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REDESIGN FOR ENVIRONMENT OF WOODEN PACKAGING FOR BULK RECYCLING AND RECOVERY

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ABSTRACT

Society increasingly demands for effective waste management policies to make industries more environmentally sustainable. Organizations are even issuing directives to drive choices about these policies. In particular, modern industries produce a lot of packaging, which soon become waste, even before product usage. Research can face the problem with improvements in recycling and recovery processes. However, even if recycling and recovery would enable waste to have still a value, most costs and benefits are determined at the design stage. Therefore, Design for Environment criteria must be adopted in the design tasks, from the early conceptual design when the main design solutions are defined. The design criteria to assess possible design choices must consider all the environmental impacts of packaging over its lifecycle. The present work focuses on Redesign for Environment of packaging solutions. Following a systematic design process, we use different criteria to evaluate the effects of design solutions on packaging, since waste can be seen just as one of the main phases of packaging life. To this purpose, we adopt the stages of the waste hierarchy set by the EU Waste Framework Directive 2008/98/EC as design evaluation criteria. The waste hierarchy sets a priority order for five life cycle stages that a packaging can go through. The stages of the hierarchy can be differently weighted according to the costs and benefits they involve. The proposed Design for Environment method based on the waste hierarchy criteria is finally applied in the redesign of an industrial case study. The packaging solution as foldable wooden crates were chosen for their capability to already comply with the first stages of the hierarchy, that is reducing waste with high customization to customer requirements and crate reuse. Hence, the case study improved the next stages with easing the wood recycle and recovery processes.

Keywords: design for environment, waste hierarchy, packaging, foldable wooden crates, recycling, recovery.

INTRODUCTION

Waste management is fundamental to seek for a sustainable future. Therefore, organizations are promoting plans for managing waste. The EU Waste Framework Directive 2008/98/EC sets a five-stage waste hierarchy as prevention, preparing for re-use, recycling, other recovery and disposal, [2, 3]. The hierarchy is intended to guide choices for waste management policies of EU members with a priority order, from the first stage of prevention to the last one of disposal. An important share of all domestic and industry waste is packaging. In fact, a specific European Packaging and packaging waste directive 94/62/EC deals with reuse, recovery and recycling of that kind of waste.

Some packaging can be reused. Others can be recycled to get new materials or make composite products or panels, shredded to chips and recovered or burned to produce energy. However, packaging can easily introduce problems in case it was manufactured with adhesives, painted, protected with preservatives, it contacted hazardous materials in its lifetime, or simply it cannot be separated from other parts made with different materials. In the end, just part of packaging is reused or recycled, while the rest is landfilled or burned. Even if improvements in recycling processes would enable waste to have still a value, most costs and benefits are determined at the design stage, since it is able to improve also the first levels of the aforementioned waste hierarchy, [1, 9].

Design for Recycling is a topic addressed by many works in recent years. Environmental impact and financial aspects must be assessed from the early conceptual design stage, [10]. Each design choice has to be assessed in order to maximize the value that can be recovered at the product's life end, minimizing the effort for its disposal. Transportation costs, value of component reuse, disassembly and separation processes, material reuse and landfill fees must be accounted, [22]. However, it is difficult to reliably evaluate the costs in the early design stages, since the same packaging can be handled by many different industries. The cited work uses very detailed formulae, accounting for probability densities of occurrence of the parameters, multiplied by cost coefficients variable over time. However, it also admits the possibility for an empirical assessment.

The present work aims at introducing the described waste hierarchy into a systematic redesign process for the evaluation objectives of possible design improvements. The redesign of packaging solutions is difficult due to demanding costs constraints, but any little improvement has important effects, due to the high volumes of production.

The paper is organized as follows. Section II reports a literature search on Design for Environment methods. Section III introduces the Design for Recycling method, while section IV describes its application in the redesign of foldable wooden crates, followed by conclusions.

