimated the use of the poll conducted by ENERGIS, which showed that coal and wood heat up as much as 48.3% of Sarajevo Canton residents, 43.1% of gas. Based on this, we can conclude

that we have a very unfavorable fuel structure used for heating, and it is necessary to work on improving these indicators in order to reduce pollution and improve the energy efficiency of energy sources.

In addition, 49 928 apartments in Sarajevo Canton are supplied from the central heating system, which means that about 37% of the population is reliant on such a heating system, so that all energy efficiency projects must also include improvements in this system.

In order to achieve energy efficiency effects, it is necessary to collect data on energy consumption for public utilities, traffic and public lighting, and also introduce better regulation and control in the subsidized fuel system. In the case of utopia projects, change the approach so that besides the problem of thermal insulation, the issue of energy sources will be solved. For reduced environmental impact, it is also necessary to use alternative energy sources, also to encourage the population to set up mini-fuels (photovoltaic panels on buildings). Encourage the population to use central heating systems, to minimize individual heating that has proved to be inefficient.

8 SUMMARY

There are numerous surveys in Sarajevo Canton regarding the above mentioned topics, which concern the creation of a sustainable and green city. One of the key problems in this area is that there is no interdisciplinary, holistic approach to this topic. Important actors involved in creating an urban space that is sustainable and healthy for citizens, plants and animals are not connected, nor they cooperate and communicate with each other. An urgent strategy is needed to gather all these actors, and of course the political will to make Sarajevo go in the direction of being a green city. Only together, a strategy can be made which will outline the necessary actions to be taken, as well as concrete steps how to achieve the goals. Important aspect is the cost that needs to be developed and the financing mechanisms outlined how this can be achieved. There are number of possibilities for financing of proposed activities, from local level, by green taxation and green public procurement measures, as well as savings from each activates or projects. In addition to this, there are EU IPA programs and other donor activities that could support great part of the activities which will lead to full achievement.

Financing and determination of concrete steps are beyond the scope of this initial paper. The goal of this paper is to analyze only some of the areas that fall into the criteria for the European green city award and come up with some of the procedures that should be urgently undertaken. This paper only seeks to bring attention to this topic and spark up a conversation and communication between all the stakeholders that should be involved in this procedure, starting from authorities, industry representatives, environmental specialists and active citizens.

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Influence of Pedestrian Accessibility to Walkability of Predominantly Residential Areas – Example of New Belgrade, Serbia

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Abstract
Walkability is one of qualities needed in contemporary city; it encompasses numerous factors with pedestrian accessibility as one of them. Pedestrian accessibility is particularly interesting topic in "small scale context" where it significantly affects overall walkability potential of given environment (micro-location).

Aim of the paper is to examine and workout this phenomenon from the viewpoint of the architect/urban planner, and to analyze pedestrian accesibility within the land use of New Belgrade (the largest municipality of the City of Belgrade, Serbia; dominantly features the residential content of collective housing), and by that to contribute to wider elaboration on its' walkability potential.

Keywords:
walkability, pedestrian accessibility, urban land use, residential areas, New Belgrade

1 INTRODUCTION /TERMS DEFINITION

All aspects of human existence, today, are under a question, with possible catastrophic consequences if aren't going to be directed towards stability – from interpersonal relations, migrations and cultural "melting pots", through ecology – climate change threat, extinction of species and exhausting resources, to serious damage of states economies and rise of globalization – world economic order deprived of basic humanity. Such complexity of modern world impose the problematic aspects within almost all human action plans where domain of modern city planning and management is for sure one of the greatest challenges. Multidisciplinarity – joint action of various professions – is recognized as necessity, inter alia, in order to better understand, better explain and better manage such complexity.

Interpretation of human activities through the balance of aspects of Economics, Ecology, Social and Culture, as it proposed by sustainable development concept, opened the practice of studies that are dealing with many of data, complexity and with the lot of forseen scenarios as a result, provides the possibility of achieving the most adequate one for the specific space in its specific time. To observe and manage complexity with the aim of sustainable living in our cities – seems to be the main course of all today's studies.

1.1. Urban Land Use and Accessibility

Agenda 21 in Chapter 7. "Promoting sustainable human settlement development," emphasize theme of "Promoting sustainable land use planning and management" and the theme of "Promoting sustainable energy and transport systems in human settlements", with the suggested activity: "Integrate land-use and transportation planning to encourage development patterns that reduce transport demand" [1]. Polzin discussed this relationship on the three hierarchical levels: the site, the neighbourhood and the urban area level. He concluded that of importance is to notice the way the features of a single site affected habits in traffic; for the neighbourhood level of importance are: density, urban design and the presence of diverse/mix uses; for the urban area, the entire surface that are built are considered, also the density, mix of uses, urban form, urban design, level of activities and spatial continuity of buildings [2].

Rodrigue, Comtois and Slack explain the interdependence that develops between traffic and land use in cities and introduces the notion of accessibility. They conclude that changes in the characteristics of investments, services and technologies in the field of transport can affect the overall levels of accessibility as well as the accessibility of different specific locations. Changing the degree of accessibility can cause changes in the land use that affect the matrix of activity in the space, and the activity matrices are in direct relation with the travel matrices - the number of trips, the time in which they are taking place, the matrices "starting – finish point". These changes in travel requirements have a significant impact on the development of a new transport network and services, and these changes again affect accessibility [3].

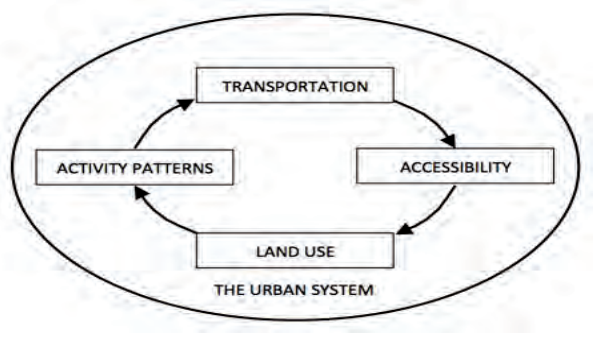

Figure 1. Interdependence between land use and transportation in urban system [4]

Land use-transport integration has been recognized as one of the factors related to urban traffic that can help to reduce crowds and make changes in the choice of means of transportation different from individual car driving, and in that way: reducing the need to travel and the length of trips, making it easier and safer for people to access services and facilities, reducing transport impacts on communities, providing for the efficient distribution of goods and services to businesses and the community [5], [6].

1.2. Walkability

The term "walkability" with its health, environmental, and economic benefits, was created, defined manly qualitatively as: "The extent to which the built environment is friendly to the presence of people living, shopping, visiting, enjoying or spending time in an area“ [7]. Since the goal of walkability also requires quantitative assessment of pedestrian mobility, quantified domain included: the presence of safe and attractive streets and paths, block lengths or street connectivity and the location, diversity, and frequency of destinations [8].

It could be concluded that the walkability basically deals with three principles: physical access, place, and proximity. But the factors affecting walkability are numerous: street connectivity, pedestrian accessibility, land use mix, residential density, presence of trees and vegetation, frequency and variety of buildings, entrances and other sensations along street frontages, transparency (amount of glass in windows doors, orientation and proximity of homes…), places to go to near the majority of homes, placemaking, retail floor area ratio [9].

1.3. Pedestrian Accessibility

Pedestrian Accessibility within the wider topic of Land Use and Accessibility primarily deals with uses and their positions in city space relative to certain points – from which we are supposed to walk to and from. As one of the factors affecting walkability, Pedestrian Accessibility could be basically described as "The ease of travel by foot between destinations". Following the glossary of "the KonSULT" (the Knowledgebase on Sustainable Urban Land use and Transport): "The pedestrian accessibility of an activity to an individual is the ease with which the individual can get, by foot only, to the places where that activity can be performed") [10], [11].

2. TRAFFIC MANAGEMENT AIMING TO REDUCE CARBON DIOXIDE EMISSION IN CITIES

Cities produce most of the greenhouse gases that endanger the ecosystem. Some authors point out that 70-80% of the total emissions of these gases in the world are just generated in urbanized environments [12], [13]. The focus of transport in order to influence habits of the inhabitants can have fair effects in urban sensitivity management for climate change, since pollution from public and private urban traffic makes up half of CO2 emissions [14].

Interesting trends that link urban structure and traffic management are detected: less emission of pollutants per inhabitant are usually encountered in the denser urban tissue with quality public transport and in warmer climatic zones. More densely populated cities have a great potential to limit the use of motor vehicles (and in this respect, to reduce the use of fossil fuels, as well as reduce emissions of harmful gases). The more densely populated cities allow more journeys by hiking or biking, whether the use of public transport is increased. Many advanced cities in Europe with the highest quality living conditions use one fifth of the amount of gasoline per year used by less compact and auto-dependent cities in USA. Most European cities have densely populated centres where most residents prefer walking and cycling, especially when the system is organized so that there is support for these types of movements. In European cities, there is also a trend to reduce the number of private car ownership and introduce "shared ownership" over cars [15].

Within the project "Index of the European Green City" there are listed actions in the field of transport carried out by cities of Europe [14]:

Budapest- include public personalities (celebrities) into the game/competition "Smartly Moving Through the City", showing that the public transport is faster than private car, from the suburbs to the centre;

Brussels - supports a specific action of hitchhiking around the city ("Drive with a passenger")

Dublin - supports the "Bike to Work" campaign, abolishing tax on entrepreneurs for buying bicycle for workers (which reduces bicycle prices by up to 47%);

Tallinn - equipped buses with electronic equipment that is connected with traffic signalization and thus provides faster passage through intersections;

Stockholm - three important components of creating environmentally friendly urban transport are integrated: 1. the availability of public or private alternative forms of transport that are safe, quality and comfortable; 2. the policy of the city administration that encourages the use of these alternatives; and 3. the use of technology solutions for urban vehicles and infrastructures that are in harmony with nature ("green technology"). The result is that in Stockholm, 68% of the inhabitants ride bicycles or walk to work and only 7% use their own car, although it is a city with very low average temperatures.

It can be concluded that traffic is one of the important elements of the overall ecological state of the city. In car-oriented cities, 30% of the urban environment is under the streets. However, it is clear that energy used for transport represents the largest negative share in the general ecological performance. In that sense, we need to consider new concepts of mobility in cities that will reduce emissions of greenhouse gas, noise and pollution, perhaps through the idea of eco-cities oriented exclusively on pedestrians, cyclists and accessibility of content, with the aim of quality life without reliance on motorized transport [16] Zehner concludes: "Many communities have embraced pedestrian mobility as an alternative to older building practices that favour automobiles. Reasons for this shift include a belief that dependency on automobiles is ecologically unsustainable. Automobile-oriented environments engender dangerous conditions to both motorists and pedestrians, and are generally bereft of aesthetics" [17].

3. URBO-MORPHOLOGY APPROACH TO PROBLEMS OF MOBILITY IN CITIES

In a study on the travel behaviour in cities concerning accessibility and balanced mix of uses, which was conducted by an expert team in the San Francisco 1997, it was concluded that increased accessibility of workplaces to place of living and significant mix of uses reduces the number of use and possession of private cars. It was also concluded that in the areas with mixed uses, travel trips are shorter [18]. It has been proven that in the absence of other legal measures, four urban variables can contribute to the maintenance of mobility: density of construction, mix of uses, balanced relationship of "business – housing" places and presence of such design, which encourage /is pleasant for/ walking. [19]

Excerpt of the papers prepared by Frank, Engelke and Hourigan as part of a study of the impact of land use and traffic on human health, with hundreds of different projects and scientific papers on this subject, shows that the topics that are being processed by architects - urban planners in most cases are based on issues of attractiveness, comfort, convenience, security, coherence and system continuity, most often for the level of non-motorized forms of movement (cycling and hiking) [20].

The IPEN (International Physical Activity and the Environment Network), international interdisciplinary project, developed the methodology for finding the Walkability index. It consists of four partial indexes: Connectivity index, Entropy index, FAR index (floor area ratio) and Household density index. Final Walkability index is the sum of partial indexes (where the weight of the Connectivity index is two times bigger than the weight of the other indexes) [21].

In study of urban walkability index of Toronto, “built environment characteristics that have previously shown an association with //physical activity levels, //transportation choices, //perceived walkability, and //body weight, were identified, combined using factor analysis, and evaluated against measures of physical activity derived from three different population-based sources” [22].

The problem aspect of the land use and accessibility necessarily requires interdisciplinary engagement, but it is essentially, especially in the case of global considerations – (e.g. general, master planning), more oriented to the traffic professionals, while the viewpoint of the architect in this relationship (mobility/ movement through space and land uses in the space) strengthens with a reduction in the scale (as it goes towards a more detailed planning level). Commitment to urbo-morphological approach from the point of view of the architect - the urbanist thus places this work in the field of relation between land use and pedestrian accessibility.

3.1. Recommended walking distance and morphological typology

A Planning Commission for the State of Virginia in the US published in 2007. numerous surveys conducted by US and Canadian experts to determine pedestrian distances, with the comment that the average speed of the foot is 4 km / h (335m for 5 min) [23]. The second study they are calling upon adopts 450m as the maximum distance people are willing to cross over for purchasing or transit between stations and suggests that blocks with shorter sides increase the attractiveness of pedestrian movement [24].

An interesting study is one that examine the people's tolerance for walking in relation to environmental conditions [25]:

quality of the environment:	max.duration of walking (minutes)	walking distance (m)
Very attractive, fully protected from weather conditions, artificially air-conditioned	20	1500
Very attractive, with protected pavements from sun and rain	10	750
Attractive, unprotected against negative weather conditions	5	380
Unattractive (parking lots, garages, streets with lots of traffic)	2	180

The team of the Architecture Commission and the Built Environment of the United Kingdom adopted a 400m radius in the Better Places to Live: By Design study, which provides walking access of 5 minutes (or 800m and 10 minutes of pedestrian access) in standard conditions [26].

When the chosen criterion for the morphological analysis of the urban structure is the accessibility of certain uses, the basic types that are formed in the space are:

- monocentric (one strong centre that meets the needs of all-round urban needs)

- polycentric (more powerful centres that provide for the fulfilment of comprehensive urban needs)

Basically, the idea of good accessibility of various uses in the urban environment is in favour for polycentric type, but in the form of dispersion - that is, such coverage by the uses that the "strong city centres" essentially disappear, so that almost every spatial unite in the city has in a pedestrian distance of max.10 .min. as much uses as possible. The problem of monotony in architectural / design sense can happen here, but it is also predictable, and so it is possible to overcome it by the design diversity [27], [28].

From the point of view of the architect/urbanist, the environment that will make walking pleasant or desirable are certainly important and the goal is to achieve such ones that will initiate pedestrian movements. With this in mind, as a fundamental it is important to avoid dangerous crossroads/crossings, isolated or unsafe areas, high traffic flow roads, narrow pavements, poor street lighting ... The assumption is that in case of a pleasant environment without obstacles, it is most likely to take longer walking to the destination.

3.2. Basics of Human Needs in the Urban Environment

Habermas describes three main fields of people's needs in contemporary society: a technical domain that reflects the need to control the environment/nature, a hermeneutic domain that reflects the need to communicate, interpret and be understood and accepted; and the domain of emancipation that reflects the need for freedom. In general, community needs can be identified as: 1) physical, 2) economic, 3) managerial, and 4) social [29]

For the purposes of this study, the focus is primarily on physical and economic needs /which are mostly concerned with everyday existence in a modern civilized society/. Specialized uses concerning community functioning - from the governing and social sphere - health centres, courts, municipalities ... are not the subject of this study.

4. EXAMPLE: NEW BELGRADE - ANALYSIS OF PEDESTRIAN ACCESSIBILITY

4.1. New Belgrade – genesis /brief

New Belgrade, as an urban structure based on the principles of modernity was built in the period after the Second World War to about 4074 ha of once-flooded and wet ungraded soil of the Bezanija field at the confluence of the Sava in the Danube between historically independently formed cities of Zemun and Belgrade. The idea of building on this space dates back to period before the Second World War, but a large organized construction began in 1948, with the infrastructure works on the ground, and soon afterwards, the first buildings [30].

Challenge posed here is connected to the fact that whole New Belgrade area were built out during the second half of 20th century - when the latest thinking of the time valued real estate served by automobiles. In addition, the ex. state of Yugoslavia provided resources to create massive infrastructure project - highway that cut through the New Belgrade area. As a result, much of the land that connects residential superblocks are not pleasant for walking, not walkable at all.

Through the realization, until the beginning of the seventies, this space was built only by elementary uses within the superblocks - housing, shops with the basis of daily supply, kindergartens and schools, greenery and recreation (within the block and/or surrounding schools). Only one more significant centre (built in 1967) was not enough to meet the overall urban needs of present population. The first large shopping mall was built in 1972-73, and in the mid-seventies, in various parts of New Belgrade, two Local Community Centres were built, with more comprehensive offer for inhabitants. Nevertheless, during the eighties, New Belgrade was justifiably held the "dormitory" epithet – as a place that primarily serves the purpose of housing. As a reflection of the changes that happened during the 1990s socio-political transition in Serbia, without involvement of urban planning at the general/global/master level, New Belgrade was built, site-by-site by a large number of new market and business centres, which, from the viewpoint of accessibility, makes this space more different than before

New Belgrade today is an advanced municipality of Belgrade with a population of 236.000, with a notable development potential, which is now only seen in the economic sphere - through the rise in property and land prices and large investments in the construction of business, housing, business and trade uses

4.2. Methodology applied

Since the research of the urban form of New Belgrade on relationship of its mobility and uses is in the initial phase, method implied is fundamental, included “contour measures” (defines catchment areas by drawing one or more travel time contours around a node, and measures the number of opportunities within each contour (jobs, employees, customers etc.), and “time-space measures” (measures travel opportunities within pre-defined time constraints) [31], [32], [33].

Note 1: Facilities/uses that are commonly implied with the housing and which are mostly present in each superblock of New Belgrade from the very beginning of its construction (daily supplies, kindergartens, primary schools, playgrounds and greenery) were not the subject of analysis, but the uses of the upgrade: a comprehensive supply of consumer goods, specialized sports and recreation centres and cultural and entertainment facilities (with the aim of satisfying the majority of the populations’ needs, thus improving the quality of life, while at the same time reduce the number of journeys to the traditional centre of Belgrade and Zemun).

Note 2: The "Macro-plan" – position within the city of Belgrade, position and connections to Zemun, and to the traditional centre of Belgrade, is a topic that remains outside the domain of this study, but it is important to note that there are problems and potential within this topic and that an interdisciplinary approach is also important for its resolution. The problem of New Belgrade's access to the whole of the city has been recognized for a long time as the "actual" of Belgrade's general planning, and it is worthwhile to mention that elaboration of this problem is a suggestion for further research.

