An overview of circular economy for wooden construction

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Abstract

Circular Economy(CE) is an economic concept, which is in the framework of sustainable development. Circular economy is mostly related to the use of material after their life cycle, and has to be implemented at the design stage of a product or a system. On the one hand, increasing the taxes and the expenses for waste disposal, and on the other hand, decreasing in the resources push industries forward in using circular economy. Nowadays due to the increase in the population, the need for shelter increase and among the materials, which can be used in building, wood is becoming more popular. As wood resources face depletion and wooden houses can have a long lifetime, there will be lots of possibilities for re-using the wooden parts. But as the types of wood for being used in different industries differ, selecting the best type of wood and the future use of it in other industries have to be considered in the buildings' designing stage.

In this work at first the structure and life cycle of the buildings were studied. After that, a new circular structure has been proposed by involving CE in the previous structure. Then by defining appropriate indicators, the use of wood as the main raw material for constructions evaluated. This evaluation has been done by the means of multi criteria decision-making(MCDM) methods.

Keywords:

Circular Economy(CE), construction, wood, indicator, multi criteria decision-making methods

INTRODUCTION

Environmental issues are becoming more important for us. Lots of wastes and used materials have already affected the nature and living creatures and have put them under the threat of distinction. Environmental damages have caused the researchers to become concerned about the after-use life of the materials and to come up with some solutions for tackling these problems.

Building and construction sectors are areas in which great deals of wastes are produced. When the life of a building is over, most of its initial materials turn into wastes and a small percentage will be recycled or reused. Many improvements could be made in the construction process in order to reduce these wastes and to save a huge amount of the materials. Therefore, building and construction sector has raised our interests to be focused on.

Implementation of circular economy(CE) in the procedure of the building structure and changing it from a linear to a circular structure is one way to enhance the use of materials and reduce the wastes. In order to assess this implementation we will feel the need of material flow analysis(MFA) and life cycle assessment(LCA) for understanding the amount of the inputs/outputs and to know how much building structure affects the environment.

In 1990 (1) became the first study studied the concept of CE in order to fulfill the gap between economy and environment. It became a great motivation for expanding this concept and led to a legislation in Germany in 1996. Since then the number of studies for implementing CE in different sectors increased. However, it could be said that the number of studies about CE implementation in construction sector are limited.

By doing the literature reviews in this scope, study of Hossain and Ng (2) could be named as the most complete review study in CE and building sector. This study which is a review on 181 papers, has categorized all the previous studies and recognized the lacks of using these subjects in construction sector. For instance assessing operational energy consumption based on climate conditions, considering renovation and material use and maintenance impacts, consideration of the mentioned aspects based on local and regional conditions and adopting CE and assessing it by LCA and MFA were some fields were there has been no research in.

Articles, written about CE implementation and constructions could be categorized as below.

Some articles like (3), (4) and (5) have been done on wooden houses in which an evaluation of CO2 emission and embodied energy have been done.

Comparison studies such as (6), (7), (8), (5) have been done to compare the performance of three construction materials based on CE implementation. Among these, (7) can be mentioned as the most comprehensive one.

As a few number of studies indicate, the use of circular economy in constructions has not been studied much so far and huge lacks like not having generality in information, evaluation methods and variety of comparison indicators could be named. In this study we proposed a new structure for better implementation of CE in constructions and a way to better evaluate this implementation.

METHODS

1.1 Structure proposition

By reviewing the literature about the use of CE in construction sector, the structure proposed in EN15978 standard was the one, used in most of the studies. We find this structure incomplete for CE implementation and vague in describing the relations between stages and material flows.

Therefore we tried to enhance the structure in the way to make it more circular and to identify what are the use stage activities in details and how activities in end of life or beyond life could affect other stages. The proposed structure is shown in Fig. 1. General steps of this structure is the same as ones in EN15978 standard. As it is evident, the structure is drawn in two colors: orange activities represent the areas which had been studied by other authors so far, while green ones show intact fields of research. Apparently, activities in the use phase and end of life phase are the ones mostly neglected in previous researches. In the structure there are also two kinds of arrows, the blue and the orange ones. Blue arrows are the forward flows, the same as the flows in EN15978 standard and orange ones represent backward flows. For instance in the use phase, the blue arrow from application to maintenance show that there are parts which would need maintenance activities in the use phase while the orange arrow indicates that after maintenance, parts will be used in the use phase again. It could be said that the orange flows are the ones that make the structure circular.