LITERATURE BACKGROUND

Green Design deals with sustainability and reduction of the environmental impact of products, involving generation and selection of design concepts, choices on materials as well as on manufacturing processes. Green Packaging Design is part of Green Design, as an expression of the development of Green Design concept of a product. In order to reduce costs and impact on the environment, specific requirements and criteria should be taken into account in green packaging design, [21]. First, literature guidelines for Green Packaging Design give priority to the selection of reusable and biodegradable materials. Second, the layout must be simplified, without excessive packing of the goods. Simple shapes should be preferred, in order to reduce material waste, [21]. The packaging layout should use lightweight containers, reducing the amount of material per container. Natural materials should be preferred, e.g. paper-based, wood and bamboo-based materials, since they directly communicate a green appeal to the user. Also the moderate design of Qi *et al*., [11], demands for reducing material usage.

The problem of evaluating Green Design solutions is well established being a decision-making problem, with several alternatives and accounting for different conflicting objectives. Pahl *et al*., [10], suggest a method for evaluating conceptual design alternatives under given objectives with different importance weights. The evaluation algorithm leads to unbiased decisions. The choice of weights for the objectives is a well-known problem in the decision-making works, [8]. As for evaluation in Green Design, Stanujkic *et al*., [15], discuss the selection of Green Packaging Design alternatives for a wine bottle, by means of a decisional method based on a weighted sum called Step-wise Weight Assessment Ratio Analysis (SWARA). Zhang, [18], proposes an evaluation system of Green Design based on life cycle considerations. A fuzzy hierarchy structure model of Green Design is described which takes into account several factors based on the ISO 14000 standard. The weight of each factor is given by experts' judgement. Moreover, a fuzzy hierarchy evaluation on the performance of Green Design alternatives is performed.

Other multi-criteria decision making methods have been implemented in Green Design as well as in Green Packaging Design topics. Again, the selected design is function of the number of alternatives, the vector of objectives and the vector of weights. The objectives, dependent on technology and environment performances, resource efficiency, as well as cost, have to be concurrently accounted into a decision-making analysis, [4], [5]. Criteria for Green Packaging Design alternatives have been assessed in the literature, including development and design, manufacture, packaging, sales and transport, use and maintenance and recycling to describe a green product, [20], as well as materials, production methods, packaging and transportation, usage, waste and recovery, [16]. The importance weights for the criteria can be evaluated also by means of the Analytic Hierarchy Process approach, [19].

The waste hierarchy defined by the EU Waste Framework Directive 2008/98/EC is used in research works as criteria for life cycle assessment in Green Design. Wang, [17], addresses the green packaging problem with a 4R (reduce, reuse, recycle, recover) and 1D (degradable) principle, listing three aspects to be included in the design process, namely, the packaging modelling design, the packaging structure design, and the design of packaging material. Rossi *et al*., [13], use the waste hierarchy as evaluation criteria for the end of life of biodegradable materials in packaging design. In Sørensen and Wenzel, [14], the waste hierarchy is at the basis for the comparison of the environmental impact of four alternative hospital bedpans in their entire life cycle.

In this paper, a decisional method for the evaluation of design alternatives is adopted, which is based on a weighted sum approach. Moreover, the waste hierarchy stages are used as design criteria for the selection of green design alternatives. In group decision-making activities, designers, experts and technicians are required first to define the importance weights of the criteria and then to assess the design alternatives by these criteria. The weighted sum approach has been chosen since it does not require high computational efforts, it is compliant with the new waste hierarchy approach and it closes the gap between research and industry.

ASSESSMENT OF A DESIGN IMPROVEMENT WITH WASTE HIERARCHY CRITERIA

The present work follows a systematic design approach with four main stages, as a) planning and task clarification, b) conceptual design, c) embodiment design, d) detail design, [10]. In case of mature products, like most packaging solutions, their redesign doesn't start from scratch, but it is an improvement of their impact on the environment. Their utilization within the existing supply chain demand for easy or no adaptation of logistics equipment all over the world. In [10], recycling considerations set the objectives for the evaluation of possible design solutions in different design tasks, starting from the early conceptual stage.