Common starting assumptions for analysis:

- A distance of 400m (about 5 minutes of walking) is adopted as the preferred walking distance from the use which accessibility is analysed /with regard to the structure of superblocks and wide boulevards - roads that do not offer particular attraction during walking, which significantly induces inhabitants to use the car when it is estimated that the walk can take longer/;

- The highway that passes through the structure of New Belgrade has been recognized as the cause of segregation for the level of pedestrian accessibility /the circle of accessibility is marked only on the highway side where is the analysed content(use) position/

- The diameter of the circle in graphics (figures 1, 2 and 3) represents the pedestrian accessibility of 10 minutes.

4.3. Accessibility analysis - large shopping centres /trade

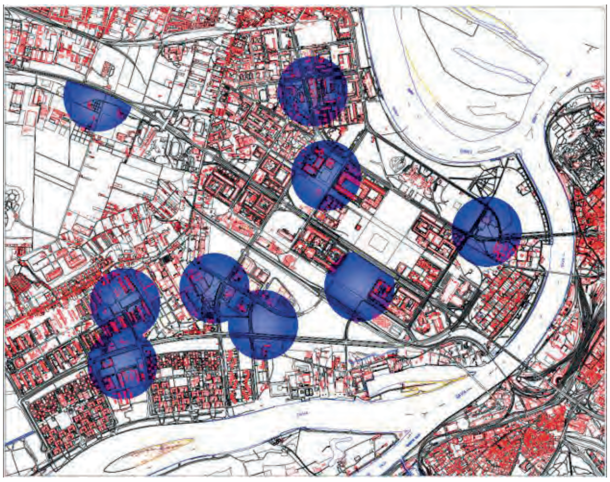

Figure.1. Accessibility - large shopping centres

Large shopping centres, which provide residents of New Belgrade (but also the entire city) with a comprehensive trade offer, are dispersively located in the area, which from the standpoint of pedestrian accessibility is quality.

RECOMMENDATION: To nurture the quality achieved and to confirm it through the future planning guidelines for New Belgrade, especially in the zones that are seen as having no accessible shopping centres in the given radius of 5-10 minutes walking distance. It is very important to consider the contents/uses that will be located in the zone of the originally planned centre of New Belgrade; there is possibility to make overly strong centre and lose advantage of dispersion od uses in the polycentric structure, which wasn’t planned but had emerged.

4.4. Accessibility analysis – culture and entrainment

Figure. 2 Accessibility
- culture /yellow, entrainment /orange

The uses of culture and entertainment in the territory of New Belgrade are disproportionately represented - only the eastern zone, closer to the traditional centre, has good coverage with these contents.

RECOMMENDATION: All other parts of New Belgrade, and especially the zone of superblocks along the Sava River, can and should be the subject of analysis and planning of new contents of culture and entertainment. This analysis involves expert expertise on the type of content of culture and entertainment that should be represented (whether they are smaller galleries, restaurants and cafes with a specialized offer ... or larger centres of culture and entertainment).

4.5. Accessibility analysis – sport and recreation

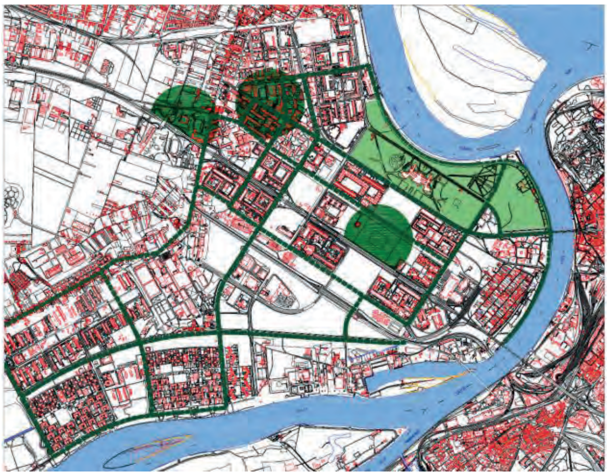

Figure. 3 Accessibility - sport and recreational centres, bycikle paths, parks

The presence of specialized sports and recreation centres is not at satisfactory level, but it should be kept in mind that within the elementary schools (and there are nineteen of them in the territory of New Belgrade) there are open sports fields and it is possible to use gymnasiums in the evenings and weekends. Bike paths greatly contribute to the quality of "alternative" accessibility of New Belgrade, but it is a remark that these routes are still not being used to a satisfactory extent, inter alia due to the lack of necessary "accompanying facilities" - marked and secured parking spaces for bicycles.

RECOMMENDATION: It is necessary to consider the possibility of building at least one specialized sports centre on the territory of New Belgrade, especially in the south-western zone of superblocks (part of New Belgrade along the Sava River). The existence of a large city park and quay along the river is a potential that is still needed to be better used and maximally activated, with the obligation to keep the use sustainable (first of all, without large-scale construction within the park).

5. RECOMMENDATIONS FOR IMPROVEMENT OF PEDESTRIAN ACCESSIBILITY IN NEW BELGRADE AIMING TO STRENGTHEN WALKABILITY POTENTIAL:

- Consideration for solution for highway /which causes spatial segregation/ (possible covering with green corridor)
- Do not build dominant shopping mall for whole New Belgrade (quit from the original idea of ONE central zone)
- It is desirable to build local shopping mall in contact zones in north and north-west
- In superblocks area along Sava river additional culture and entertainment content should be planned, as the sport-centre
- Preserve and care green park areas inside superblocks; to ban any new construction development within it
- Further favorization of cycling in New Belgrade as the support for walking (aiming to decrease use of motor vehicles for transport in New Belgrade)
- Increased accessibility to comfortable and safety public transport; introducing shorter mini-bus lines for connection to attractive pedestrian zones (Park and quay along riverside)
- Greening (formed tree-lines along boulevards/streets which connect superblocks, in order to make a shade for pedestrians, making it more attractive for walk)
- Activation of the traffic corridors/boulevards connecting superblocks - setting along the boulevard: sculptures, interactive boards, typical kiosks / cafes, smaller restaurants ... / fountains, fountains, outdoor exhibitions....

6. SUMMARY

Topic of „urban land use and accessibility" for quite a long time exists as one of the most significant when it comes to sustainability and future development of cities. Its' specificity, inter alia, lies in its integrative potential since it implies two domains: architecture - buildings, constructions in the city and traffic – in a way of how we move through the city's space

R. Dawson cites that cities are, in fact, main initiators of global climate change, and, simultaneously the epicentres of potentially major disasters, which could be triggered by bad climate. According to Dawson, it is not sustainable any more to understand cities as static artefacts in stable environment. „Environment, where cities raised, now is changing for different reasons, including long-term climate and socio-economic change. Therefore, managing the city now becomes process of dynamic control under uncertain conditions." Paraphrasing Charles Darwin, Dawson quotes: "There would not survive strongest cities, but most adaptable" [34]

Sustainable city has to provide individuals to choose their way of transport as to enable easy adaptation of different kind of transport to inhabitant needs, prioritizing those, which are not polluting the environment (which are health improving, accessible to everyone and independent of expensive and insufficiently researched technological systems for reduction of exhaust gasses)

Serbia signed Kyoto protocol since 2007. and is among the states which by its' signature do not take over a liability of reducing emission of harmful gasses (Annex 2.) but can contribute via project realization through Clean Development Mechanism (CDM); though/however, Serbia set a national goal/target to reduce emissions of harmful gasses by 20% by 2020. compared to 1990.

Analysis of pedestrian accessibility to varieties of city uses in New Belgrade, which is conducted in this paper, establishes an architects'-urban planners' view as central one. Considering pedestrian accessibility as special quality which is already fulfilled by certain point/level in analysed space, the problem is comprehended from the urban-morphology viewpoint aiming to enrich planner's ideas for Novi Beograd and to contribute to wider discussion about its' walkability potential, inter alia, of activating walking as one of inhabitants' primary choices (not just as recreational activity, but as way of commuting). In general, it could be concluded that we should perceive New Belgrade as polycentric structure, and continue further dispersion of various land/city use.

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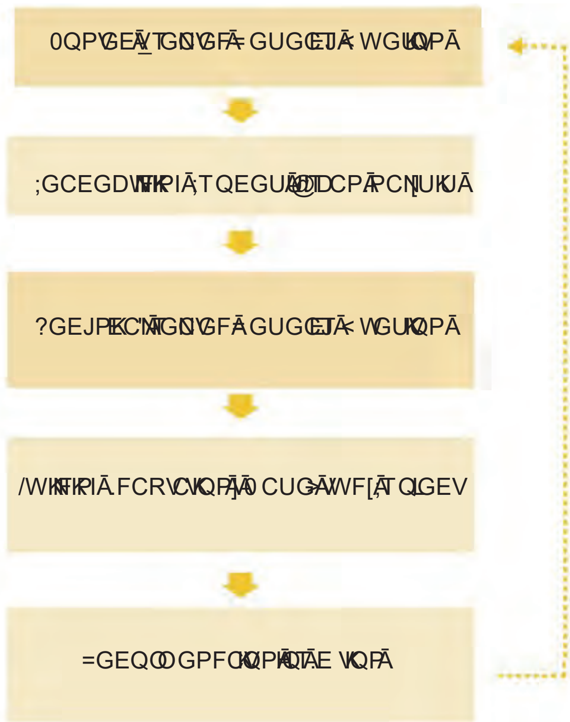

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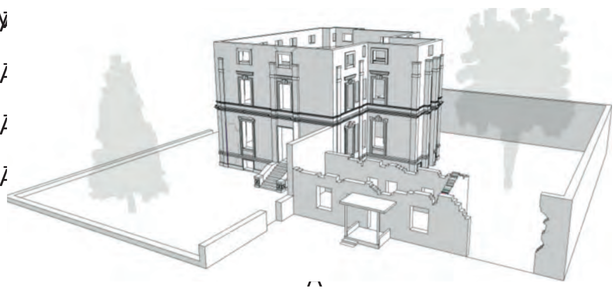

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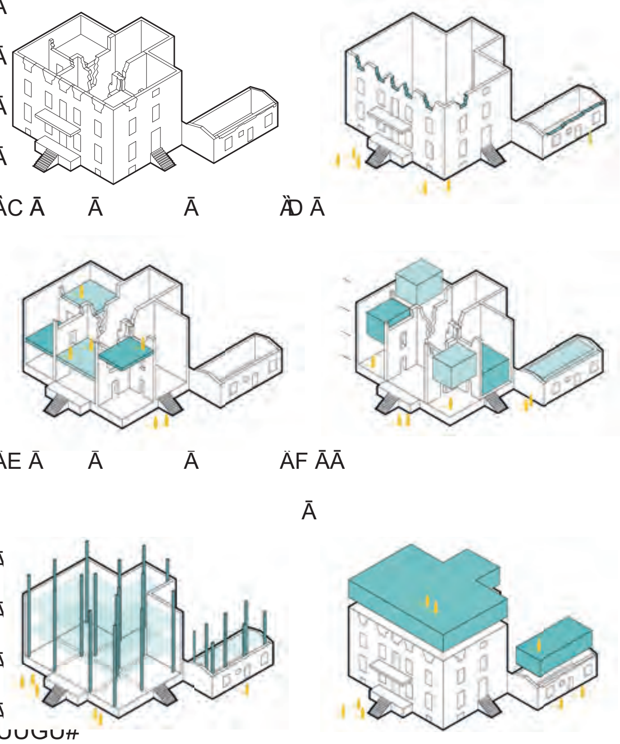

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:TARTINGĀFROMĀTHEĀSTANCEĀTHATĀSOCIALĀCOHESIONĀANDĀCULTURALĀCONTINUITYĀAREĀVERYĀIMPORTANTĀPARTĀOFĀCONTEMPORARYĀCITYĀPLANNING$ĀARCHITECTUREĀANDĀENGINEERINGĀWHENĀDELIBERATINGĀABOUTĀTHEĀIMPLEMENTATIONĀOFĀTHEĀGREENĀDESIGNĀPRINCIPLESĀFORĀTHEĀCITYĀOFĀ:ARAJEVO$ĀITĀISĀNECESSARYĀTOĀUNDERSTANDĀTHEĀSOCIALĀCONSCIOUSNESSĀOFĀCITIZENS&Ā=EĀRECOGNIZEĀTHATĀTHISĀSOCIALĀCONSCIOUSNESSĀSTEMSĀFROMĀTHEĀSOCIALĀSYSTEMSĀTHROUGHĀHISTORY$ĀWHICHĀINĀTHEĀCASEĀOFĀ:ARAJEVOĀAREĀLAYERED&ĀĀ

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;HEĀRESULTĀOFĀTHISĀPAPERĀWILLĀSERVEĀASĀAĀSTARTINGĀPOINTĀFORĀCREATINGĀAĀSTRATEGYĀFORĀIMPLEMENTINGĀTHEĀGREENĀDESIGNĀPRINCIPLESĀINĀTHEĀCITYĀOFĀ:ARAJEVO&Ā

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6NĀRESPONSEĀTOĀSUCHĀANĀAPPROACH$ĀAĀGREENĀDESIGNĀAĀĀHOLISTICĀMOVEMENTĀ ĀPROPAGATESĀTHEĀIMPORTANCEĀOFĀEDUCATIONĀANDĀTHEĀDEVELOPMENTĀOFĀAWARENESSĀOFĀRENEWABLEĀENERGYĀSOURCES$ĀTHEĀUSEĀOFĀAPPROPRIATEĀLOCALĀMATERIALS$ĀLOCATIONĀAWARENESSĀ ĀCONDITIONSĀANDĀREALĀNEEDS&Ā

6TĀISĀNECESSARYĀTOĀPAYĀATTENTIONĀNOTĀTOĀFALLĀINTOĀTHEĀTRAPĀWHILEĀIMPLEMENTINGĀPRINCIPLES$ĀASĀITĀHAPPENEDĀWITHĀOTHERĀÀGLOBALĀMOVEMENTSĀTHATĀWEREĀIMPLEMENTEDĀINĀAĀALLĀENVIRONMENTSĀEQUALLYĀ ĀTHEYĀWEREĀIMPOSED&Ā;HEREFORE$ĀUNDERSTANDINGĀTHEĀCULTURALĀCONTINUITYĀOFĀEACHĀINDIVIDUALĀSOCIETYĀANDĀENVIRONMENTĀISĀONEĀOFĀTHEĀSTARTINGĀPOINTSĀFORĀDEFININGĀHOWĀTOĀIMPLEMENTĀAĀGREENĀDESIGNĀPRINCIPLEĀINTOĀTHATĀSPECIFICĀENVIRONMENT&Ā

6NĀORDERĀTOĀBEĀABLEĀTOĀMONITORĀTHISĀCONTINUITYĀWEĀNEEDĀTOĀUNDERSTANDĀWHATĀISĀAĀACTUALĀCULTUREĀ ĀSHAREDĀPATTERNSĀOFĀBEHAVIORSĀANDĀINTERACTIONS$ĀCOGNITIVEĀCONSTRUCTSĀANDĀUNDERSTANDINGĀTHATĀAREĀLEARNEDĀBYĀSOCIALIZATION&Ā;HUS$ĀITĀCANĀBEĀSEENĀASĀTHEĀGROWTHĀOFĀAĀGROUPĀIDENTITYĀFOSTEREDĀBYĀSOCIALĀPATTERNSĀUNIQUEĀTOĀTHEĀGROUPĀ?)@&Ā

;HEĀCITYĀOFĀ:ARAJEVOĀHASĀBEENĀSELECTEDĀASĀAĀCASEĀSTUDYĀFORĀPROCESSINGĀINĀTHISĀPAPERĀBECAUSEĀITĀREPRESENTSĀAĀSPECIFICĀURBANĀENVIRONMENTĀ ĀAĀMULTICULTURALĀ ĀWHICHĀISĀAĀPRODUCTĀOFĀVARIOUSĀINFLUENCESĀTHROUGHOUTĀHISTORY&Ā:ARAJEVOĀCANĀBEĀCHARACTERIZEDĀASĀAĀMULTICULTURALĀCITY&Ā?*@ĀĀ

;HEREFORE$ĀTHISĀPAPERĀWILLĀDEALĀWITHĀTHEĀROLEĀOFĀCULTURALĀCONTINUITYĀASĀAĀSOCIOLOGICALĀELEMENTĀESSENTIALĀFORĀUNDERSTANDINGĀTHEĀCURRENTĀSITUATIONĀINĀ:ARAJEVO$ĀINĀRELATIONĀTOĀTHEĀPRINCIPLESĀANDĀPHILOSOPHYĀOFĀTHEĀGREENĀDESIGN&Ā

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7BSERVATIONĀINĀTHISĀPAPERĀBEGINĀFROMĀTHEĀ(,THĀCENTURYĀWHICHĀSIGNIFIESĀTHEĀARRIVALĀOFĀTHEĀ7TTOMANSĀTOĀTHEĀCITY&Ā1FTERĀTHEREĀISĀTHEĀ1USTRO%5UNGARIANĀMONARCHYĀTHATĀWASĀHELDĀBETWEENĀ(...ĀANDĀTHEĀBEGINNINGĀOFĀTHEĀFIRSTĀ=ORLDĀ=AR&Ā;HEN$ĀWEĀDISTINGUISHĀPERIODSĀOFĀTHEĀPERIODĀBETWEENĀTHEĀTWOĀ=ORLDĀ=ARS$ĀTHEĀPERIODĀOFĀ4UGOSLAVIAĀANDĀTHEĀPERIODĀAFTERĀTHEĀWARĀFROMĀ ĀTOĀTHEĀPRESENT$ĀEACHĀWITHĀITSĀSPECIFICĀSOCIALĀCHARACTERISTICS$ĀIDEASĀANDĀORDER&

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The Challenges of Urban Farming: Ideas vs. Applicability

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Abstract

The paper focuses on the spatial, social and organizational aspects of urban farming and its possible application in Serbian context, which is redefining its position and role in accordance with the latest sustainability trends. Providing an insight into different aspects of urban farming worldwide, the paper also presents the results of students' projects conducted at the University of Belgrade - Faculty of Architecture, during the school years 2014/15 and 2016/17. Testing the possibilities of urban farming in Belgrade, these projects provide some interesting solutions for contemporary issues of resilience and green design, applicable in the post-transitional framework of (sub)urban settlements.