1.2 Comparison procedure

One methodology for assessing the implementation of CE is doing a life cycle assessment(LCA). In the description of LCA presented based on ISO 14040, LCA is known as a standardized methodology, which gives the assessment its reliability and transparency and contains four phases: a) goal and scope, b) inventory analysis, c) impact assessment and d) interpretation.

In our case, after setting the goal which is comparing the performance of wood with other materials, for the second step we have to introduce some indicators by which the analysis could be done.

To define the best indicators, a summary of used criteria in previous studies was prepared. Carbon dioxide and embodied energy were selected as the two indicators, widely used in articles such as: (4), (8), (3) and (6).

Other chosen indicators in this work are: air and water pollutions due to their imposed risks to human health, resource depletion because of the importance of resources and acidification potential caused by gasses such as NOx, NH3, SO2, HF, H2S and H2SO4. Cost and customers' idea were two other important indicators we decided to include in this study.

The method we used in this study to evaluate the performance of wood, was to compare it with concrete and steel as the main materials for constructions. According to (9) the main parts of a building could be listed as Table 1. Quantitative indicators were calculated for one square meter(m2) of each used material and the idea data has been gathered by filling a questionnaire by 50 people.

Table 1: Building main sections

	Wooden house	Concrete house	Steel house
Foundation	Concrete ground	Concrete ground	Concrete ground
Floor	Timber, carpet	Concrete, carpet	Gypframe steel, carpet
Walls	Timber, nails	Concrete, paint	Curtain walls
Structural frame system	Hardwood timber	Concrete with bottled connections	Prefabricated steel with bottled connections
Windows and doors	Timber windows and frames(+Aluminum)	Aluminum frames	Steel windows and frames
Ceiling system	Treated timber	Soffit plaster, paint	Aluminum strips
Roof system	Insulated slate, timber truss	Concrete roof	Steel plate flat roof

Because of having various indicators and criteria, the comparison could be done only by MCDM methods. Different indicators were weighted by Analytical Hierarch Process(AHP) method. In the evaluation the highest weight belongs to cost, following by water pollution, embodied energy, CO2, idea, abiotic resource depletion and water and air pollution.

By having the weights and the amounts of each indicator for each construction, we can use PROMETHEE method to complete the comparison procedure. PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluation), which was firstly put forward in 1982 by Barns is a family of ranking methods, used when we have various indicators for comparison. To do the

evaluations in our work, we used Visual PROMETHEE software.