Waste hierarchy approach

The present work adopts the aforementioned European waste hierarchy to set the evaluation objectives for a design solution. A packaging may subsequently follow the different hierarchy stages in its lifecycle, eventually skipping some of them. A design choice can make the system more or less efficient in each single

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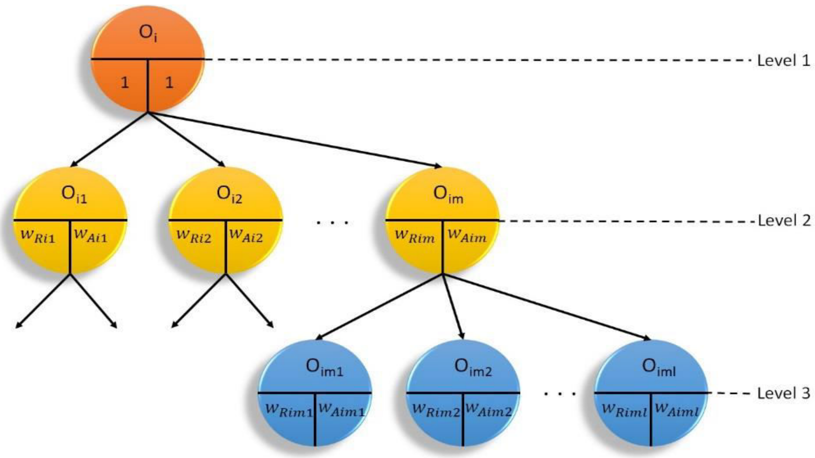
stage. The stages are not mutually exclusive each other, meaning e.g. the reusability property of a packaging doesn't imply it cannot be recycled or recovered some utilizations later. Each stage of the hierarchy is weighted depending on its importance for the fulfilment of the goal of being environmentally friendly. Of course the overall evaluation of the choice must account for all other objectives of the packaging. Generally, the material usage reduction must trade off with performance and resistance. Savings for reusing a product must overcome reconditioning and handling costs. Then, some Life Cycle Assessment works agree with the waste hierarchy that recycling has always environmental benefits, [6], [12]. Knauf, [7], includes in his evaluation also the energy recovery by burning biomasses from wood waste, thus saving fresh energy sources. With this new point of view the waste hierarchy must be reconsidered and the importance of the different stages are not linear along the hierarchy. In order to evaluate a new technical solution, the design team must assess its costs and benefits in each stage.

Waste hierarchy assessment

The first step of any evaluation of a design solution requires to set the objectives tree in order to derive the evaluation criteria, as shown in Figure-1. The objectives can be derived from the design requirements, resulting from the task clarification phase. The objective tree has different levels, as O_i, O_{ij}, O_{ijk}, and so on, and their number reflects the complexity of the product. Finally, the evaluation considers the objective at the last level. A relative weighting factor w_{Rij}, w_{Rijk}, …, must then be assigned to each sub-objective. These factors must be weighted in turn times the weighting factor of the previous level ones to obtain the absolute weighting factors w_{Aij}, w_{Aijk}, … . The sum of w_{Aij} factors must equal 1, as the sum of w_{Aijk} factors must equal w_{Aij}, and so on. The waste hierarchy sets such objectives at a level below the green level, as shown in Figure-2.



$$w_{Aijk}=w_{Rijk}/w_{Aij}$$

$$\sum w_{Aijk} = \sum w_{Aij} = 1$$

Figure-1. Objectives tree with weighting factors.