Keywords:

urban farming, resilience, sustainability, green design, post-transition cities

1 INTRODUCTION

The problem of climate change, as well as its implications to the sustainability of architectural design and urban planning, have become increasingly topical during the last two decades. The generated challenges have imposed new imperatives to professionals and researchers, who need to conceptualize a new model of resilient habitat, applicable both on local and global level, in outdoor and indoor environments. The processes of mitigation and adaptation should also enhance the quality of life in the future communities, becoming an essential component of a truly sustainable development [1]. The holistic approach, contributing to both a knowledge acquisition and practice, is recognized as a necessity, especially in developing countries which face numerous socio-economic obstacles in implementing the general goals of sustainability and resilience.

The concept of resilient cities has become one of the key features of urban sustainability, widely promoted in 2011 by UNISDR [2]. The City of Belgrade, which is the focus of our paper, has joined the 100 resilient cities programme in 2015, after the devastating floods from 2014. As a result of this initiative, Belgrade started developing strategies for urban resilience. Their main goal is a development of urban resources, capacities and systems that will withstand, react and adjust better to actual shocks and chronic stresses, enabling easier and faster recovery from hazards and better overall functioning in non-stressful times [3]. Resilience, being strategically important topic in urban planning, represents an adequate answer to climate change and increased appearance of natural disasters, which spread out to other physical, social and economic challenges that contemporary cities are faced with. The selected Belgrade sites (suburban areas Sremčica and Ovča), which were used as research polygons for the studio work during the courses Studio project 3 (2014/15) and Sustainable urban communities (2016/17), represent the zones of interest for the City of Belgrade in terms of developing affordable housing. They have been exposed to the process of redevelopment and upgrading, improving their general connectivity on the metropolitan level. However, the environmental setting still has to be significantly improved and adjusted to contemporary imperatives of sustainability, providing a fertile ground for new and modern practices and a better quality of life. The studio work presented in this paper (conducted under the supervision of professor Aleksandra Stupar) was based on the trends of resilience, biomimicry and biophilia. It stimulated innovative and experimental approaches to environmentally friendly and energy efficient (r)urban living (Sremčica), supported by the development of a pecific socio-environmental interface (Ovča). Green architecture and urban design were used as the main drivers of future (sub)urban transformations, re-articulating the existing urban tissue, open public spaces and multi-levelled interactions between their users. While embracing the idea of a city as a living organism, the students detected and investigated significant problems in the area and analysed successful local traditions and latest global examples. Working within the scope of green urban design, they provided the proposals/solutions for the emerging changes, which were later evaluated in accordance with the anticipated contextual improvements.

2 GREEN ENVIRONMENT?

Currently, there are two noticeable trends in architecture and urban design which are providing answers to contemporary sustainability and climate issues. The first one advocates the return of traditional principles and various modes of climate control [4], while the second focuses on (re)introduction of nature inside urban areas by using the principles of biophilia and biomimicria and showing a higher level of generalization and universal application. Nevertheless, they are not exclusive and often cities combine both in order to raise the environmental quality and environmental awareness.

Biophilic design represents a deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes, into the design of built environment [5]. It could be seen as an effective approach to sustainable design, focusing on the elements of low environmental impact. Kellert defines two basic dimensions of biophilic design – the organic or naturalistic, which defines shapes that reflect nature; and the place-based or vernacular dimension, related to the connection of built structure and landscapes with local culture/context. Therefore, the theoretical framework, as well as the guidelines for studio design, were based on the key biophilic elements - environmental features (e.g. air, water, plants), natural patterns and processes, and the place-based and human-nature relationships. The implementation of biophilic principles was conditioned by the local setting and its characteristics detected via the contextual analysis of space and culture. Focusing on local specificities and addressing the resource issues in a sustainable manner, the students were encouraged to explore the possibilities or new models and means of resource management. One of the main topics was related to the problem of water and food, where both selected sites have had the background of agricultural production, currently experiencing a transition from rural to urban features. Consequently, the role of urban agriculture was emphasized, especially having in mind its importance for reducing the environmental impacts of urban food demands [6]. The literature defines two categories of urban agriculture: cultivation within cities (community gardens and urban farms), and peri-urban agriculture. Since both Sremčica and Ovča have blurred lines separating the urban from the rural, the selected approach combined general aspects of urban farming (if applicable) with the possible community empowerment, i.e. the local initiatives which would contribute to basic or advanced food supply.

3 SREMČICA – A (R)URBAN NEIGHBOURHOOD

3.1 Local context

Sremčica is a suburban settlement located in the southern part of Belgrade, with approximately 21,000 inhabitants. Originally a rural area, its development followed the longitudal direction of the main street. The inevitable urbanization resulted in population increase, thus setting in course many housing projects in order to meet the demands of newcomers. The rural character of Sremčica remained intact until the mid-20th century, when multi-family housing started replacing the previously dominant single-family houses. Following the spatial logic of satellite settlements, the north-south orientation dictated the further development and all major urban activities concentrated the along the main street. This logic is typical for (sub)urban settlements surrounding Belgrade's central area and could be also found in Altina, Kaluđerica and Železnik. The majority of inhabitants work in the central areas of Belgrade, but the connectivity of Sremčica is very problematic – the main transit street (5,9 km long) connects this settlement with the adjacent settlement of Železnik and via this route it becomes a part of the metropolitan transportation matrix.

The rural characteristics of Sremčica are still visible in its central zone, along the axis. The dominant housing model is a single-family unit, situated on a lot surrounded by agricultural land. During the 1980s, the high-rise housing assembly ‘Gorica’ was initiated, redefining the urban tissue in the area, but the intensity of building declined after the 1990s. However, the turbulent years of transition and the Balkan conflicts triggered a process of transformation, which was rather spontaneous and uncontrolled. The available agricultural land was exposed to illegal construction, resulting in changed morphological patterns and typologies, resembling the slam areas. Nowadays, the built environment of Sremčica represents a mixture of inherited structures – both planned and unplanned – but it still reflects the elements of rural patterns, based on the characteristics of terrain, climate, land use and status, as well as local social relations [7].

3.2 Toward solution: The concept of Green Ring

After the analysis of the contextual advantages and limitations, the students were required to summarize the current issues in Sremčica and define development goals. The poor general connectivity and lack of urban activities were emphasized as main problems, while natural surroundings and favourable micro-climate represented main potentials. Consequently, the main goals were oriented toward better connectivity on the city level, as well as to the environmental and functional improvement of the whole area. The general idea was to create a 'green ring' around Belgrade's central area, with Sremčica being its southern part. Other satellite settlements in the metropolitan area would also represent a part of this green belt, serving as a unique source of food supply to the inner city. Sremčica would be the first experimental neighbourhood to test out this idea. The interconnection between the city centre and the surrounding ring would not only affect the chain of food production and supply, but would also try to solve the daily migration problems, characteristic for this area.

The spatial organization within the anticipated Green Ring follows the logic of interlinking the surrounding settlements of similar character, where each of them produces one type of food and shares it with others, while redirecting the extras to the inner city. The students defined three phases in order to shift the current north-south development into east-west orientation. Production increase, higher quality of life, community well-being and new investments are just some of the expected effects of this concept. The concept, defined within a group, was further developed by each member/student (Tihomir Dičić, Andrea Đorđević, Tamara Đorđević, Danica Lečić). One of the individual project was focused mainly on community/public spaces such as green market and educational zones, while others targeted residential zones and the areas of food production. Depending on the focus, these projects included different types of housing and food production, but the idea of organic food was underlined and a new research centre for these type of products was also proposed as a part of solution.

The redefinition of the current housing typology into a food providing unit was also considered. The transition toward sustainable settlement of Sremčica was widley affected by Adolf Loos' working house programme. The main principles of construction included the elements of green design, which resulted in a self-sustainable housing unit. Loos inverts the logic of garden (lot) and the object, creating the garden as a primary, and the house as a secondary element by applying basic bio-climate principles. Energy efficiency in this newly created type was improved via technology, by introducing a water-pump systems and solar panels on both existing and future housing units. The students also proposed the reactivation of the central area of Sremčica by upgrading natural resources and rehabilitating devastated/polluted sites (e.g. pond/lake called Rakina Bara). The Green Ring concept incorporated principles of 'green' settlement, where the community itself would produce food and energy within a household unit. Simultaneously, the role of collaborative practices was underlined as a tool for achieving the social sustainability. The students also used the Holcim 2012 competition winner ('The Commons', Vienna) as a role model. In this example, 1/4 of every housing lot is intended for plant growing, enabling urban farming in newly built neighbourhood.

All ideas and tools applied and elaborated by students in the Green Ring concept could have an impact on the environmental condition of Sremčica, upgrading its green features, efficiency and comfort on the local level, while stimulating its higher connectivity and accessibility within a metropolitan system of Belgrade.

4 OVČA - STIMULATING VARIETIES

4.1 Local context

Ovča is one of the oldest settlements on the left bank of Danube in the area of Pančevački Rit. With a population of approx. 2000 inhabitants, Ovča is a part of the Palilula municipality. It belongs to Belgrade urban area but has noticeable rural features. The name Ovča derives from the main occupation of its first settlers - shepherds (serb. *ovčar*). During its turbulent history of wars, various voluntary and compulsive migrations, Romanians first inhabited the territory of Ovča. According to 1931 census, they were the majority of the population (96,42%) while Serbs represented 1,58%. According to census from 2002, there was 63,96% of Serbs and 27,46% of Romanians. Despite being classified as an urban settlement, the majority of economic activity in Ovča is still agricultural. The territory has been exposed to indirect urban transition – on both morphological and socio-cultural level, resulting in a mixed and unarticulated environment with both urban and rural features. The area is anticipated as one of the development zones of the City of Belgrade, while recently built transportation corridors/nodes represent significant drivers of that idea (a segment of Belgrade's outer ring, a railway station and the nearby bridge Mihajlo Pupin across Danube, connecting the area with Zemun and Novi Beograd). The longitudal orientation, as noted in the case of Sremčica, is also present, defining the character of urban tissue. Surrounded by agricultural land, the typology of houses and their distribution reflects the rural character of the whole settlement and its previous activities.

4.2 Toward solution: H2Ovča

The idea of creating a resilient and sustainable urban community evolved around the problem of floods and water - as a natural force (and resource), characteristic for this area. The students, who defined this development concept (Sara Popadić, Jovana Vasić, Dušan Međedović, Uroš Majstorović, Marko Đorđević), proposed a closed system of water circulation (regulatory canals), using its multifunctionality. Consequently, the system represented a tool for flood prevention, irrigation of farmland and/or an aesthetic element in urban design and landscaping. The main idea was to use river water in this closed system, conducting it to households. Part of it would be used as technical water, while parts of it would be conducted to agricultural areas. The household water would be further sent to water factory located to the west areas of the settlement, where it would be processed and sent back into the system. The canal orientation and distribution defined the zones of intervention. The main goals of future transformation, which would respond to challenging sustainability of Ovča, included the introduction of urban agriculture and hydroponics, and enabling of closed ecosystem with multicultural equity. The sustainable principles were set to unify and rearticulate both existing and future built structures. Environmental imperatives included the openness of space, integration of built and unbuilt areas, as well as their natural ventilation, while another group of interventions targeted technological improvements focused on energy efficiency of buildings, proposing modularity for easier application.

Zonal distribution was set in accordance to the main element of a newly formed water grid. The northern zone, adjacent to existing built structure, uses green roofs and walls in order to inspire new attractiveness and liveability of the area, while raising the level of interaction with the environment. The multifunctional spatial installation, as an element of landscape design, improves the overall character of space and becomes community market and meeting point. The integration of nature is also noticeable in the zone of student housing, where buildings blend into their natural surroundings. Meanwhile, the regulatory canals open a possibility of creating a fishing settlement, using aquaponics system in order to breed fish and experiment with the possibilities of their cultivation.

While intact land remains the dominant feature of the landscape, the introduction of regulatory canals into the production area opened the possibility for the cultivation of various agricultural goods. For example, the area divided by the main traffic artery offers a place for (sub)urban farming. The single-family houses also offer free accommodation to students willing to help with farming run by families. This type of organization is trying to increase community engagement and affect both social and environmental issues. The cultivated goods are used for personal needs, but extra production could be sold at the local market, contributing to self-sufficiency of the future Ovča.

5 SUMMARY

The presented students' projects, focused on suburban areas of Belgrade, provide an insight into possible holistic approach to green/sustainable/resilient urban design. Conceived as main drivers for future transformations, these visions and concepts might be used as signposts for the future redevelopment of rural patterns in changed and urbanized settings. While trying to define sustainable modifications of typology and materialization, they offer a redefinition of inherited and/or neglected identity and existing urban patterns, channelling change within a targeted urban community. Although both Sremčica and Ovča represent the parts of Belgrade with prevailing rural characteristics, the current trend of urbanization is changing them into more dense areas, where agricultural land might be totally replaced by new urban tissue.

Bearing in mind all these problems and current trends of resilience, the presented ideas integrate food production into further (r)urban development, providing and testing several hybrid concepts of urban settlement. They include both the commodities of the rural and the urban, merging urban content with technological upgrading, while relying on rural features. The food production is, therefore, considered as a competitive advantage of selected areas, stimulating resilience and smart use of available resources. Sufficient for the needs of local communities, it can be also used for further distribution across the metropolitan region.

Although reality might restrain or even disable the implementation of these concepts, they should not be overlooked as initial steps toward higher environmental awareness. Relocation and optimization of resources do represent important aims for our urban living, and the inclusion of local communities into these processes has already had positive effects. Being only the visions of future, without any financial and market constraints, these mini-projects should be tested on several levels. For example, the influence of construction market and, indirectly, food market, might limit the scale of (r)urban farming [8], while the proposed ideas would have to reconsider the share of open spaces (vs. built areas). These limitations would further influence the relocation of urban farming to public spaces, while a self-organization of communities would be needed in order to achieve production goals.

The projects based on communitiy initiative are already a part of urban dailiness, constantly fighting the limitations in a creative way. Simultaneously, new trends and innovations in contemporary urban space have become a part of urban competitiveness. However, their scale is still small or experimental and their outomes have to be verified in a long run. Therefore, the visions and problem solutions suggested by new generations of professionals could be interpreted in several ways – as a fresh prospective, a tool for self-expression or a reflexion of the global and local influences. Facing reality is not an easy task, but their education, within a framework of resilience, certainly represents an important step toward the challenging years ahead.

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FRC Connections As Support Tool For Design Of Reversible Buildings With Insufficient Earthquake Resistance

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Abstract
Analysing our and other regulations, and most of all by analysing the latest knowledge from geology and seismology, it can be concluded that with years the design load for earthquakes has almost exponential growth. Therefore, it is correctly to raise the question of determining the actual seismic resistance of existing buildings, which are often not adequately designed and cannot sustain the projected load from the earthquake. Buildings that do not have the required resistance by regulations need to be strengthened in some way, e.g. it is necessary to define a strategy for design of reversible buildings. Introducing prefabricated panels with fiber reinforced concrete compounds it can be achieved buildings recovery as well as increasing its durability during exploitation.

Keywords:
Seismic resistance of buildings, masonry structures, fiber reinforced concrete, design of reversible buildings

1 INTRODUCTION

Since the 1960s, the development of seismic engineering is intensifying. According to the Federal Hydrometer Institute [1] in Bosnia and Herzegovina there are several significant regional faults (bugojanski, višegradski, neretvanski, banjalučki). Along all of these faults, earthquakes of considerable magnitude can be generated. In addition, in the area of Treskavica mountain (it was named due to this characteristic), the epicentral zone of very strong earthquakes was registered.

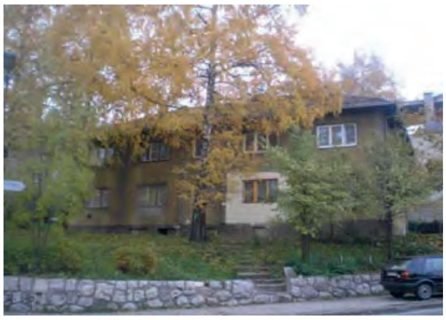
(a)

(b)

Figure 1: (a), (b) Otorhinolaryngology clinic in Sarajevo - buildings before collapse.

By the same source, for a period of 100 years or more, using mathematical-physical seismic models, destructive earthquakes can result, which can cause enormous material damage to building objects and take many lives.

The first brick building in the mortar in our region dates back to the Austro-Hungarian period (Figure 1). They regularly contain cracks, even faults, primarily from settlement of the soil, and from seismic influences through long years of exploitation. Damage is more pronounced if the object is less maintained.



(a)

(b)

Figure 2: (a), (b) Example of the buildings from 1960s.

These buildings do not have special constructive elements with which they would receive seismic influences, and seismic resistance is based exclusively on its robustness. After the Second World War, a large number of masonry buildings were built in our country (Figure 2). By the 1960s, those buildings had no RC beams and columns. Later on, by introducing reinforced concrete ceilings instead of timber beams, the buildings from that period got the first horizontal and then the vertical RC elements. If these buildings were to be calculated according to modern regulations, most of them would not have the required resistance.

As a reminder of the seismicity of the region and inadequately constructed existing buildings, here is indicated the catastrophic consequences of the earthquake that hit Banja Luka in October 27, 1969, Figure 3. At that time, 86.000 flats were completely destroyed; also large damages were inflicted on school, cultural, health, social and public administration facilities. The economy also suffered significant losses. In order to prevent such tragic events, it is necessary to understand the lack of existing regulations seriously and the buildings from the previous period strengthen adequately and thus put it in safe use again.

Figure 3: Banja Luka after earthquake in 1969.

2 REGULATIONS AND PROVISIONS

The first seismic guidelines in our area [2] date from 1964 when the "Provisions on Temporary Technical Regulations for Construction in Seismic Areas" was adopted. In the everyday design practice, the outdated "Provisions on Technical Norms for the Construction of High-rise Buildings in Seismic Areas" from 1981 is still in use [3]. For masonry constructions, the "Provisions on Technical Norms for Masonry Walls" from 1991 are used [4].

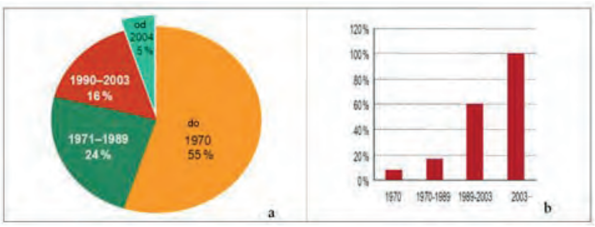


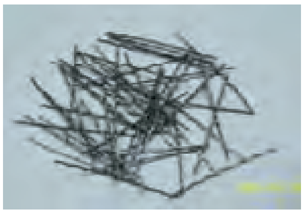
Figure 4: (a) The age of buildings in Switzerland, (b) horizontal load intensity for design of four-storey building, depending on the evolution of Swiss regulations.