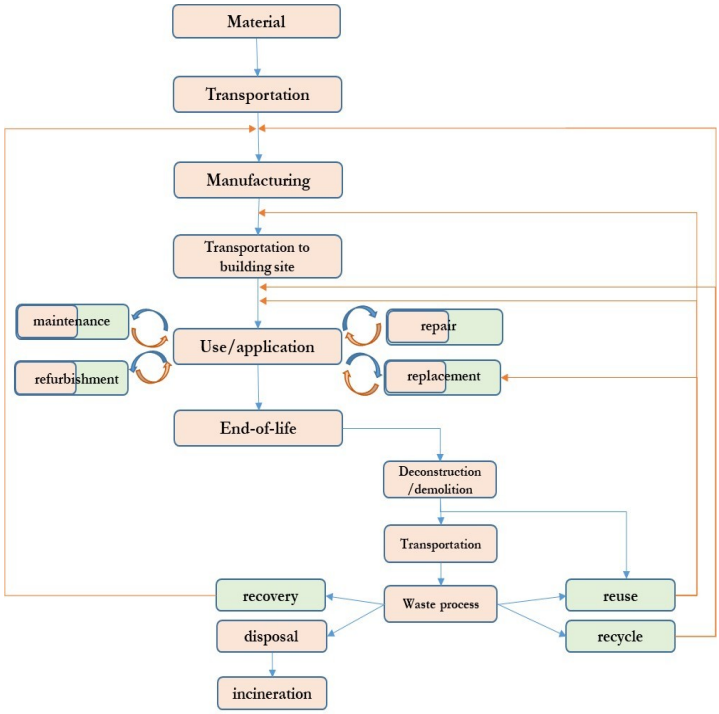

Fig. 1: Proposed circular structure

1.3 Results

The results of this work show that base on the input data for each indicator and thee weight of each indicator, the wooden house has the best performance regarding all the criteria, then the concrete house and steel house has the worst performance. These results however might change if the decision makers preferences in the indicators change.

CONCLUSION AND DISCUSSION

1.4 Conclusion

For doing this study, we initially reviewed a wide range of articles in order to come up with a comprehensive definition of circular economy and it's implementation in construction sector. At the beginning and based on the identified lacks in previous studies, a useful structure for construction of buildings proposed. This structure could be mentioned as a development of EN15978 structure in which the relation of different stages are shown by forward and backward flows.

Then as the next goal of this work, to better evaluate CE implementation and to do a comparison among different materials for buildings, we identified some indicators and criteria. Finally, according to the chosen indicators we proposed MCDM methods so that the best decision for using materials could be done, based on the performance of materials in each indicator and decision maker's preferences.

1.5 Discussion

In this work, the proposed structure shows the detailed activities in the use phase and end of life in comparison with the EN standard which was widely used previously. As there is no particular description for CE implementation and the fact that each activity, named in the structure vary according to the type of the building and the used materials, the details were not considered in this study. Therefore one future direction for this work could be studying and categorizing activities based on materials. As a result of grouping the materials would be the easy evaluation of recyclable and reusable amounts and then using these information in the decision process.

One important criterion which affects the availability of materials and the use of materials' sources, specially when talking about wood, is land use. This indicator is useful in order to evaluate the negative impacts imposed to the environment or the positive ones such as enhancements in the performance of the land and jungles for example. Consideration of this criterion in evaluations could be the other promising direction in future studies.

As the other future proposition, a mathematical model could be written by considering the regulations and all the restrictions imposed due to materials' recycling and reuse potential. The problem could be described as a multi-objective-decision making problem by having incompatible objective functions and the aim of determining the optimized amount of each material for buildings.

REFERENCES

[1] Pearce, D.W. and R.K. Turner (1990) Economics of natural resources and the environment., JHU Press.

[2] Hossain, M.U. and S.T. Ng (2018) Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: An analytical review. Journal of Cleaner Production. 205:763-780.

[3] Gustavsson, L., A. Joelsson, and R. Sathre (2010) Life cycle primary energy use and carbon emission of an eight-storey wood-framed apartment building. Energy and Buildings. 42(2):230-242.

[4] Hafner, A. and S. Schäfer (2017) Comparative LCA study of different timber and mineral buildings and calculation method for substitution factors on building level. Journal of cleaner production 167:630-642.

[5] Petrovic B, Myhren JA, Zhang X, Wallhagen M, Eriksson O (2019) Life Cycle Assessment of Building Materials for a Single-family House in Sweden. Energy Procedia 158: 3547-3552.

[6] Council, C.W., Wood-frame housing-A north American marvel (2002) Report No. Building Performance Series.

[7] Akanbi LA, Oyedele LO, Omoteso K, Bilal M, Akinade OO, Ajayi AO, et al. (2019) Disassembly and Deconstruction Analytics System (D-DAS) for construction in a circular economy. Journal of Cleaner Production.

[8] Nässén J, Hedenus F, Karlsson S, Holmberg J (2012) Concrete vs. wood in buildings–an energy system approach. Building and environment. 51: 361-369.

[9] Kylili, A., M. Ilic, and P.A. Fokaides (2017) Whole-building Life Cycle Assessment (LCA) of a passive house of the sub-tropical climatic zone. Resources, Conservation and Recycling116:169-177.