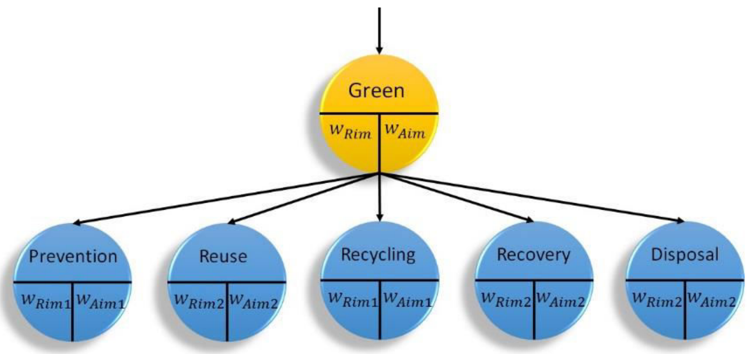


Figure-2. Structure of the objective tree for the green sub-objective.

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The design team must then assess the objectives. This is a difficult task in the early conceptual design stage, when parts and systems are still not modeled, so that only rough estimates are possible. Also many uncertainties affect the future lifecycle of the single product. In case of the considered packaging, a designer can make precise evaluations just for production and supplying to the first customer. Then, the lives of products diverge. For instance, some packaging travel on trucks few hundreds km and maybe then they are used to store parts. Other packaging are shipped to customers across the world and then burned to recover energy. The design team can define rules to evaluate the performances of design solutions with probabilistic distributions, [10]. It is also effective to judge the solutions with structured interviews which can point out also non obvious qualities or weaknesses, like e.g. easy of handling or green image.

In order to fill the green objective in Figure-2 the solutions are first classified as: not recyclable, two-step recyclable and one-step recyclable. Not recyclable includes also the solutions which require hard processing in order to be prepared for recovery. Two-step recyclable means the product must be disassembled or shredded to separate materials in order to be compatible with the recycling or recovery processes. One-step means the product can be directly trashed in a recycling process by the final customer, without any preparation. One-step clearly reduce the cost for the customer, so that little additional costs can be acceptable.

Any evaluation hardly avoid bias from subjective sight. However, a structured scheme as of Fig.3 aids the design team to make better decision. The graphical tool compares two solutions. The length of a bar shows the assessment of a sub-objective for a variant from 0 to 5, while its width shows its weighting. The area of a bar is the weighted score of a sub-objective, while the sum of all bar areas is the overall score of the variant.

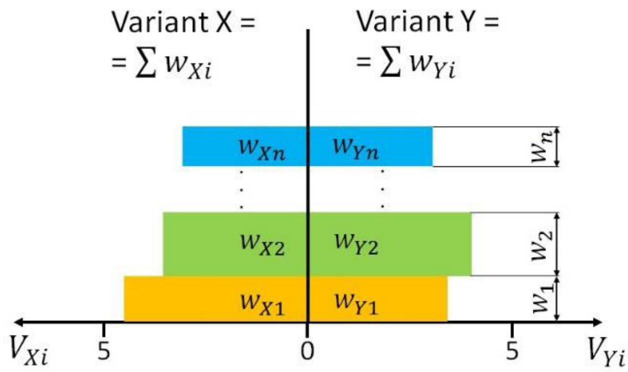

Figure-3. Value profile for the comparison of two variants.

REDESIGN OF FOLDABLE WOODEN CRATES

The Systematic Redesign for Recycling was adopted to improve the solutions of foldable wooden crates, used in the logistics of many heavy industry products. Foldable wooden crates were chosen since their concept already complies with the first stages of the hierarchy. First, wooden crates can be produced in very low batches and fit well to the specific requirements, preventing most material waste. Second, they reduce the logistics costs when emptied and folded, so that it is cost effective to transport, unfold and reuse them.

The clarification of the tasks for the wooden foldable crates analyses the requirements of the actually and past produced crates. The crate requirements define the objective tree, as shown in Figure-4. The weighting factors are set with structured interviews with the designers. The green property of the crate is very high ranking, as 0.26 out of 1.00. A design solution might enable different stages of the hierarchy in sequence, with their own weighting factors.