A study carried out in Switzerland [5] indicates that most of the Swiss buildings were constructed before 1970, Figure 4 (a), when the first regulations were adopted in the field of earthquake engineering were adopted [6]. The first significant correction of Swiss standards [7] was carried out in 1989, and the current version [8] dates back to 2003. Figure 4 (b) shows the horizontal load for the calculation of a four-storey residential building according to Swiss standards over time. The evolution of regulations in Switzerland went hand in hand with the adoption of regulations from the former SFRY, so certain parallels can be withdrawn.

It is encouraging that in our country, [9] after twenty years of delay, is working hard on the adoption of new regulations that we hope will soon be applied. The horizontal design load according to regulations is much higher than the valid ones, so the issues analysed in the work will be exceptionally interesting. In the following chapters, a suggestion for building strengthening is given by using micro-reinforced concrete joints.

3 INTRODUCTION TO THE FRC

Modern trends in construction continuously require the introduction of new technologies in order to design and build better, lasting and economical constructions. This, of course, implies the use of new construction materials with better physical, mechanical, rheological, technological, exploitation and other characteristics in comparison to already existing, known materials. The fibers for microarming concrete are made of steel (the most common applications are steel fibers; the characteristic shapes are given in Figure 5), polymer (Figure 6), glass (Figure 7) and natural materials.



(a)

(b)

(c)

(d)

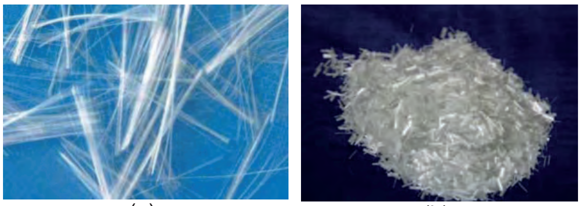
(e)

(f)

Figure 5: Forms of steel fibers: (a) corrugated round fibers, (b) corrugated flat fibers, (c) straight round fibers, (d) even straight fibers (e) straight fibers with curved ends (f) wool fibers.

(a) (b)

Figure 6: Forms of polypropylene fibers: a) twisted bundles, b) open continuous mesh.



(a) (b)

Figure 7: Forms of glass fibers: (a) bundles (b) sliced glass fibers.

Total absorbed energy of fibrous concrete is 10 to 40 times higher than ordinary concrete. Energy is absorbed through the stretching of fibers and the separation of fibers. The total energy absorbed before the total destruction of the sample is toughness. In normal concrete, the toughness depends on the crack growth, while in the fibrous composite; the cracks cannot expand without stretching and separating the fibers. Therefore, significant additional energy is required to make the total fracture of the material. The increase in toughness is one of the most important advantages obtained by microarming.

The primary parameters affecting the toughness are type, quantity, shape factor, nature of deformation and fiber orientation. Also, the stress-strain curve of the fiber itself affects the total absorbed energy [10].

A detailed relationship between load and deformation will depend on a number of fiber-matrix-related parameters, such as:

- volume fraction of fibers: a higher proportion of the fiber produces a higher load after cracking and a smaller crack width.
- modulus of elasticity of fibers: high values of modulus of elasticity have the same effect of increase (although in practice it can cause the possibility of fiber stripping).
- the connection between the matrix and the fiber: the high bond strength will also reduce the crack width, but this will result in a much more frequent cracking.
- variation of the strength inside the matrix: if the matrix material was completely homogeneous, all parts of the matrix would reach the fracture stress at the same time, and this would lead to a sudden change in the gradient at the first crack. In practice, there is a natural variation of the strength in the matrix material, so that the weakest place cracks first.
- Fiber strength: increasing the strength of the continuous fiber increases the length of the load-deformation curve. In this way, ductility is increased before fracture, assuming no disconnection occurs. The strength of the fiber required in practice depends on what characteristics are required after cracking, as well as the volume contribution and characteristics of the connection with the used matrix.

Analysing the problem of the building recovering and forming a reversible buildings, requires a systematic approach to the study and finding of standardized calculation methods for testing the properties of fiber reinforced concrete both at the design and at the exploitation stage.

3.1 Basic concepts of panel building design

Connections in large-panel buildings, as well as monolithic reinforced concrete walls, are specific structural components that can significantly affect the overall seismic resistance of the building.

The basic idea is to allow certain "controlled" deformations for higher earthquake intensity, mainly in vertical connections of panel walls, but also in horizontal joints if necessary. Such deformations would affect the overall resistance of the building by reducing the rigidity of the structure and making the energy dissipation mechanism.

It is known that the concrete is subjected to a brittle-non-ductile fracture, due to crushing caused by pressure stresses, or cracking due to the exceeding of the smallest tensile strength. A properly constructed concrete structure is one in which any kind of brittle fracture is prevented. This is achieved basically in two ways; by selecting a structure that does not bring the object into a state of brittle and sudden fracture, and by properly reinforcing the element of construction, their connections and details. Since the construction has to be provided with the possibility of plastification, during the design process should also be foreseen the places where it will develop.

Plastification must not occur in places that directly endanger the overall stability of the structure. For example, the appearance of plastic joints in pillars is much more dangerous for the stability of the object than occurrence in the beams or secondary support elements, such as short beams above the door or window. The designer should take care that the structure has no the only one "defence line". The process of occurrence of plastic deformations should preferably be done in sequences: first in structural elements that do not affect the stability of the structure, with the aim of absorbing as much as possible the energy involved. In the beams where the appearance of plastic joints does not lead to progressive breakage of the entire structure. The opening of plastic joints in the columns should be the "last line of defense" of the loaded structure. The basic principle is to put the building into usage after earthquake with minimum demolishing, construction waste and financial investment. All these characteristics define reversible buildings. Because of this, multiple statically un determined systems are always safer than statically determined because they have the possibility of redistributing static influences. In principle, three concepts of design of panel buildings are possible (Figure 7), [11].

- The first concept is the concept of an undamaged building. According to it, the building behaves like an elastic system and is strong and rigid enough to overcome the complete seismic force that can occur without any damage (Picture 7 (a)). This practically means that the building should be designed for the acceleration that can be obtained from the acceleration spectrum for elastic systems, which can be three to four times the maximum acceleration of the soil. In this way, smaller buildings can be constructed, if they are successfully funded.

- Another concept is the concept of "strong connections" (Figure 7 (b)). In these buildings, plastification is predicted in the panels themselves and not on connections at all. Apart from the walls themselves, as the primary absorbers (absorbers) of kinetic energy, there are also short beams above the doors and windows that exist in all buildings with load-bearing walls. In monolithic buildings, there is no difficulty in applying this concept. Difficulties can occur in prefabricated panel buildings, where a good connection between reinforcement and concrete should be organized in a very cramped area. Classic connections with the dropped reinforcement loops from the panels are very complicated to perform and do not always guarantee the required quality. By applying welding or screws, connections can be achieved that ensure plastification of panel.

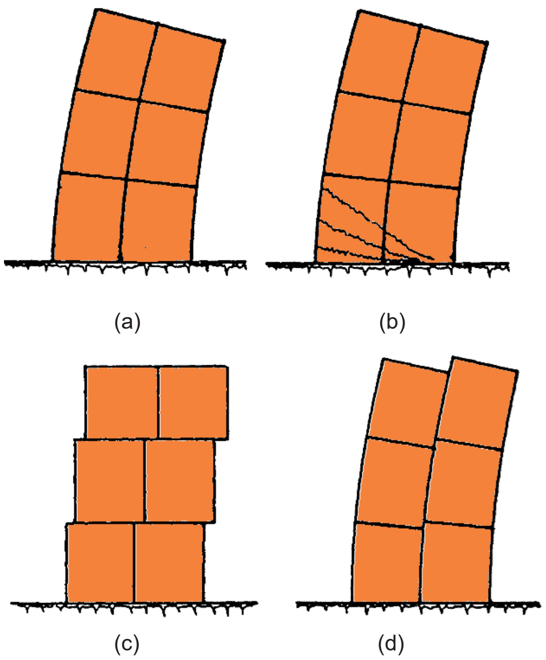


Figure 7: Panel buildings: design concepts.

- The third concept is the concept of "weak joints", that is, connectors are weaker than the panels. Here, energy is dissipated (consumed) by the inelastic work of the connections, as well as by the beams above the openings. There remains a choice of joints in which there will be damage. This should not be the coupling between the ceiling slabs or between ceilings and vertical panels, as this will disrupt the assumed way of transmitting horizontal forces. If a "weak" horizontal connection is selected (Figure 7 (c)), a sliding in the connection will appear as soon as its shear capacity is exceeded. In this case, the transverse force is limited by capacity of connections. After exceeding the capacity of the connections, the residual strength depends exclusively on friction and partly from the action of the dowels. The influence of the FRC dowel can be achieved only for continuous sliding within the connection. This design method is not recommended for many reasons. First, the damage of this horizontal connection can call into question the whole of the building, because it transmits gravity load through it.

  Second, and without the demolition of the object, the repair of these joints is very difficult, and the correcting of the sliding parts is practically impossible. It is possible to recommend such elements that will safely take the shear forces of the joints and ensure them from movement.

- Choosing "strong" horizontal, and "weak" vertical connection is a more favorable solution (Figure 7 (d)). Vertical connections have no share in transmitting gravity loads and their damage will not cause the failure of the whole building. From the point of view of the load capacity of the vertical load, this type of coupling could remain open. Since vertical joints are designed for a particular transverse force, then their construction should be as simple as possible, have sufficient plasticity capacity and can withstand sufficient plastic deformations - and finally - their repair should be easy and simple. When constructing a connection, it is necessary to try to ensure that plastification occurs in the connection itself, and not in the reinforcement anchor in the panel, because in this way the repair of the damage is easier [12].

In general, there are two types of connections that allow the transmission of shear forces:

- wet connections (using reinforced or unreinforced concrete on site).
- dry connections (using screws or welded steel elements).

Wet joints provide uniform (even) transmission of shear forces along the length of the connection. Dry joints transmit forces through prepared details (elements).

3.2 Connections from RC panels and FRC elements

Design principles from chapter 3.1 apply globally to the panel construction system. In this paper, the subsequent installation of panels is promoted, which aims to influence the increase of the seismic resistance of the existing buildings and thus their longer usability. The panel connections, proposed by the method of installation, can be plasticized to the action of the moment and normal force, and to the shear action (Figure 8 (b)).

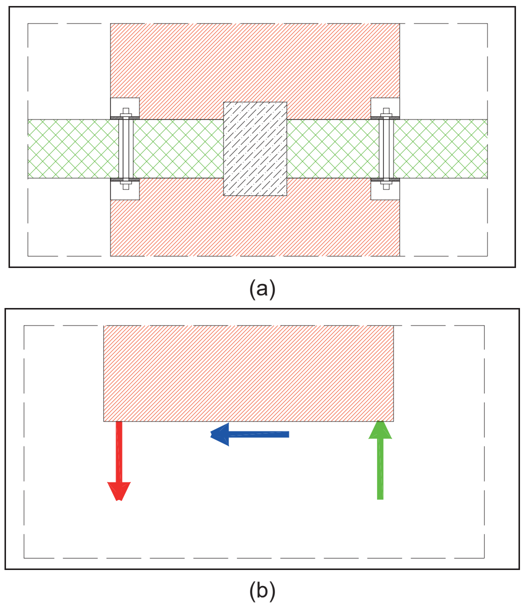
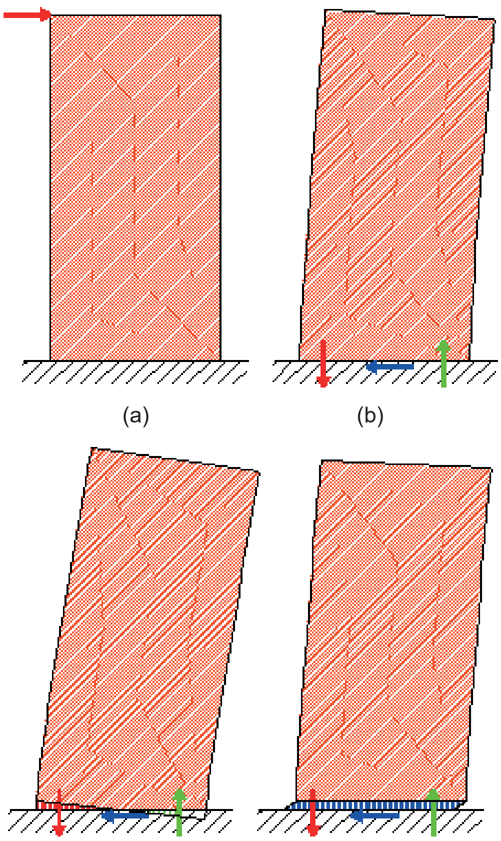


Figure 8: (a) Supposed panel connections

(b) distribution of forces in panel.

It is assumed that the panel behaves elastically according to the mechanical properties of the material from which it is made. Furthermore, it is assumed that the force in the panel is transmitted exclusively through an anchor body, whereby plasticization can occur in the anchor bodies themselves. The anchors transmit the moment and normal forces.

Anchors can be drilled through an existing slab and in holes can be filled by cement mortar. Installation and disassembly (if necessary) of such anchors is relatively simple. The anchors are made of steel Ø20, which cross-section is 3.14 cm2, and yield curve is 235 MPa. The panels are made of reinforced concrete with a thickness of 5 cm and class C25/30. RC panels, anchors and FRC elements are positioned as reinforcements on either side of the existing wall. The panel is placed on the existing building, its height is the same as the height of the existing wall and it is not loaded with gravity loading (Figure 9 (a)). The increase in displacements leads to the appearance of a moment of bending and shear force in the base of the panel. For small increments of displacement, the panel should behave elastically as shown in Figure 9 (a). If the connections are sufficiently rigid, there should be no difference in the behavior of such a system and a console wall built of the panel material. A further increase of displacements leads to two possible scenarios. By yielding of anchor Figure 9 (c) there is a significant rotation of the panel above. The panel behaves as a rigid body for a further increase of displacement of the wall peak.



(a) (b) (c) (d)

Figure 9: (a) loading of the panel, (b) elastic phase, (c) yielding of the anchor, (d) yielding of the FRC elements.

In the case of achievement of the shear strength of the FRC element, the panel should slide for further increments of the peak movement. By sliding the panels, which according to the previous description represent a scenario that should be avoided, after a stronger earthquake in the building, there are permanent plastic deformations that are difficult or impossible to repair. Therefore, the mentioned sliding should be viewed as protection of the building from collapse, Figure 9 (c).

By adequately designing an anchor and FRC element, it can be influenced on the behavior of the presumed system and adjust it for an adequate reinforcement of the building [13].

4 RESEARCH RESULTS

Application of panels with fiber reinforced concrete joints, as structural elements for reinforcing masonry structures, is a rather unexplored area. From the research relevant for this paper, tests were carried out at the Faculty of Civil Engineering in Mostar [12], [13].

A numerical model applied in the work will be briefly presented. The walls of masonry buildings consist of at least two constitutive elements: masonry blocks and mortar connections [9], [14], [15], [16], [17], [18], [19], [20]. These elements have different mechanical characteristics. Both transmit pressure, limited shear, and generally do not transmit tension. Due to the heterogeneity of the wall, the stress state inside the wall composite is spatial, in all stochastic, even for elementary stresses. A calculation model that the wall elements treat separately is not practical for everyday engineering use [21], [22], [23]. Therefore, a homogenized replacement element of larger dimensions has been developed, composed of finite and binding elements, which is adapted for use in the software package *SAP2000nl.*

The reality of the adopted wall model was first checked on the simplest compositions of the final and binding elements from which the console wall was formed. After that, spatial models of construction, from simple family buildings, to collective building houses were formed. With the Pushover Analysis method, the building's capacity for horizontal loading was defined, and a nonlinear dynamic analysis (Nonlinear Time History Analysis) was performed for different earthquake acceleration intensities [24]. By introducing the strengthening elements, in a way that does not significantly affect the geometry and architecture of the object, the analysed building models certainly demonstrated better behaviour for the earthquake effects, without significant changes in linear behavior. This is mainly due to the considerable stiffness of the buildings. For a gradual increase in displacements, by achieving the tensile strength of the wall edges, the rigidity of the buildings decreases and the strengthening elements begin to participate in the overall seismic model of the building. In the most favourable case, the resistance to the seismic force has increased approximately two times comparing to the console wall. Other analysed cases give less favourable results.

5 THE RESEARCH FINDINGS IN RELATION TO THE REVERSIBLE BUILDING DESIGN PRINCIPLES

This paper presents the results of the research of fibre reinforced connections as support tool for design of reversible buildings with insufficient earthquake resistance. According to the latest provisions, a large number of masonry buildings from the 20th century don't have sufficient seismic resistance. Here are proposed some improvements of construction method in order to increase reversibility. Improvements are based on implementation of FRC elements and RC panels (as presented on Figure 8) which increase seismic resistance and safe reuse of the building. These strengthening elements are easy to build on the existing buildings; if necessary they can easily be removed or replaced. If it's reached sufficient earthquake resistance, the damage in structural (beams, columns and plates) and non-structural elements (partition walls, windows etc.) after the earthquake will be smaller and easy to repair. As there will be no or very small demolition of building, there will not be large amount of waste. All these mentioned above, are the basic principles of reversible design of building.

6 SUMMARY

Earthquakes are the phenomenon with humanity should live; they will be happening in the future and they have been happening in the past. Knowledge in this area is rapidly increasing and successively incorporated into new regulations. By analysing the existing already constructed buildings, conclusion is that they are not adequately constructed in order to be able to take seismic actions with certainty. Therefore, it is necessary to redesign existing facilities and put them in safe reuse.

The paper proposes the reinforcement of such buildings with RC panels with FRC elements. These strengthening elements are easily to constructed or deconstructed, they are not expensive. Strengthening elements have shown improvements in the behaviour of buildings most in the non-linear area, although the proposed system needs to be designed so that they are effective even for relatively small displacements.

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Review on Circular Design

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Abstract
Through the centuries of architectural practice, people have used most accessible and local materials. Only exceptionally, to show the power and supremacy of the ruler, they were putting great effort to provide materials from distant locations. Wars, natural disasters or changes in ideology and authority have impacted architecture in respect of design and construction. It was a common practice to build from ruins of previous buildings, using the site and majority of the materials. The motivation to do so was either ideological or practical. The repeated use of a site or element meant honouring the past function as well as in a post-war scenario, the winner could decide upon representative building components of the enemy and the re-composition of those was common sign of victory in ancient times. Beyond that, reuse was motivated also against the historical background of material scarcity, which can be traced back to the recent past.
The expansion of construction and new artificial materials in the twentieth century led to ecological and economic problem in their production, transportation and after the expiration of buildings life-time. Great differences in levels of adjustability of the buildings to new users and purposes – resilience - became one of the most important issues of the present time.
The concept of circularity addresses the two aspect of high functionality and low environmental impact in order to reduce the pressure on nature and integrate it a as design parameter for new usage concepts. Based on the approaches formulated in Cradle to Cradle, circular economy is a young concept which focusses on financial and economical incentives proposing the shift from product to services in the building context.
This chapter will give an overview of concepts for circular designs throughout history and contemporary approaches, show the challenges in design and construction through case studies and provide guidelines for circularity in the built environment.