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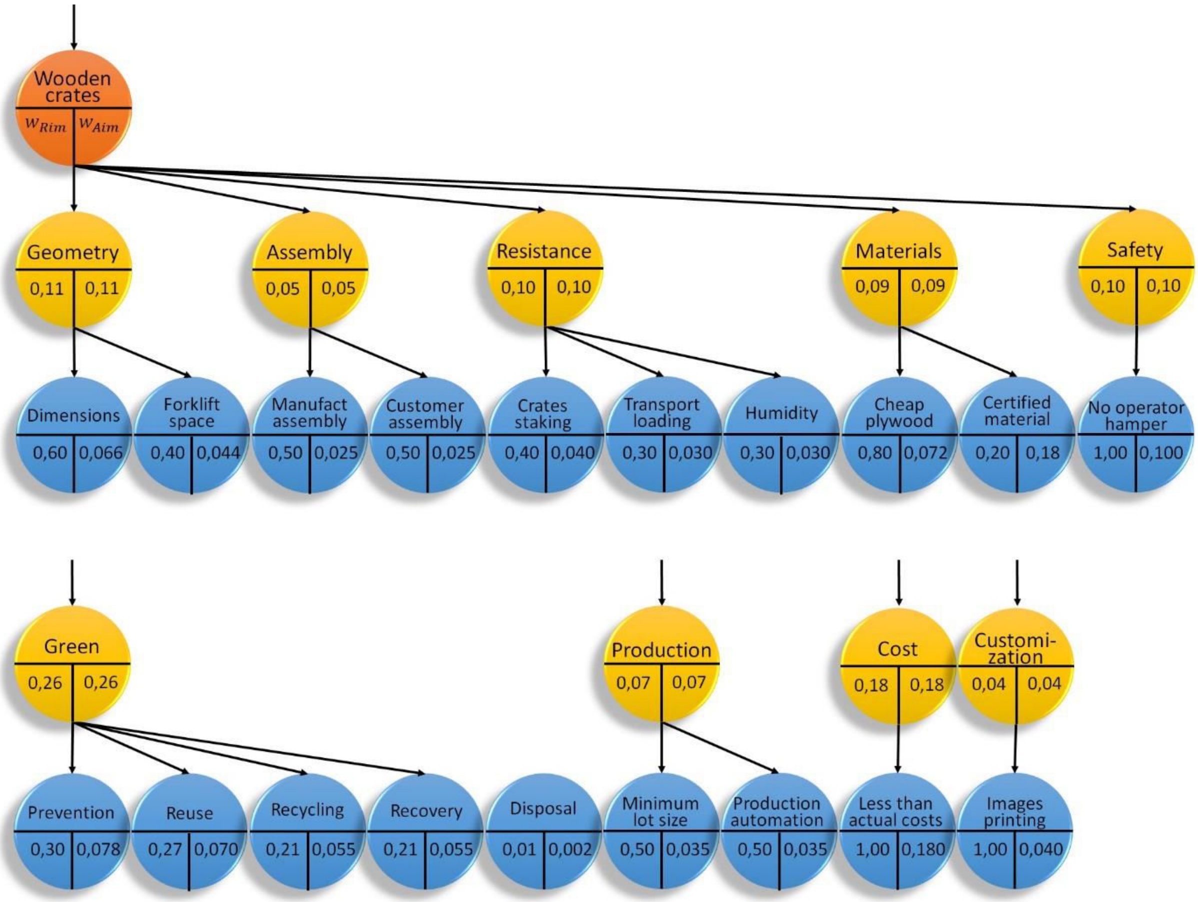

Figure-4. Objective tree for the foldable wooden crates.

The following conceptual design analyses first the structure of existing foldable wooden crates. The actual structure, shown in Figure-5, consists of three modules. The base sustains the product and the crate sides. The sides can be folded to take less space when the crate is not used or just empty supplied to the customer. The cover closes the crate. Other parts join ad fix the sides on the base and the cover on the sides.

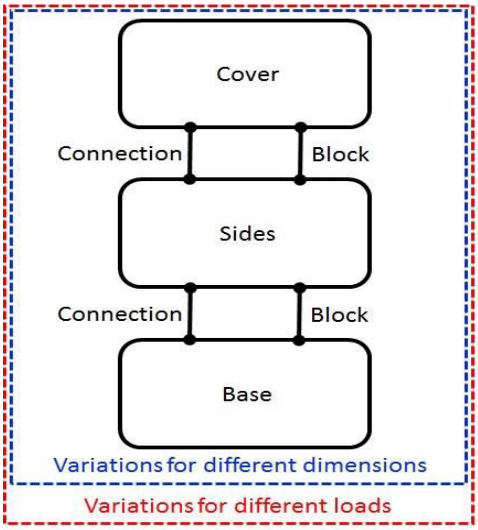

Figure-5. Functional structure of a foldable wooden crate.

In order to avoid hard changes in the logistic chain, the architecture with three modules is kept. The modules are further analysed to improve the objectives already reported in Fig.4. Among all the evaluated possible variants, the final design choices are here discussed.

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The crate base consists of a traditional pallet. At present, any new solution is less convenient the traditional one since this has such advantages: it can be reused many times, it has a parallel market of used pallets, its recovery process is already running in many parts of the world with shredding, metal separation and wood chip burning. The cover is not reported since it is just a wood sheet and can already follow a recycling process without shredding. In case the customer demands for additional strength, the cover is reinforced with nailed beams. In this case, the cover follows the pallets recycling process.

The value profile for the best solution for the foldable sides is compared with the traditional ones in Figure-6. This result is possible due to the introduction of a new material, the Arboblend V2®, from TECNARO GmbH. Arboblend V2® consists of lignin by 99% and of some natural additives. It is obtained from renewable sources and it is easily recyclable. This blend behaves more like a classic polymer and appears compact and white. It can be easy moulded thanks to the low melting point of lignin.

The green variant scores slightly better than the traditional one for Prevention, due to the reduction of weights and transportation costs. The traditional variant is better for Reuse, since metal fittings are more durable. Finally Recovery and Recycling are well addressed by the Green variant only, since it is compatible with wood life end processes. The sum of scores makes the Green variant preferable.

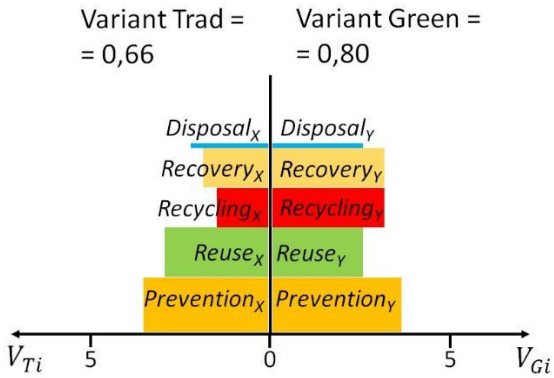
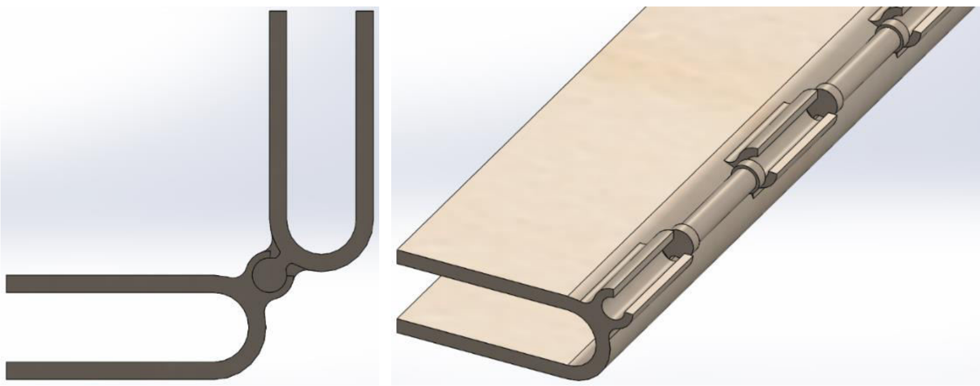


Figure-6. Value profile for the comparison of the green sub-objective for two variants of foldable sides.