Keywords:
Circular design, circular economy, reuse, reconstruction, regeneration, sustainability, resilience

1 INTRODUCTION

What circularity in the built environment really means? How buildings get in that circularity process?
Building materials are all around us. They are used to build our homes, bridges, sacral buildings, various objects of vernacular architecture. One of the natural ways how buildings get in that circularity process is by aging. Buildings get older, very often abandoned, and with lack of maintenance they soon collapse. Building material is there, to be used again, for new homes and buildings. A bit different path in circularity process would be reuse. At one point in life of the certain building, a new owner would appear and adopt a building to its own needs. Some old parts and building materials would be reused, some new added. Recycled process would create new home and new architecture.
Beside, already prepared building material found in the walls of the old buildings (such as bricks, cut stone blocks, irregular stone blocks, wooden beams, steel elements, etc), process of circularity is also focused on use of waste in order to build some building elements, if not whole buildings.
Generally, circularity in the built environment could be seen as reuse of the already used (building) material with the aim of slowing brutal exploitation of the natural non-renewable sources. Viewed in the broader picture, circularity is natural process – just like in biological ecosystem, where all materials (residual products form one species) are used in some way (by some other species or by nature).
But, circularity has one very important issue to keep in mind all the time – ethics in approach.
Sometimes, buildings collapse instantly, due to the natural catastrophes or war conflicts. Sometimes they are demolished with purpose, due to decision by various political or military regimes. If someone uses the material from the building that was purposely destroyed for building a new building structure, can we call it circularity? Or is it destruction / humiliation of old culture and wish to build new culture using destroyed elements of the previous one. Even without considering such extreme situations (but in today's world unfortunately not so rare cases), should materials form some 16th century cathedral destroyed in the earthquake be used for building a new (sacral) building or we have moral and cultural obligation to used in the process of reconstruction? As Munn and Soebarto point out, it is the question of how one building has become a recycled materials shop that leads us to the fact that the use of materials in architecture has greater implications than just those to do with aesthetics and design. They have social, cultural, moral and environmental implications. These implications have largely been ignored with the focus

being on building performance, pure aesthetics and the short-term economics of materials. (Munn and Soebarto, 2004)

Architecture and materials, today, with the constant pressure for "going green", sustainability, recycle, global warming and lack of natural resources, are often considered only within the terms of user experience and need for sustainable design. But the architecture is not just material evidence of the people existence; it is reflection of the identity, feelings, culture. Therefore, the issue of where materials come from or where they ultimately end up has to have impact on the practice of architecture as a whole.

2 NEED FOR NEW CONCEPTS OR WHY TO RE-USE OLD ONES OR USE RECYCLED MATERIALS IN NEW BUILDINGS?

It is hard to miss the obvious: articles, books, even regular evening news have at least presentation of one new science research that is confirming the fact that we are running out of the natural non-renewable resources and that with this extensive building activity all around the globe, we are irrevocably changing the Earth, for worst.

As Metcalf has wrote down in "Archdaily", in today's world "going green" has become a top priority in our society, and sustainable buildings and design are at the forefront of this green revolution. While many designers are focusing on passive and active energy systems, the reuse of recycled materials is beginning to stand out as an innovative, highly effective, and artistic expression of sustainable design. Reusing materials from existing on site and nearby site elements such as trees, structures, and paving is becoming a trend in the built environment, however more unorthodox materials such as soda cans and tires are being discovered as recyclable building materials. (Metcalf , 2011.)

In order to understand the need for new concepts, it would be best to use literary review presented by Munn and Soebarto (2004., pg 162.) in their article, regarding the use of the recycled materials. As they suggest, to consider the role of recycled materials in architecture it may be useful to consider the life of a building in three phases: an initial phase, a middle phase and an end phase. The initial phase occurs prior to the building's existence and concerns how the materials that will constitute the building are sourced and manufactured. The middle phase encompasses the building's lifetime, and the end or final phase begins at the time of the building's deconstruction or demolition and involves the journey of the constituent parts of the building to their end destination.

Energy consumption during initial phase is present during sourcing, manufacturing and transporting building materials as well as in the construction of buildings. Studies presented by Munn and Soebarto, conducted in Australia and overseas revealed that:

"the embodied energy within a building, that is the energy needed to extract and process raw materials into finished building components, as well as the energy used in the construction of the building, in the case of large commercial buildings, can be greater than the operational energy requirement." (Lawson, 1996:11); For conventional residential buildings the embodied energy can equal as much as 15 years of the operational energy requirement (Reardon 2001).; "building's in the western world - their construction and use - are responsible for 50% of the deleterious emissions which are causing the planet to overheat." (Jones 1998:8)."; it is reported that the "building and construction activities worldwide consume 3 billion tonnes of raw material each year or 40% of total global use." (Roodman and Lenssen 1995:1) ." Munn and Soebarto (2004),

Additional concern in the initial phase is the fact that in many cases, materials used for construction are non-renewable and their extraction, whilst using a great deal of energy, may also have detrimental environmental side effects such as pollution and the destruction of ecosystems.

The middle phase of the building regards the performance of the building during its existence. This mainly concerns the energy needed to operate a building (including maintenance and repair), and issues such as water consumption and waste production. The end phase involves the end of the building's life, and in this phase the majority of the materials are demolished and "are disposed of in a landfill, where they are effectively unrecoverable and may have a variety of adverse environmental impacts." (Lawson 1996:17)

As Munn and Soebarto conclude, the issue of the use of recycled materials and its relevance to architecture and sustainability relates directly to the initial and final phase of a building. The use of recycled materials in buildings positively affects both landfill waste created at the end of a building life and the waste produced in the initial creation of buildings as well as decreasing the use of raw materials and energy.

All above stated, give us a clear answer on why we need a new concept in building – from idea, design, construction to maintenance.

Gorgolewski stress out that „At present we have a mentality of consumerism which leads to massive use of non-renewable, primary resources, which are often extracted with great environmental damage, and create a huge amount of waste. Construction and demolition waste (C&D) contributes about 35% of the total waste stream in Canada1, and the Worldwatch Institute estimates that by the year 2030 the world will have run out of many raw building materials and we will be reliant on recycling and mining landfills." (Gorgolewski, 2009. para 1)

It is our obligation, as engineers of different fields, to make some change. For many years now, three solutions have been proven:

- improving the performance of new buildings - making them more resource efficient and with increased potential for recyclability and reusability (to be thought about during design phase and, partly during construction phase) ,
- directed use and reuse of existing buildings (as Gorgolewski states, "Existing buildings and infrastructure are a huge store of potential resources, not something to be thrown away. In Europe, the expected life of a building is usually at least 60 to 100 years and many buildings last considerably longer. In North America, much shorter time periods are typical! Buildings are long-term resources that need to be allowed to evolve and change with societies' changing needs; otherwise they often deteriorate and end up being demolished. (...) A starting point for any project should be – can we reuse and adapt an existing building? Demolition should be a last resort, and even then, can we reuse components from an old building into a new structure avoiding the use of new materials?

This preserves much of the value of the components and minimizes reprocessing that is often required when materials are recycled." (Gorgolewski, 2009.)

- use of the resources from the built environment (abandoned building, decommissioned buildings, building already in ruins).

3 HISTORICAL PERSPECTIVE ON REUSE AND RECYCLING

Re-use of building materials, that is installation of single parts of older building or monument into new one, including spoliation (purposely removed materials from earlier buildings in order to be built into new ones) is present in the history of Europe from ancient history till nowadays. "Recycling has started centuries ago, there are records based on archaeologists that back in 400 BC people where very much conserve all the sources that they had, since there was a lack of pretty much everything, what made human daily like easier." (University College of Northern Denmark (Technology), project report, 2015).

From the ancient times, there were and still are two main approaches in recycling, opposite in their very essence, based in the question of meaning of the reuse. One is based on the pure reasonable need for re-use of the material from the fallen, naturally demolished over period of time or by the society abandoned buildings. Second one is based on the purpose destruction and wish to erase one particular culture. Of course, they are many other reasons for the recycling and re-use, but they all fall, more or less, under these two ones.

Why it is important to introduce term and examples of spoliations into story on circular design? Because every architectural approach should start from the point of ethics. This is even more important in case of re-use of the materials from older buildings.

Re-use of building materials is undivided from the question of the perception of the heritage, and is always connected to demolition and renewal after destruction (Hadžimuhamedović, 2008.). As Hadžimuhamedović suggests (2008, p.158, 159), spoliation or re-use of the fragments from the demolished buildings into completely new ones can be based on three reasons: (1) rationale use of the worthy material from the old unusable buildings in order to build a new ones; (2) complete erase of all evidences of the unwanted culture by its additional humiliation after destruction through throwing its most precious material achievements under feet (into foundations) of the new culture; (3) extension of the glory and preservation of the special values of the lost building by placements of its fragments into new one or appropriation of the legitimacy of the heir to the fallen culture.

Examples of the spoliations are numerous, as well as reasons for it. But all reasons are, somehow linked to understanding and feelings towards culture / building that is used as stock of the building materials. That understanding goes from admiration to hate and wish for destruction.

There are numerous examples of pragmatic spoliation of the heritage. As Hadžimuhamedović states (2008. p. 161.), word recycled can be linked to this type of spoliation, since it represents cases in which old sites were viewed as desirable places for borrowing of the materials. At the time of the Roman Imperia, by the Law number 459 for the buildings that were in such state that their repair was not possible, spoliation was legalised (Hadžimuhamedović, 2008.).

Some of the most known examples of spoliation, for many different reasons, are presented briefly below.

Arch of Constantine, Rome (Flavius Valerius Constantius c. 285.-337. CE). Hadžimuhamedović (2008. p. 161.) gives interpretation of the reasons for spoliation by Rene Sheidal that says that one possible explanation is the lack of skilled craftsmen; second possibility for the recycling could be lack of time; third, wish of the Constantine to be placed into same group of the imperators with the ones that were remembered as good ones, Trajan, Hadrian and Marco Aurelia. Also, combination of reasons is possible as well.

Use of the historical structures as quarry can be dated to 13th century. As Hadžimuhamedović presents (2008. p. 161., 162.), groups of priests have transformed the Roman theatre in Trier into a stone quarry and completely demolished the amphitheatre at Le Man (1271), as well as Temple in Turu in the 13th century. Fragments of the roman capitals, bases, and columns can be seen on numerous buildings around Europe.

This view of the historical site, as a quarry, unfortunately, can be seen even today; for example in Mostar, where few of the remarkable fortifications built in Austro-Hungarian period were illegally demolished in order to use fine cut stone blocks to build supporting wall of the private residences.

Zadar Cathedral, Croatia, presents case where recycling of the antic monuments in middle ages was clear combination of the pragmatic relationships towards sources of good and already processed material and towards culture of the enemy whose defeat can be confirmed also by building in fragments, those symbolical victims, into walls of new monuments, witnesses of the new glory. Many cathedrals around Europe have intentionally built in fragments from Roman buildings. There are many cases like this one in other parts of the world, and one of the most famous is "Qutb Mosque" of Delhi in India, which is regularly cited as the prime example of the appropriation of Hindu temple spoils by Muslim builders. Spoliation for this reason can be traced throughout the history, till modern times. Those who won the power wanted to express their victory but also beliefs, identity, and new political movements through architecture as well. There are examples of this in all parts and period, randomly stating just those in France from French Revolution period; in Serbia after the fall of the Ottoman Empire, or in Bosnia and Herzegovina in all period of its history. In some countries, like in Bosnia and Herzegovina, story of spoliation does not stop with construction of new building. Like in the case of the Qutb Mosque, modern political developments have put / or are trying to put many buildings in radically new contexts, constantly reinventing their meanings.

Spoliation is present throughout 20th century as well as in contemporary (European) architecture through the different ways in which architects have integrated older elements into new buildings, or older buildings into new spaces.

One of the cases is Hearst Castle at San Simon, California USA, listed as a National Historic Landmark and California Historical Landmark mansion (from 1976.). It was designed by American architect Julia Morgan, between 1919 and 1947., as a residence for newspaper magnate William Randolph Hearst. In the luxurious buildings, swimming pools and garden architecture as well as in the whole building site, built in are the fragments of old European buildings, which William Hearst bought from dealers of spolias all over Europe.

Some of the most fascinating parts are 14th century gothic wooden ceilings from Teruel, Spain, some of them originated from the so called House of Jews in Teruel. As Hadžimuhamedović suggests, this case is very important since it represents one of the understandings of heritage in modern period – heritage without the value other than market value. Heritage not viewed as the bearer of collective identity but as the mean of consummation and privatisation. Bought fragments are ripped from their architectural and cultural context, cleaned from all other values other than artistic and aesthetics. (Hadžimuhamedović, 2008., pg.159.)

Presented cases have led us to importance of understanding of where re-used materials come from. The use of materials in architecture has social, cultural, moral, and environmental implications. These implications, however, have largely been ignored. The issue of where materials come from or where they ultimately end up has had little impact on the practice of architecture as a whole. But this has to be changed, because our historical buildings are not stock of fine buildings materials or decorations but testimony of our identity, culture, history. Of course, not every building could or must be preserved but the question on which one does and which one does not must be answered by conservation architect, with special appreciation of the identity and feelings of the group of people who owns or care for monument in question.

At the end of this historical overview, a different approach in re-use must be mentioned. Architectural reuse processes, besides reusing salvaged materials also includes adaptive reuse of the building and conservative disassembly.

Adaptive re-use is the process of changing a building's function in order to accommodate the changing needs of its users. It is a form of preservation, and can be accomplished in a respectful way. Adaptive reuse deals with directional change, it "slows nutrient loss" while contributing to the diversity, complexity, and continuity of a particular place. Viewed from human point of view, adaptive re-use of an old building helps in preventing the uncritical new construction of "placelessness", as defined by James Kunstler.

But, the benefits of reuse extend far beyond the conservation of our cultural legacy. Re-use of an old building can be economical if we compare cost of adaptation to cost of demolition and purchase of new materials. Adaptive reuse of whole buildings conserves natural resources and the energy required to extract, process, and transport building materials, lowers amount of construction waste. Works on adaptation does not have that big significant environmental impact from noise, local pollution, traffic disruption, watercourse pollution, as construction process. Furthermore, open space is preserved by avoiding the urban sprawl that accompanies new development, and employment increases due to the fact that rehabilitation is labour-intensive. Overall, the physical and social fabric of the community is strengthened. Adaptive reuse should always be investigated, because it is the highest form of recovery. Adaptive reuse of existing structures is now relatively common for heritage structures, as they are seen to have cultural value, but it is also essential to take a similar approach for many other existing buildings.

Adaptive re-use of building has far greater impact on circularity of the whole urban area. As suggested by Gorgolewski, urban density, urban sprawl and the impact of development on the use of cars are all relevant to the long-term viability of cities. Utilizing the existing urban fabric can be a vital component of urban revitalization efforts attracting people back to city centres, rejuvenating old neighbourhoods, and reversing the trends for suburbanization. Building conservation can act as a very visual catalyst to changing the attitudes of people to consumption and encourage recycling. We should remember that sustainability is more than just about green technologies; it also encompasses local community issues and economic aspects. Here reuse of buildings (not only heritage buildings) may have particular benefits as a locally valued resource and offer potential for attracting economic benefits. (Gorgolewski, 2009. para 5).

4 SUMMARY

This paper is trying to give a broader picture of re-use, recycled materials and circular design, and seeks to examine the place and use of recycled and reused materials in architecture. The aim of the paper is not just to present possibilities and examples of circular design, which are enormous; but to also discuss the use of recycled materials as a serious consideration within the larger issue of sustainable architecture in particular and architecture in general.

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Sustainable Use of Natural Resources In Construction Works: a Case Study of Social Housing

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Abstract
Optimizing the use of resources in the building process is a current problem and is also highly regarded in the latest European legislation. The problem can be tackled by minimizing waste production, promoting waste recovery and transforming waste into resources. In this work has been experimented the elaboration of a building project, for the social building intended use, which can be realized in all aspects in accordance with current regulations and which uses products containing materials from recycling. It relates to the methodology applied and the results obtained and the difficulties encountered in the development of the project.

Keywords:
Natural resources, Building Process, Social Housing, Recycled material, Environmental certification

1 INTRODUCTION

The largest contribution to the total production of special wastes in Italy is given by the construction and demolition sector, with a percentage referring to the 2014-2015 two-year period, equal to 41.1% of total wastes produced. Hazardous wastes attributable to the construction sector account for 8.6% of the total product.
The construction and demolition sector is described by the Ateco reference codes for the classification of economic activities from 41 to 43 and constitute the national version of the European Nomenclature Nace Rev. 2, Statistical Classification of Economic Activities in the European Community, published in the Official Journal on December 20, 2006.
These official data, contained in the Report prepared by the Higher Institute for Environmental Protection and Research (ISPRA) [1], relate to the production of special wastes for the economic activity, according to the Ateco 2007 classification, for the 2014-2015 two-year period.
Regulation 305/2011 of the European Parliament and of the Council of 9 March 2011 lays down the harmonized conditions for the marketing of construction products; in Annex I, lists the basic requirements for construction works and in point 7, refers to the sustainable use of natural resources.
The use of resources, under this Regulation must guarantee the reuse or recyclability of construction works and materials, the durability of the same and the use of environmentally compatible raw and secondary raw materials.
In Italy, as in Europe, waste production has progressively increased as a result of economic progress and increased consumption. The diversification of production processes has also led to the diversification of waste types with increasingly negative effects on the environment. The considerable amount of produced waste combined with the difficulties of disposal and the increase in relative costs have led to an ever-increasing interest in recycling, i.e. the ability to recover some fractions of waste, re-inserting them into production cycles in the form of secondary raw materials . Recycling is the foundation for sustainable development and helps to reduce the cost of waste disposal in landfills or incinerators.
The European Community itself, with Directive 2008/98/EC, in adopting a new strategy for a more rational waste management and policy, has attached great importance, not only to the prevention and safe disposal of waste, but also to actions increase recycling and re-use.
Member States are required to commit themselves to ensuring that recyclable materials do not end up in landfills, and this means that by 2020 recycling of urban waste will increase by at least 50% in weight.
Decision n. 1386/2014/EU of the European Parliament and of the Council on a general EU action program on the environment by 2020 "Living well within the limits of our planet", or simply "Seventh Environmental Action Program" "(7th PPA), sets out some of Europe's priority objectives for 2020, including improving the sustainability of EU cities.
The objectives are based on the principle of "polluter pays" and are set with a clear long-term vision for 2050 where prosperity and healthy environment are based on a waste-free circular economy in which natural resources are managed in a sustainable manner .
The roadmap (COM (2011) 571) to an efficient resource-based EU is based on the actions undertaken by the flag-ship Initiative and completes, defining what elements need to be addressed and outlining their 2020 priorities. These elements are oriented towards the transformation of the economy towards an efficient use of resources and concern:

- sustainable consumption and production;
- turning wastes into a resource;
- support for research and innovation;
- harmful subsidies for the environment and prices properly defined.