The introduction of this material enables to embodiment stage for the hinge shown in Figure-7a for the foldable crate sides. The hinge is made of two equal parts, shown in Figure-7b, the second just upside down. The hinge is constrained to the wood sheet by press fit or with little glue. This hinge makes the sides one-step recyclable in the wood recovery process, enhancing the green advantages and appeal of the product. The one-step solution is assessed as very efficient since the disassembly by the final customer is quite undesirable since it would require additional tools. The crate sides are constrained to the pallet and to the cover with cable ties. This two-step solution is accepted since it can be easily handled by any operator. Also, it adds the important functions of enabling customs inspections and detecting unwanted intervention. The last stage of the systematic design process is the detail design. The final model for the hinge, shown in Figure 8 a) and b), accounts for design for operation and manufacturing issues. In fact, the new shape enables easier contacts of hinges when closing and also avoid undercuts, so that a mould without cars is simpler and much cheaper.



a) b)

Figure-7. Recyclable hinge for the foldable sides of the wooden crate: a) complete assembly made of b) two equal parts.

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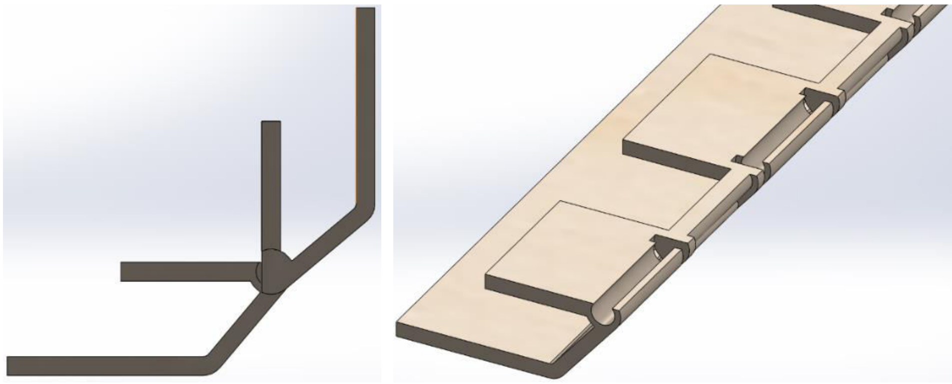

a) b)

Figure-8. Model of the recyclable hinge after design optimization: a) complete assembly made of b) two equal parts.

DISCUSSION AND CONCLUSIONS

The foldable wooden crates are improved with the application of the Systematic Redesign for Recycling method. The design tasks were focused on the objective tree, which graphically collects the product objectives and their ranking. The analysis of the product structure enables to reduce the problem to the design of different modules, each one evaluated in light of the objective tree. Many design variants were evaluated with a structured scheme of five Green sub-objectives adopted from the stages of the waste hierarchy set by the EU Waste Framework Directive 2008/98/EC. Each sub-objective is assigned with a different weight, defined from the priority order of the waste hierarchy and adjusted with structured interviews with the design team.

Recyclable design solutions are introduced only when economically feasible. The two-step recyclable solutions are preferred when disassembly does not involve excessive costs to the customer. On the other hand one-step recyclable solutions are preferred for the Green sub-objective especially when only unskilled and untooled operations are required by the final customer, thus even justifying extra costs. The one-step solutions are achieved with the introduction of a new material, recyclable in the same processes undergone by wooden products.

Future works include Redesign of other modules, extending the use of recyclable materials. The costs of the required moulds will have to be optimized with a series design activity, according with typical users expectations.

REFERENCES

[1] Dewhurst P. 1992. Design for Disassembly - the Basis for Efficient Service and Recycling. Report no. 63, Dept. of Industrial Engineering and Manufacturing Engineering, University of Rhode Island, Kingston, RI.