The Roadmap distinguishes, then, the behaviors to follow depending on the different types of resources and key areas. In particular, in the section on improving the construction and use of buildings, the stage set by the Commission states that: "*by 2020 the renovation and* *construction of buildings and infrastructure will be made to high resources efficiency levels* ", specifying that "*70% of non-hazardous construction and demolition waste will be recycled*."

In this respect, the approach to the management of construction and demolition waste in Europe differs widely among the various Member States, in fact, from the synthesis data contained in the document (Background Paper) prepared at the workshop "Improving management of construction and demolition waste" [2] it appears that a group of nine Member States (Austria, Belgium, Estonia, Germany, Hungary, Luxembourg, Malta, the Netherlands and Spain) has already achieved this sustainability goal, while the other group of nine (Croatia, Cyprus , Czech Republic, Denmark, France, Italy, Lithuania, the United Kingdom and Slovenia) is showing good recovery rates, with values between 50% and 70%, and finally the group of the remaining ten Member States (Bulgaria, Finland, Greece, Ireland, Latvia, Poland, Portugal, Romania, Slovakia and Sweden) is still far from this goal, which is likely to preclude the possibility of meeting the target set by the European Commission for 2020.

From the analysis of the European Union's regulatory documents and guidelines, two possible strategies emerge:

- the recovery of waste products or materials from C & D or other (output) through careful planning of the demolition and proper management of materials and products of existing building;
- the design of the building system that involves the use of environmentally-friendly materials and products (inputs), as products derived totally or partly from material recovery operations.

This would result in a sustainable resource management strategy that suggests reconnecting the two extremes of product life and transforming what is considered a waste in a resource so as to push the economy from a linear model (" take, produce, use and throw ") [3] to a circular one [4]. The purpose is to keep the value of good within the economic system as long as possible, even at the end of its life cycle, through the reuse of all or part of the components and materials that make up it so to reduce both resource consumption and waste production at the same time.

The European Commission [5] has long supported the efficient use of resources in the various industrial sectors (including those involved in the realization of construction products) by promoting sustainable and innovative industrial processes that use, for example, sustainable raw materials or operate industrial symbiosis [6], a system by which waste or by-products from an industry become production factors for another.

The inputs of this phase are therefore the primary raw materials, including renewable ones, which even in a circular economy will always play an important and sometimes irreplaceable role, and secondary raw materials or by-products, coming from both internal recovery to the same, or analogous, industrial process and from other economic sectors, even completely outside the building world. Outputs, however, correspond to manufacturing waste, to be identified as by-products or waste, and to finished construction products, which can be distinguished in their many different forms.

This paper addresses the design strategy of the building system oriented to the use of environmentally friendly materials and products (inputs). The aim is to experiment with the design of a building for social housing, which can be realized in all aspects in accordance with current regulations and that it uses products containing recycled materials available in the market with the purpose of calculating the recycled percentage used on the total volume of the technical elements used.

2 THE CASE STUDY

2.1 Territorial area

The case study is placed in the town of San Martino Buon Albergo, in the province of Verona (Figure 1), in a strategic position since it is the first municipality outside the Verona municipal boundary and at the same time is surrounded by greenery.

Figure 1: Localization of the Municipality of San Martino Buon Albergo in the Italian territory

At the morphological level, the municipality includes a flat territory to the south and a hilly land to the north (Figure 2). The intervention site is located east of the municipal area, in a residential area with prevalence of residential buildings. The area is well connected to the main road and is the location to an important sports center for the whole community.

Figure 2: Aerial photo of the intervention area (Source: www.gmaps.it)

2.2 Urban setting

In the extract of the Intervention Plan (IP) (see Figure 3) of the Municipality of San Martino Buon albergo, the area of interest appears to be a residential expansion with a concentration of building capacity.

Figure 3: Extract from PI of San Martino Buon Albergo with in red the area of intervention

These are parts of the territory that are not yet built or only partially built, with no primary urbanization, which the IP identifies as areas of residential expansion in which to apply the principle of urban equalization, which involves the activation of agreements between public and private entities in accordance with the meaning of Art. 6 of the Regional Law N. 11/2004, in order to ensure a balanced and functional growth for the new urban expansion. The intervention follows the prescriptions of the technical standards, which in art. 70, define the "City of Transformation" as the whole of the parts of the territory in which the process of transformation is carried out for the realization of the newly-built city and existing areas of the city which, disused and abandoned, are recovered under 'urban and functional aspect to urban contexts with retraining and reconversion actions. The operations of the "City of Transformation" are implemented with a public or private initiative plan (Piano Urbanitstico Attuativo - PUA) and must meet the urban standards specified in the technical standards.

The aim of the project is to realize the new urban layout between Borgo della Vittoria and Casette Marcellise, with particular regard to the road, the central nucleus of the new urban park and the enhancement of the services in the hamlet of Casette Marcellise. The Territorial Buildability Index is mc / sqm 0.75 as by PUA. Areas of unallocated selling Areas and Areas for enhancement of public services at Casette di Marcellise, such as the new square, the new public facilities and the adjacent green equipped area, are foreseen. The intended use is residential. The distance between the window walls should be at least 10 m and the distance from the minimum road clearance must be 5 m., as provided by DLgs n. 285/92 and DPR n. 495/92. In the PUA in force on the area of interest, the following information is given: Land area = 11,099.31 sqm; Maximum building height = 13 m; Maximum achievable volume = 33,849.75 mc. Finally, the area does not appear to be subject to constraints or particular vulnerabilities.

2.3 The design proposal

Looking at the residential environment present around the project area, it was decided, also in keeping with the PI guidelines, to build a Social Housing building that could accommodate different types of utilities. The built, horseshoe-shaped with a central courtyard, consists of 8 blocks (see Figure 4) for residential use and a building for the community.

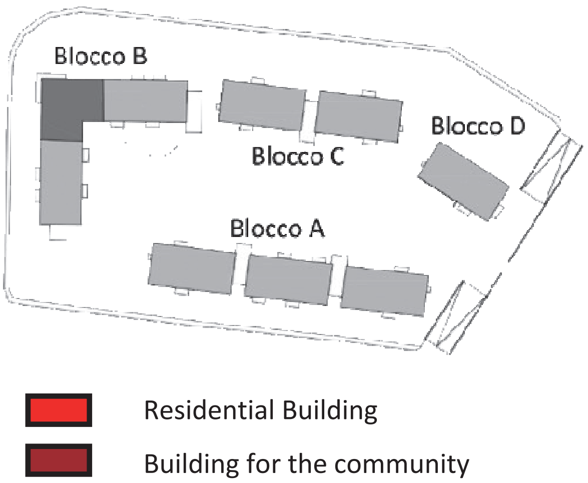


Figure 4: Schematic diagram of the layout of the designed buildings

The built-in volume corresponds to 26,160 cubic meters divided into Blocks A (9,514 cubic meters), B (10.132 cubic meters), C (4,440 cubic meters) and D (2,074 cubic meters), and meets the limits set by the PUA.

The units located south of the lot in question (see Figure 5) are developed on three ground levels, while those located north on two levels, to allow more ventilation in the central court. It has also been left more open on the east side, as a green public area is planned.

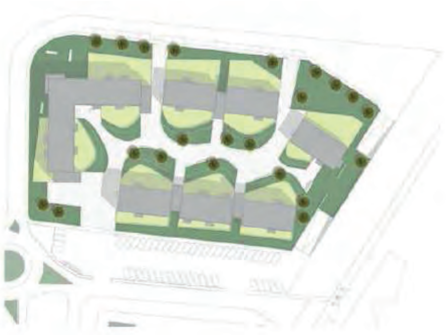


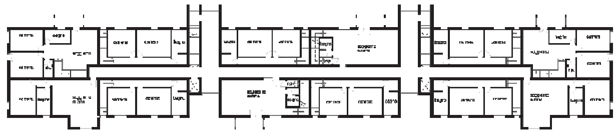
Figure 5: Project plan

Figure 6: Overview

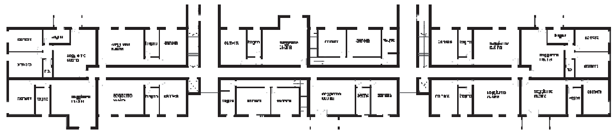
With the intention of accommodating different types of utilities, four types of apartments have been designed: two-room, three-room, duplex in two different variants (2 + 2 and C-shaped). There are small variations in sizes between the Block D and the others, due to a different structural mesh resulting from the position of the stairwell. In fact, this block is the only one to have the staircase contained inside it, while in other buildings it is inserted inside independent elements (see Figure 6).

Block A (Figure 7) provides for the construction of 26 apartments in the different types (12 two-room apartment , 2 type 2 three-room apartment, 8 duplex 2 + 2 and 2 duplex C-shaped); block B (Figure 8) provides the realization of 16 apartments (8 two-room apartment and 8 duplex 2 + 2); block C (Figure 9) provides the realization of 10 apartments (2 two-room apartments, 2 three-room, 4 duplex 2 + 2 and 2 duplex C-shaped); and Block D (Figure 10) of 5 apartments (2 two-room apartment, 2 three-room apartment and 1 duplex 2 + 2), for a total of 57 apartments. The basement is unique throughout the complex and there are garages, cellars and technical rooms. There are 60 garages as the housing units are 57. Furthermore, there is the possibility of making public parking (Figure 11) available in accordance with Regional Law 11/2004, which provides 2.5 square meters per inhabitant dedicated to public parking lots, and will fully meet the needs of 68 parking spaces, including two for disabled people.

Ground floor

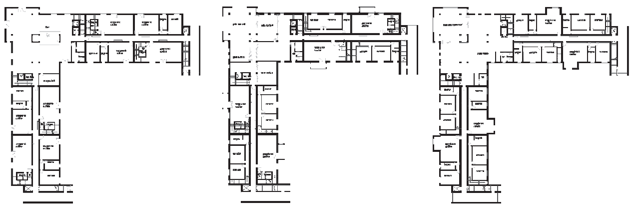


First floor



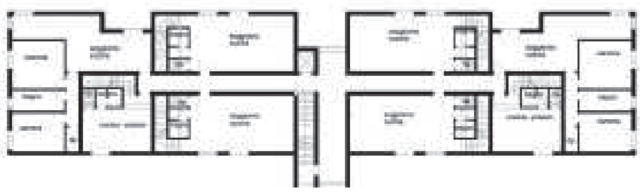
Second floor

Figure 7:Block A diagram

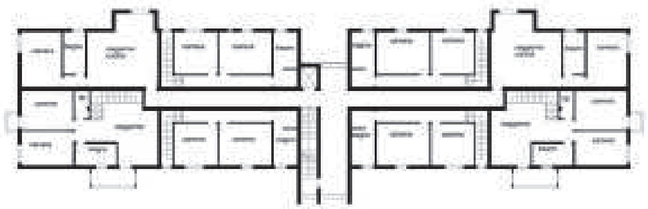


Ground floor First floor Second floor

Figure 8:Block B diagram

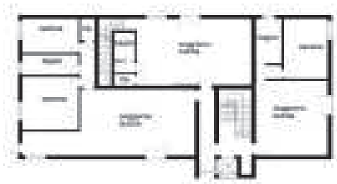


Ground Floor



First Floor

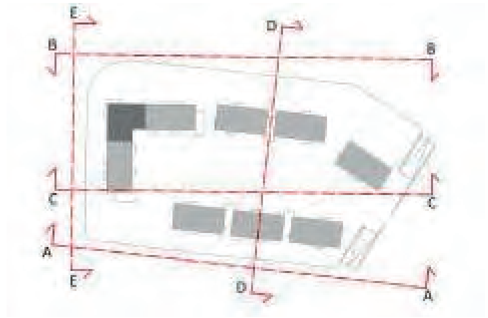
Figure 9: Block C diagram



Ground floor

First floor

Figure 10: Block D diagram



Section B-B

Section D-D

Figure 11 Sections

2.4 Exterior spaces

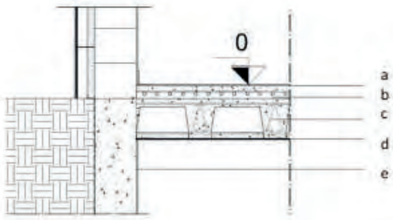
Social Housing presumes the implementation of strategies designed to create a community and to foster integration through the use of common spaces and services among the inhabitants. For this reason, in addition to inserting a building for common activities, a green interior space has been designed to be a place of aggregation for users (Figure 12). Space is determined by a cyclopedestrian path which in turn widens at certain points to accommodate rest areas (Figure 13). The apartments on the ground floor are provided with a private green space, which is bordered by public greenery placed at a higher altitude (+1 m). This split off is due to the need for greater ventilation in the basement.

Figure 12: Project rendering

Figure 13: Project rendering

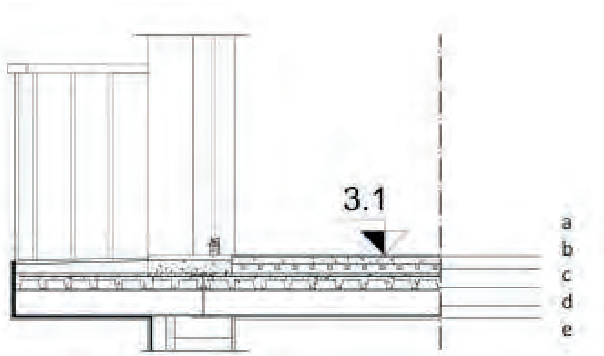
2.5 Technological choices

In order to achieve a good percentage of total recycled builds, it was considered appropriate to use a steel skeleton for this project.
The slab on the ground floor is a predalles type (Figure 14) with elements of Beton lightening, while the tops, and the flat cover, are made of the beams and the steel sheet system (Figura 15).
As for the perimeter walls (Figure 16), going from inside to outside, can be found the following stratigraphy: kerakoll plaster, Vibrapac vibropressed concrete blocks, Insulation of Maiano Companies, a layer of air, being provided a ventilated wall, Acquaboard di Siniat plates of exterior plasterboard and Kerakoll plaster finish.
Darkening systems with recessed concealed drapes have been conceived so as not to alter the elevation layout linearity. The internal partitions (Figure 17) are designed with plasterboard walls with a double insulating layer. Such solutions are used in all buildings of the complex.



a. finish layer: Caesar ceramic; b. plant integration layer and bedding screed; c. support layer: Predalles slab with Beton lightenings; d. finish layer: Siniat plasterboard; e. finish layer: Kerakoll plaster

Figure 14: Ground floor slab Predalles type detail



a. finish layer: Caesar ceramic

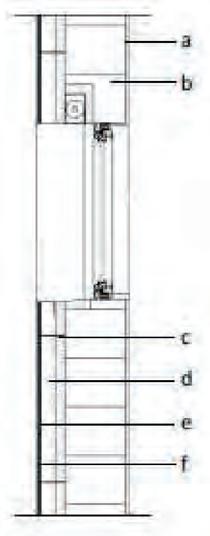
b. plant integration layer and bedding screed

c. support layer: slab with steel sheet and filling jet with electro-welded mesh

d. support layer: IPE 140 secondary beam

e. finish layer: Siniat plasterboard

Figure 15: Steel slab of the first floor detail



a. Internal finish layer: Kerakoll plaster

b. support layer: vibropressed concrete blocks

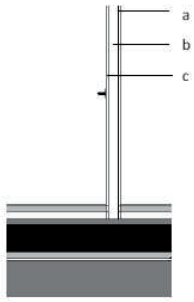
c. insulation layer: Syntherm panel

d. ventilation layer

e. external finish layer: AcquaBoard panel

f. external finish layer: Kerakoll plaster

Figure16: Perimeter wall detail



a. finish layer: Siniat plaster board

b. Internal finish layer: Syntherm panel

c. finish layer: Siniat plasterboard

Figure17: Internal partition detail

3 PROCEDURE FOR CALCULATING THE QUANTITY OF RECYCLED MATERIAL

The first addressed issue was to produce a catalog, though not exhaustive, of products on the Italian market for which the manufacturer declares the significant percentage of recycled content compiled according to the classification system identified in UNI 8290-1:1981- Residential Construction. Technological system. Classification and terminology, issued by the Italian National Unification Body. Many difficulties have been encountered in carrying out this activity as many companies do not declare the exact percentages of recycled content for their products. The reasons behind this situation is unknown, so it is supposed that production inputs are lacking in control or that little attention is paid to making this data available. The work was developed in the period January-June 2016 and 10 companies were identified for a total of 20 products.
The second issue addressed was the calculation of the amount of recycled material. For this purpose, have been taken into account the criteria used in the LEED [7] and ITACA [8] environmental certification systems.
The LEED evaluation system is structured in seven thematic areas organized into prerequisites and credits. For the purpose of the work, the section "Materials and Resources" has been analyzed. Regarding the content of recycled material, the certification system provides 2 points out of a maximum of 14 available. In the section in addition, all materials and construction products used in the project must contain a quantity of recycled material such that the sum of the post-consumption and half of the pre-consumption materials constitutes at least 10% or 20% of the total economic value, exclusively considering in the calculation the materials permanently installed in the project.

Also in this case, difficulties were encountered in knowing the value of % of the content of recycled material, since both the cost of the material and the exact percentages of pre- and post-consumption content are to be known as input data. Both of these data are not always released by companies or are not reported in a certified data sheets.

For this reason, it was considered more appropriate to carry out this analysis with the method proposed by the ITACA protocol; in fact, it is more simply based on volumes and percentages, partly inferable from project choices and partly from data provided by the manufacturer.

For this has been used the Itaca Protocol Reference Routine Procedure, UNI/ PdR 13: 2015 Environmental Sustainability of Constructin works – Operational tools for Sustainability Assessment, published on January 30, 2015, splitted into two sections and based on the ITACA Residential Protocol.

In the used Itaca protocol evaluation criteria for calculating the performance score of residential buildings are organized in "Criteria Sheets" and are grouped by reference category.