[2] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste (Waste Framework Directive), Brussels, http://ec.europa.eu/environment/waste/framework/

[3] Gharfalkar M., Court R., Campbell C., Ali Z. and Hillier G. 2015. Analysis of waste hierarchy in the European waste directive 2008/98/EC. Waste Management. 39: 305-313.

[4] Haihong H., Guangfu L., Zhifeng L. and Zhang H. C. 2007. Research on decision-making method for Green Design based on Green Utility Similarity. Proceedings of the 2007 IEEE International Symposium on Electronics and the Environment. pp. 196-201.

[5] Liu F. 2013. Brief analysis on green design and manufacture of furniture products. Advanced Materials Research. 694: 3269-3272.

[6] Kim M.H. and Song H.B. 2014. Analysis of the global warming potential for wood waste recycling systems. Journal of Cleaner Production. 69: 199-207.

[7] Knauf M. 2015. Waste hierarchy revisited - an evaluation of waste wood recycling in the context of EU energy policy and the European market. Forest Policy and Economics. 54: 58-60.

[8] Korhonen P.J., Silvennoinen K., Wallenius J. and Öörni A. 2013. A careful look at the importance of criteria and weights. Annals of Operations Research. 211(1): 565-578.

[9] Kriwet A., Zussman E., and Seliger G. 1995. Systematic integration of design-for-recycling into

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

product design. International Journal of Production Economics. 38(1): 15-22.

[10] Pahl G., Beitz W., Feldhousen J. and Grote K.H. 2007. Engineering design. A systematic approach. 3rd edn. Springer-Verlag, Berlin, Germany.

[11] Qi Z., Xilong J. and Weiqiong H. 2011. A research into the tendency of green package design. Computing and Intelligent Systems. Springer Heidelberg, Berlin, Germany.

[12] Rivela B., Moreira M.T., Muñoz I., Rieradevall J. and Feijoo G. 2006. Life cycle assessment of wood wastes: A case study of ephemeral architecture. Science of the Total Environment. 357(1-3): 1-11.

[13] Rossi V., Cleeve-Edwards N., Lundquist L., Schenker U., Dubois C., Humbert S. and Jolliet O. 2015. Life cycle assessment of end-of-life options for two biodegradable packaging materials: sound application of the European waste hierarchy. Journal of Cleaner Production. 86: 132-145.

[14] Sørensen B.L. and Wenzel H. 2014. Life cycle assessment of alternative bedpans–a case of comparing disposable and reusable devices. Journal of Cleaner Production. 83: 70-79.

[15] Stanujkic D., Karabasevic D., and Zavadskas E. K. 2015. A framework for the selection of a packaging design based on the SWARA method. Engineering Economics. 26(2): 181-187.

[16] Taghaboni-Dutta F., Trappey A.J. and Trappey C.V. 2010. An XML based supply chain integration hub for green product lifecycle management. Expert Systems with Applications 37(11): 7319-7328.

[17] Wang Y. 2014. On green packaging design in packaging design. Advanced Materials Research. 971: 2251-2254.

[18] Zhang Y. 2010. Analysis on fuzzy evaluation of green design based on life cycle. Applied Mechanics and Materials. 34: 1436-1440.

[19] Zhang Y. 2009. Research on evaluation method of green design based on Topsis principle. Wuhan Ligong Daxue Xuebao/Journal of Wuhan University of Technology. 31(15): 141-144.

[20] Zhou C.C., Yin G.F., Hu X.B. and Liu L. 2008. Multi-objective optimization decision-making of material selection oriented to green design. Computer Integrated Manufacturing Systems. 5: 028.

[21] Zhou F.F. 2014. The theory of green packaging design and its application. Applied Mechanics and Materials. 635: 248-252.

[22] Zussman E., Kriwet A. and Seliger G. 1994. Disassembly-Oriented Assessment Methodology to Support Design for Recycling. CIRP Annals - Manufacturing Technology. 43(1): 9-14.