Specifically for the 'Resource Consumption' Assessment Area, and for the application of the evaluation criterion the B.4.6 'Recycled / Recovered Materials' criterion sheet has been taken into account [9]. This criterion sheet specifies the calculation method to be applied and the performance indicator to which it refers and which corresponds to the percentage ratio between the volume V_{rtot} [m³] of recycled/recovered materials used in project (B) and the totality in volume V_{tot} [m³] of the materials/components used in the test (A) according to the following formula:

$$Indicator_{ed} = V_{rtot}/V_{tot} \times 100$$

Particular attention should be given to note 7 of the B.4.6 criterion sheet specifying: "The percentage of recycled material R must express the sum of pre-consumption and post-consumption recycled content." The definitions of pre-consumption recycled content and post-consumption recycled content refer to UNI EN ISO 14021.In order to calculate the amount in percentage of recycled material present in the case study, it was decided to proceed with the study referring only to one block of the residential complex (Block D). The choice is relapsed to this building because it is the only one to be independent and it can be assumed that such simplification results in an extensible result to all the other blocks because they are designed with the same characteristics and with the same technological choices. Due to the limits imposed by the regulations, the basement has been designed entirely in concrete. For this reason only the part of the building out of the ground was taken into account for the calculation of materials. In any case, it has been attempted to limit as far as possible the use of concrete as it is a material that has limitations relative to the content of aggregates from recycling. It was therefore mainly used for the hoods and screeds and for the parapets of the external balconies. In order to improve the energy efficiency, the installation of thermal and photovoltaic solar panels is planned. To carry out the calculation quickly, the Revit program was used to model the building. The Recycled Content item has been added among the parameters attributed to each single material. With a simple spreadsheet, the V_{rtot} volume [m³] of the recycled/recovered materials used in the design and determination of the volume V_{tot} [m³] of the materials/components used in the operation was determined. Through the calculation, a percentage of 64% volumes of recycled material was reached (see Table 1).

Category	V_{tot} [m³]	V_{rtot} [m³]
Walls	298.57	155.37
Slabs	183.11	153.48
Pillars	1.8	1.8
Beams	1.47	1.47
Stairs	1.31	0.78
Doors	3.09	0.79
Windows	1.22	0.29
Total	490.57	313.98
Total Percentage	**64%**	

Table 1

4 CONCLUSIONS

In this work has been experiment the design of a project using products containing certain percentages of recycled material as declared by the manufacturer. The main aim was to demonstrate that it is possible to design a building for social use according to the current regulations and that it uses the classified products that are actually present on the market containing recycled material, reaching the 64% .

Many difficulties have also been reported, especially in finding information from companies that are willing to provide data on the content of recycled material for their products. To overcome this problem, it is suitable, therefore, that companies should be able to provide certification products that accompany a product even with recycled material content.

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Flanders' and Brussels' emerging businesses and products for a circular construction economy

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Abstract

Today, in Flanders and Brussels, a transition towards a circular construction economy seems to unfold. After the development of research projects and policy frameworks, various frontrunners demonstrate how that transition could take shape. Larger manufacturers increasingly emphasize the circular nature of their recycled products and contractors implement long-term maintenance and management agreements. They do so in demonstration projects and in collaboration with their most ambitious clients. They are not the only ones however; small businesses too seem to align their activities and products with this circular transition.

In the present paper, we discuss several smaller initiatives, including demountable brick systems, reversibly connected wood structures, greenhouses made of recuperated materials and disassembly and resell activities. Because these developments are made within practice, we expect they have the best chance to grow further and inspire others. Therefore, on the one hand, we have questioned the role of the circular economy in the development of those activities as well as in their current implementation. On the other hand, we have made a preliminary review of their "potential" impact on the environment and economy.

Without the ambition of giving a complete overview of initiatives within this dynamic transition, we have collected a series of emerging activities and products and identified some of their key characteristics. In most cases, establishing a circular business is not their sole or most important motivation. Mostly, it is an attempt to make construction practice more efficient that lays at their origin. Nevertheless, the growing attention to the circular economy and the rising awareness of the environmental impact of constructions are identified as an important leverage for almost all cases' implementation. This might clarify to other entrepreneurs that the circular economy is never the goal itself, but a responsible business approach.

Theme

Green Materials and Technologies

Keywords

innovative businesses, circular economy, life cycle design, reuse

1 INTRODUCTION

1.1 Observation

Informed about the environmental impact of buildings by certification programs such as BREEAM and LEED, environmental product decelerations (ISO 14025) and hand-on tools such as the OVAM Ecolizer 2.0. and MMG design tools (OVAM 2013a, 2013b), Belgian contractors, manufacturers, architects and clients are increasingly aware of the impact of their choices and the difference they could make. Encouraged by policy initiatives such as Flanders' Green Deal on Circular Purchase, the Circular Economy Package and Action Plan of the European Commission, and the climate agreement of Paris, some local governments (e.g. Anderlecht, Genk and Tervuren) and administrations (e.g. POM Oost-Vlaanderen) are taking the lead and ask explicitly for circular design and construction proposals during procurement.

Simultaneously, through the different research projects our TRANSFORM Research Team is involved in, we were able to identify a series of manufacturers and contractors that propose alternative materials, construction techniques, building systems and collaboration methods. For the identification of this focus group the Circular Retrofit Lab, one of the Belgian Buildings As Material Banks pilot projects, has played an important role (VUB 2016). Nevertheless, the fact that innovation in construction was identified in the context of a circularity oriented research project does not guarantee the suitability of those initiatives for closing material loops and reducing the sector's environmental impact. Therefore, a critical look remains necessary to verify if material consumption and waste production are reduced effectively - a task for which independent researchers are well placed.

1.2 Objective

To be able to follow those emerging innovation initiatives and conduct more research on them, it was first necessary to identify such initiatives in a systemized yet explorative manner. The market exploration presented in this paper allows getting a preliminary understanding on the motivations of contractors and manufacturers when addressing the increasing attention to the circular economy, and to identify the support they still need from researchers and policy makers.

Furthermore, sharing information about these initiatives through publications like this paper can inspire other entrepreneurs and could inform existing alternatives to clients. After all, the transition towards a circular built environment not only requires innovative ways to design, build and operate buildings, but also towards better-informed clients.

2 METHODOLOGY

2.1 The survey

To find out how the identified innovation initiatives and other emerging practices relate to the growing attention for the circular economy, we invited the selected companies to fill out a 5-question survey. The first question to this survey procured the initiative's and organization's names. This brief survey allowed us to reach a high participation rate while collecting required information.

With the objective to identify the innovators' motivation to reach a circular construction practice, the current state of their development and their further needs, we asked four more questions - the complete survey can be consulted in Annex 1. Varying per purpose, the questions were based on multiple-choice suggestions, on a multiple-choice grid or a short answer.

For practicality, we used an online Google-form survey written out in three languages: Dutch, French and English. The questions were translated as consistently as possible, considering the nature of each language, to avoid misunderstanding or any an undesirable interpretation. None of the answers were compulsory and respondents could go back and forth to change given answers as all questions were prompted on the same page.

In return for their answers, we offered respondents the opportunity to share their projects as examples in this international publication and potentially other future publications. At the end of the survey, they had the option to indicate whether they want to be cited, mentioned or stay anonymous.

Organizations were proposed, during the survey, to fill out a second form for other initiatives they might have. None of the respondents however did so.

2.2 Collection of respondents

Proceeding from the background knowledge and network of our TRANSFORM Research Team, built during earlier collaborations in context research and consultancy projects, we were able to invite about 30 innovation initiatives. This list of initiatives was subsequently completed after suggestions by research partners such as Circular Flanders, the Belgian Building Research Institute BBRI, Flanders' Public Waste Agency OVAM and the Flemish Institute for Bio-Ecological Construction VIBE. Furthermore, the list was extended after a call for initiatives on social media including LinkedIn (1.832 views) and Twitter (384 impressions). In each case, we personally invited one or more contacts per organization by mail, and sent one reminder when there was no response after 5 days.

This personal approach allowed us to keep track of who participated and verify if they belong to our focus group and innovate with circular ambitions. Nevertheless, this approach does not guarantee that all organizations that filled out the orm are closing material loops in the most effective way.

2.3 Collection of results

The invitations and subsequent reminders were send between September 15th and 26th of 2017. By September 26th, 49 initiatives of 45 organizations were invited, which resulted in 34 responses related to 31 initiatives. A rate of participation of 63 percent was thus reached. After this day, the survey was kept open, and an update of the results can be presented if new responses are collected.

For 3 initiatives, two responses were collected, which were submitted by different persons. For some questions, their answers were quite different and could not simply be merged into a single answer. Although this outcome triggers reflection and discussion, it was necessary to take a pragmatic approach here and integrate only the answers that were submitted first in the results below. One company replied by e-mail that their product was not related at all to circular economy. Another company replied by e-mail that they believe their product is not a good example of a circular practice yet. We nevertheless asked these companies to fill out the survey.

3 RESULTS

3.1 Categorization of respondents

Amongst the collected responses two groups of initiatives relating to the circular economy could be identified. On the one hand, concrete innovation in construction products and building systems takes place - these technical innovations include 24 out of 31 initiatives. On the other hand, new collaboration methods and processes are being proposed. Procedural innovations are reflected by 7 out of 31 initiatives. Although this separation allows structuring the findings for the rest of this paper, it should be noted that this separation is not indisputable. After all, several technological innovations trigger or even require procedural changes and vice versa.

Most construction product and system innovations, for which responses were collected, are proposed by building contractors (14) and product manufactures (6). Only a few non-profit organizations (2) and architects (2) seem to take the lead in this category. This seems to align with current construction practices in Flanders and Brussels in which the voices of contractors are often decisive in the selection of construction techniques and materials. Innovation in collaboration and construction processes is in turn tackled by non-profit organizations (3), building contractors (2), product manufacturers (1) and consulting firms (1) (Figure 1). The small number of respondents for this category does not allow us to draw any general conclusion, though it could suggest that innovation in the architectural design process might be lacking or they might not be interpreted and marketed as innovation yet.

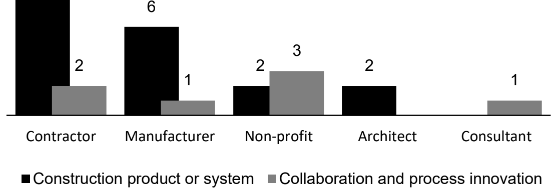

Figure 1 : number of respondents per type.

Several initiatives are illustrative for each category. They are selected and presented here for that purpose. Like the survey itself, this paper has not the intention to give a complete overview. All respondents, sorted per category and type, can however be reviewed in Annex 2.

First, in the category of construction product and system innovation, 14 responses were given by contractors. In addition to other construction techniques they offer, each of them develops or resells an innovative one. These innovations are related to the circular economy in diverse ways: because of the adaptability or reversibility they introduce and the reuse or recycling they facilitate.

Skilpod, for example, develops a series of 3D modules that can serve as a temporary pavilion or extension of an existing house (Debacker et al., 2015). The generality and mobility of each of these module allows its relocation and thus the optimization of the utility of the invested materials (Galle et al., 2016). After serval prototypes, Skilpod is currently engaged in the realization of large scale construction developments in Belgium and abroad, growing an urban mine of reusable modules.

In parallel, companies such as CLT-s, Hahbo - Llexx, Newcraft, Rose's Natural Homes, WOODinc, Skellet and Jonckheere are developing and marketing 2D building elements. Being part of wooden or metal kit-of-part systems, these elements can be assembled to complete buildings, with Junovation and Wall-linQ proposing likeminded interior solutions, Speed Building System Belgium offering the demountable masonry Façade Click system, while Zehnder and Bao are exploring the idea of circular building appliances. A distinct innovation track is followed by Rotor DC. As a spin-off of the architectural research office Rotor DB, they are engaged in the inventory, disassembly and resell of second hand construction elements, mainly interior finishing materials from post-war buildings.

Also 6 product manufacturers responded to the survey with their innovative construction materials and systems in mind. For example, Le Relais, a company for socially responsible and inclusive employment, is the producer of Métisse, an insulation material made from non-reusable cotton textiles collected by their network in France and Belgium. They offer a 100% recycled product, allowing them to valorize 90% of collected goods.

Other recycling activities are explored by Chap-yt (aerated concrete), Reynaers aluminium (window profiles), and Orbix curbstone (iron slag and CO_2). Further, focusing on reuse, Plaka Belgium developed the PlakaClamp, a modular system for edge and beam formwork.

Within the same group of technical innovations Dzerostudio Architectes, a Brussels based architectural office, gathers expertise in the reuse of construction materials through their Tomato Chili project. Taking greenhouses as the scope of their project, they explore the practical and financial feasibility of reusing locally recuperated wood element and window panes. After a brief introduction phase, they currently notice a rapidly growing interest in their greenhouses. A similar product-oriented innovation by architects is the renewable, rammed earth and lime construction technique explored by BC architects & studies.

Furthermore, two non-profit organizations take the initiative to develop new construction techniques. On of both is Samenlevingsopbouw Brussel, an association without lucrative purpose conceptualizing Woonbox, a fit-out system that, based on a box-in-box principle, allows organizing residential functions in vacant Brussels' buildings. The second non-profit organizations in this field of development wanted to stay anonymous.

Second, in the category of collaboration and process innovation, 3 non-profit organizations have initiated or are introducing innovative ideas. Labland for example, creates a network of architects, contractors and manufacturers to share and demonstrate futureproofed and adaptable housing solution. Supported by financial means of the provincial administration, they do so in the context of their goal to enable the realization of 4 zero-impact housing projects. On its turn, Cooperative Wooncoop builds expertise on collective housing property, while Rotor DB developed the online Opalis platform, where contractors can find resellers of second hand construction materials.

Simultaneously, new business models are being conceptualized and implemented. This is done for example by consulting firm Factor4 (energy performance contracts), manufacturer Desso (leasing C2C carpet flooring) and contractors like Nearly New Office Facilities. Nearly New Office Facilities or NNOF, has the ambition to transform conventional office environments by supporting, advising and managing them in all their aspects: including workplace design, organization and operation, while closing material loop by remanufacturing.

3.2 Development

The respondents were asked at which stage of development they would situate the project they represent. Based on their responses most innovation in construction products and systems seems to be situated in the introduction and growth phases, few are situated in conception and prototyping, while only one is related to the stabilizing phase (Figure 2). This trend seems to align with the idea that for circular construction and building innovation, high-tech developments are not necessarily required (Vandenbroucke, 2016). Simply smart material applications might find a market as soon as they are economically compatible with conventional construction practice (Galle et al., 2015). Nevertheless, it should be noted that not all studied products are, as of today, part of a circular material loop, and that upcoming innovations might not be detected by this survey.

Most collaboration and process innovations are on the other hand situated in the early phase (such as WoonCoop) or in the growth and stabilization phases (such as NNOF and Desso).

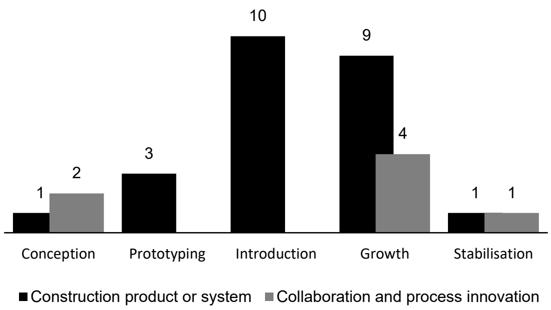

Figure 2 : number of respondents per development phase.

3.3 Motivations

To find out what the circular economy means to the respondents, they were asked to indicate in a multiple-choice grid to what extent a series of given needs have been a motivation for them and their organization to develop the product or service at the table. In an additional question they could also list their other motivations.

For both technical and procedural innovations, a client's specific question has been a motivation for most initiatives (Figure 3), amongst them are Hahbo – Llexx (absolutely) and Junovation (quite a lot). For some that was however not the case, as for example for WoodInc or Carbstone who indicated 'not at all'.

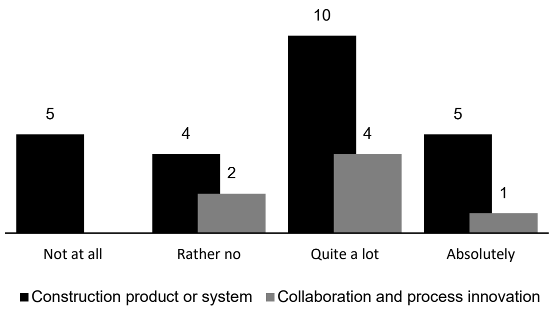

Figure 3 : number of respondents indicating a client's specific question as a motivation.

For most technical innovations, production cost reduction has been a motivation (Figure 4). Nine amongst them, including Skilpod, Newcraft and Wall-linQ even indicated 'absolutely'. For Chap-yt and Rotor DB – Opalis, production costs where however 'not at all' a motivation during their development process. The complementary answers that were given, indicate further that this production cost reduction is often seen as a leverage to make more environmental friendly construction techniques financially competitive with conventional practice, and should not only include initial costs, but should be seen from a life cycle cost perspective.

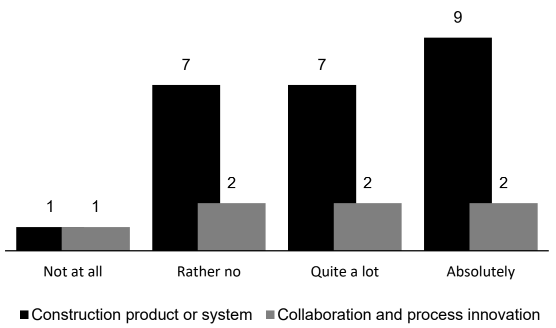

Figure 4 : number of respondents indicating production cost reduction as a motivation.

Almost all respondents indicated that improving the efficiency of construction was 'quite a lot' or 'absolutely' a motivation for the development of their product, system or service (Figure 5). Although efficiency is a broad term, the complementary answers indicate that the challenges that are tackled in this respect related to time efficiency, materiel efficient and quality and comfort assurance.

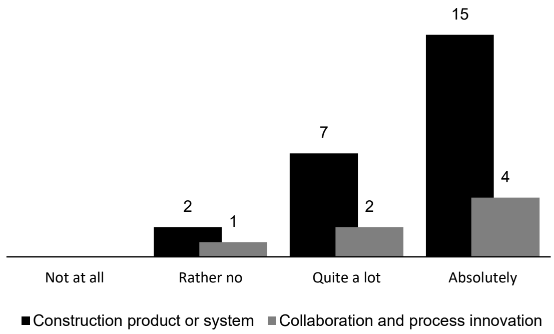

Figure 5 : number of respondents indicating construction efficiency improvement as a motivation.

Furthermore, most initiatives indicated that opening their business to new markets was a minor to important motivation. In a complementary answer, one respondent relates to this when observing "an increased demand for circularity within the business world". Except one, all process innovators indicated even 'absolutely' on this internal rather than external trigger (Figure 6). This finding could be related to the financial pressure and saturated market the sector faces at this moment (Galle et al., 2015).

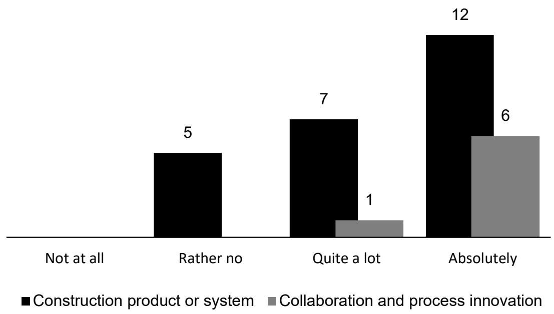

Figure 6 : number of respondents indicating opening up to new markets as a motivation.

Even more convincing is the outcome of the question to what extend reducing environmental impacts has been a motivation for the discussed initiatives (Figure 7). Except three respondents, all state that this aspect was 'absolutely' a motivation. Although it is impossible to know if this was actually the case from the initial stages of development, this result indicates the awareness about the importance of the environmental impact of construction or about the increasing attention that is given to it.

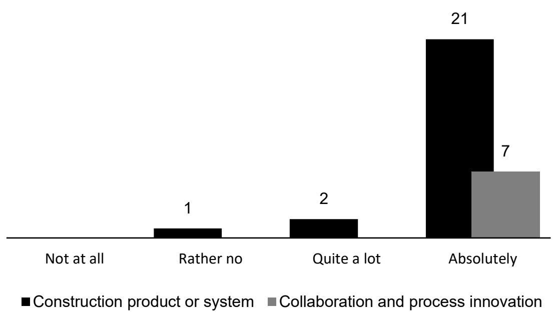

Figure 7 : number of respondents indicating environmental impact reduction as a motivation.

In line with the impact of policy initiatives we researchers identify increasingly often in practice, new policy opportunities are indicated frequently as a significant but not the most important motivation for the studied initiatives (Figure 8). For some organizations such as Desso and Labland, it absolutely was. For others, such as Skellet and NNOF it was not at all a motivation.

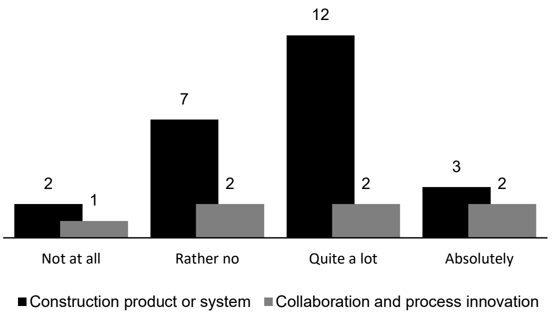

Figure 8 : number of respondents indicating aligning with policy opportunities as a motivation.

Actual legislation is in contrast indicated less frequently as a significant motivation for innovation that relates to the circular economy (Figure 9). Except for the increasingly stringent requirements on energy performance and interior comfort for schools that triggers Hahbo to develop their kit-of-parts construction system Llexx, as indicated by the complementary answer they gave, few other legal requirements are known to us. What could be a motivation however is the demolition inventory that is required in Flanders for non-residential constructions larger than 1000m³ since 2009.

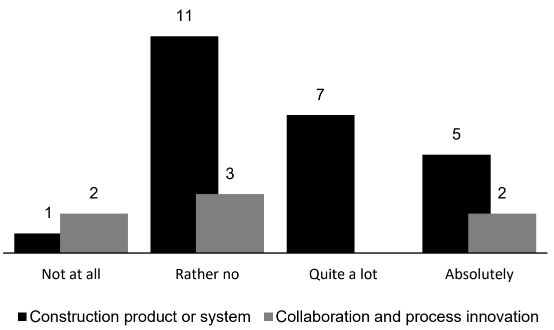

Figure 9 : number of respondents indicating adapting to new legislation as a motivation.

Finally, for both technical and procedural innovations, improving the affordability of construction was indicated as a motivation 'quite a lot' or 'absolutely' (Figure 10). Taking the perspective of the client here, this motivation applies to Factor4 who indicated 'absolutely', and to Cabstone and CLT-s who indicated 'quite a lot'. It does however not apply at all to for example Métisse that has to operate in a very cost-competitive market.

In the open field were respondents could give other motivations, several motivations that relate to the user perspective where nevertheless given. They include the ability of adaptable building systems to follow dynamic user demands, the issue of rapid urbanization that calls for smart living spaces and an accessible housing market and the need for healthy buildings to live in.

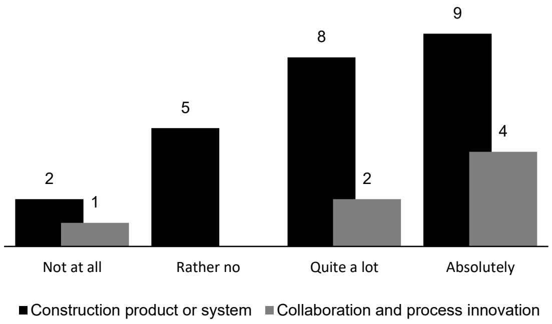

Figure 10 : number of respondents indicating better affordability of construction as a motivation.

Additional motivations that were entered in the open field included the willingness to accelerate the debate, be a frontrunner and change construction practice, the valorization of research and design insights by means of another kind of economic activity, and the opportunity to establish personal development.

3.4 The circular economy discussion

Furthermore, we asked the respondents how they judge the growing attention for the circular economy in relation to the marketing of their product, system or service (Figure 11). They could select one of the suggested statements or could enter another one.

Although recycling is often cited as an impediment for the marketing of sustainable products, because of an assumed quality reduction for example, none of the respondents indicated that relating their initiative to circularity could frighten potential clients.

Only one respondent (CLT-s) picked the option that stated that the circularity has no effect on the marketing of his initiative; their product would sell as good without that attention.

The majority indicated however that their product does relate to the circular economy, but that this characteristic is only one of its many strengths. The variability of motivations cited above is consistent with this finding.

Finally, 11 out of 31 responses was that the circular economy is one of the main selling points for the product at the table. This is the case for process innovators like NNOF, Desso and Rotor DB and product innovators including Junovation, Plaka, Orbix, Rose's natural homes, Wall-Linq, Tomato Chili and two anonymous respondents.

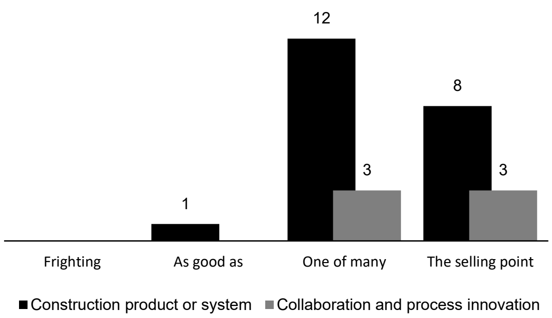

Figure 11 : number of respondents per role of the growing attention for the circular economy.

3.5 Needs

With the aim to assist in the transition towards a circular economy, the last question of the survey invited the respondents to indicate what could help the marketing of their product as a circular one (Figure 12). One or more of the following options could be selected.

Once was selected a) “Nothing, I don’t want to market my innovation as a circular one”, while eight time was indicated b) “Nothing, I can already argument, prove or demonstrate my initiative’s circularity”. Nevertheless, challenges for researchers and advisor remain d) “New business models to market my product in a circular way” and e) “An objective evaluation of the (environmental) benefits related to my project”, that were selected 16 and 14 times respectively. Furthermore, several innovators knowledge the need for c) “Further selling points that relate my product's properties with the circular economy” and f) “General support in the development of my circular product or service”.

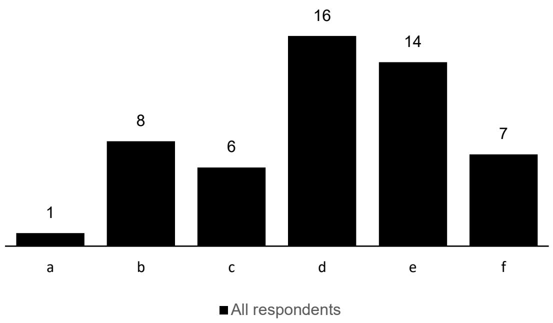

Figure 12 : number of respondents indicating one of the suggested needs.

In the entry field for open answers, respondents could share the complementary needs they have. Internal and innovation specific needs that were suggested and could indicate a current weakness of the initiatives include:

- The need for co-creation and collaboration amongst architects and contractors.
- The need for contracts and licenses to entrust commercial partnerships.

Moreover, external and market specific needs that were suggested and might be a potential threat for initiatives relating to circular economy include:

- The need for a larger public awareness about the impact of construction.
- The consequent market demand that is necessary to establish viable businesses.
- The related need for policy changes, concerning for example mandatory certification.

4 DISCUSSION

4.1 Potential impact of the initiatives

The diversity in motivations and attitudes towards the circular economy identified with the conducted survey, illustrates the complexity of understanding and fostering the transition towards a circular built environment. In addition to the research challenges that consequently remain, it is necessary to verify what the intended potential of all initiatives could be. As a quantitative evaluation of this potential would require knowledge on the market share of each initiative, this evaluation is limited to a qualitative evaluation in this explorative study. To conduct that evaluation Lansink's ladder is used as a first framework, taking a material-environmental approach. The second framework that is used to extend that approach is the triple-p paradigm of sustainability, balancing people, planet and profit. Both are suitable in the definition of the circular economy as a new operational approach for sustainable development, based on closing material loops effectively, as explained in the beginning of this paper.

Taking into account current energy recovery and recycling practices in Flanders and Brussels (BIM, 2009; OVAM, 2009, 2010; Dubois & Christis, 2014), the initiatives included in the present survey foster recycling in 20 cases and reuse in 7 cases (Figure 13, grey colour). That direct reuse was noted for the products and system of Dzerostudio Architectes, Rotor DC and Plaka Belgium, and are inherent to the approaches of NNOF, Labland, Wooncoop and Rotor DB. In a fully circular economy (Figure 13, black colour), the reversibility, modularity and durability would allow to extend this list of reuse initiatives with Skilpod, Speed building system Belgium, WOODinc, Hahbo, Newcraft, Skellet Benelux, Woonbox and Desso. Moreover, NNOF, Labland and Wooncoop have the potential to develop their approach further. Doing so, the resulting smart building stock management could reduce the need for more resources to fulfill their customers’ requirements. In other words, both today and in the future, the majority of initiatives has the potential to close material loops in and effective way. The ambitions in relation to the circular economy of Zehnder and Bao, manufacturing technical appliances, is less apparent in their public communication. Nevertheless, taking into account the Flemish criteria on Design for Change (Debacker et al., 2015) their preassembly could be an incentive for more effective take-back actions, off-site remanufacturing and reuse in another building.

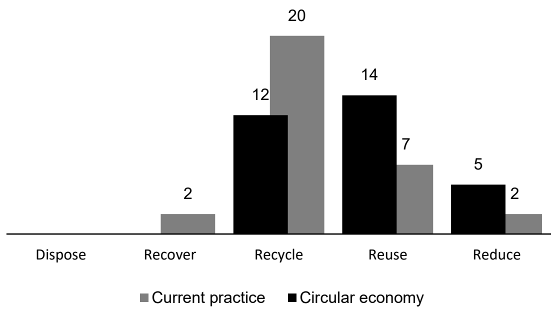

Figure 13 : number of initiatives sorted per level of Lansink's ladder.

The reduced resource consumption and waste production when climbing Lansink's Ladder could result an important reduction of the construction sector’s environmental impact. The feasibility and appropriateness of such changes should nevertheless be verified by evaluating their impact on people and profit. That social and economic impact is difficult to generalize. Nevertheless, the following initiatives clearly foster social and economic development (Van Dyck et al., 2016).

First, the deconstruction activities of Rotor DC, and the collection and sorting activities of Le Relais require and aim for generating employment opportunities for non-specialized persons which are increasingly often excluded from the conventional labor market. Second, Woonbox by Samenlevensopbouw Brussel seems to identify in the dynamism of circular buildings solutions the opportunity to transform temporarily vacant Brussels building into residences for families that are increasingly often excluded from the conventional real estate market. And third, Labland and Wooncoop take up innovative property models, based on performance rather than ownership and collaboration rather than individualism to increase the social return on invested money and materials.

4.2 Representativeness of the survey

Because the conducted survey was based on the selection of a focus group based on the experience or our research team, it might not be representative for all emerging activities within the construction sector. To improve the representativeness, a larger and broader recruiting of initiatives would be needed, requiring at the same time an extensive verification of the innovative nature of all activities and of their level of circularity. Such a research was not possible within the scope of current research projects but could be aimed for soon.

At the same time, a more profound survey would be useful to identify the actual rationales behind the respondents' answers, to understand on which knowledge or gut feel their opinion is based, and to be able to better value the relevance and reliability of their responses. A semi-structured interview would probably be more suited for that purpose than the semi-open survey that was conducted.

Altogether, the present survey revealed that, in addition to the indicated trends, motivations and positions with respect to the circular economy, diverse actors in the construction sector, large- and small-scale companies, with a different expertise and situated in various development phases, are aware of the discussion on the circular economy and already identified its possibly positive impact on their business. Most innovators stated that this debate offers and addition selling point for their activity, but is certainly not the only one. Their motivation is very diverse but almost always includes environmental impact reduction. What they indicated as further needs include objective evaluations and appropriate business models. Providing these is a challenge researchers and governments should take up. Align their priorities with the needs of frontrunners will support their initiatives in developing further towards closed material loops.

5 ACKNOWLEDGMENTS

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7 ANNEX 1

English version translated from Dutch and French

7.1 Invitation mail

Circular innovation in construction,
international publication

Dear [name]

Because the [innovation] you deliver, we believe you might be interested in the circular economy, like increasingly more colleagues. To find out how your and other innovations are related to the circular economy, we invite you to fill out our 5 question-survey. The good news: the answer to the first question is just your product's and company's name.

Filling out the survey will take only 3 to 5 minutes. If you could do this one of the next days, we could share your innovation as a Belgian best practice in our next international publication and at the Green Building Conference in Mostar.

Take me to the English form:
https://goo.gl/forms/

Thank you in advance.

On behalf of the TRANSFORM Research team

7.2 Survey

With this short survey, we want to collect information about how your innovation project relates to the circular economy. It will take no more than 5 minutes. In return, we offer the opportunity to share your project as an example in our (international) publications. At the end, you can decide if you want to be mentioned as a best practice or stay anonymous.

Question 1. Your project

Which innovative project, product or service do you offer?

In our email, we already mentioned the project because of which we contacted you. You can enter that project here. For another project, you can fill out the form a second time.

[short answer]

Through which organisation do you do so?

[short answer]

On which website can we find most information about it?

[short answer]

Question 2. Your development process

At which stage of development would you situate your innovation project?

[multiple-choice: Conception, Prototyping, Introduction, Growth, Maturity] [or other: short answer]

Question 3. Your motivation

Which needs have been a motivation to develop your product or service?

Indicate to what extent the following needs have been a motivation in your case.

[multipl-choice grid]

[options: A client's specific question, Production cost reduction, Construction efficiency improvement, Opening up to new markets, Environmental impact reduction, Adapting to new legislation, Aligning with new policy opportunities, Improving the affordability of construction]

[values: Not at all, Rather no, Quite a lot, Absolutely]

To which other needs is your project a response?

[short answer]

Question 4. You and the circular economy

How do you judge the growing attention to the circular economy for the marketing of your product?

Indicate, to your opinion, which statements are true.

[multiple-choice: Relating my product or service to circularity could frighten potential clients, Circularity has no effect on the marketing; my product would sell as good without that attention, My product relates to the circular economy, but that is only one of its many strengths, The circular economy is one of the main selling points for my product today] [or other: short answer]

Question 5. Your needs

What could help you marketing your product as a circular one?

[multiple-choice: Nothing, I don't want to market it as a circuar one, Nothing, I can already argument, prove or demonstrate its circularity, Clear selling points that relate my product's properties with the circular economy, New business models to market my circular product in a circular way, An objective evaluation of the (environmental) benefits related to my project, Support in the development of my circular product or service] [or other: short answer]

Confidentiality (next section)

Thank you for your answers, they will be sent to us when you will click 'submit'. We will treat them confidentially, but what want to give you the opportunity to appear as a best practice in our publications and through our partners such as Circular Flanders and Brussels Environment. We will keep you informed if we mention you in any case.

Do you allow us to...

[multiple-choice: ... use your project as a best practice with citation of your answers, ... use your project as an example without any relation to your answers, ... not mention you or your project in our papers and blog posts]

Other innovation

Other innovators I know, that could be contacted for this survey are:

[short answer]

Thank you, you can now submit your answers.

8 ANNEX 2

List of responding companies per group.

8.1 Construction product and system innovation (24)

Architects (2)

BC architects & studies	www.bc-as.org
Dzerostudio Architectes	www.tomatochili.com

Contractors (14)

Bao	www.baoliving.com
CLT-s	www.clt-s.be
Hahbo – Llexx	www.hahbo.be
Jonckheere Projects	www.jonckheereprojects.be
Junovation	www.JuuNoo.com
Newcraft	www.newcraft.be
Rose's Natural Homes	www.rosesnaturalhomes.be
Rotor DC	https://rotordc.com
Skellet Benelux	www.skellet.com
Skilpod	www.skilpod.com
Speed building system Belgium	www.facadeclick.be
Wall-linQ	www.Wall-linQ.com
WOODinc	www.woodinc.be
Zehnder group	www.zehnder.be

Manufacturers (6)

Chap-yt	www.chap-yt.be
Le Relais – Métisse	www.lerelais.org
Orbix – Carbstone	www.orbix.be
Plaka Belgium	www.plakagroup.com
Reynaers aluminium	www.reynaers.be
Anonymous respondent	-

Non-profit organisations (2)

Woonbox	www.samenlevingsopbouwbrussel.be/Woonbox
Anonymous respondent	-

8.2 Collaboration and process innovation (7)

Consultant (1)

Factor4	www.factor4.eu

Contractors (2)

Nearly New Office Facilities	www.nnof.be
Anonymous respondent	-

Manufacturer (1)

Desso	www.desso.com

Non-profit organisations (3)

Labland	www.newcraft.be
Wooncoop	www.newcraft.be
Rotor DB – Opalis	www.opalis.be