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Improving the Skills and Knowledge of Future Designers in the Field of Ecodesign Using Virtual Reality Technologies

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Abstract

Nowadays future designers are required to explore different fields of engineering (e.g. basis of design and operation of machines, methodology of process design, characteristics of phases of a product life cycle, ergonomics, etc.) in order to obtain sufficient knowledge about the product, the problems of its operation and related services. Currently, there is a strong tendency to take into account the impact of a product on the natural environment. The handling of products that are withdrawn from usage is one of the big problems emerging in a modern society. One of the possibilities to solve these problems is taking into account the environmental issues at the very early stage of the product design. Authors created the methodology to include recycling requirements in the phase of design of the product with support of the CAD 3D systems[14,15]. In details, the method of ecological-oriented product assessment during the design process was implemented in CAD 3D environment in order to improve the skills and knowledge of future designers about environmental aspects of the designed product[12]. In order to enhance the effectiveness of the training of designers, authors decided to use immersive Virtual Reality (VR) technologies that are more and more often used as advanced training systems. The user/trained person can explore Virtual Environment (VE) for educational and exercise purposes[5]. Immersive VR technologies are gaining wider use as engineering design tools to support the product design phase because of their ability to deliver an immersive and user friendly environment that can be used as digital test-bed for prototypes of the product[30]. Paper briefly describes the analysis of the recycling of selected product designed in the CAD 3D system with the support of Virtual Reality technologies that were based on the recycling product model (RpM) and the agent technology[12,14,15]. The RpM, developed during the geometric modelling phase, includes the data necessary for a comprehensive product recyclability evaluation already at the design stage. This approach allows designer to select appropriate solutions that facilitate future disassembly and to choose materials most suitable in terms of future recycling. The analysis allows to make an assessment of the susceptibility of the product for recycling using the agent system. The agent system, in accordance with the recycling

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product model (RpM) that was implemented in the 3D CAD system, is an innovative tool for the designer to enable a comprehensive assessment of the product in terms of its susceptibility to recycling.
Future designers (students of mechanical engineering fields) gained possibility to improve their skills and knowledge in the field of ecodesign through the immersive trainings of virtual product design for recycling. Applying the Virtual Reality technologies for training of the future designers was aimed at enhancing the effectiveness of training mainly due to immersion and interaction with the virtual environment and to explore the product before it is constructed, as well as provide learning of the environments in which the finished product will be operated. As the example of the recycling-oriented virtual product design, case study of the design of small household appliance is presented. Participants of the immersive training (students) have a possibility to design the product in the Virtual Reality and select the optimal variant, which meets all environmental requirements. Short description of the recycling modeling (creation of connections, defining the extended materials and disassembly attributes) as well as an example of recycling assessment such as calculation of recycling assessment measures or providing tips and suggestions generated by agent system is also presented.

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Keywords: ecodesign; design for recycling; virtual reality; immersive training;

1. Introduction

Nowadays designers of innovative products are required to explore different fields of engineering (e.g. basis of design and operation of machines, methodology of design, characteristics of phases of a product life cycle, ergonomics, etc.) in order to obtain sufficient knowledge about the product, the problems of its operation and related services.

Design process is still one of the most important phases of the product's lifecycle[16]. An innovative approach to design of products is strictly related to a holistic approach to all stages of the product lifecycle[14,15]. Many aspects need to be taken into consideration during the design phase[16]. Currently, there is a strong tendency to consider the impact of a product on the natural environment. Since there is also a trend to shorten the lifecycle as much as possible, intensified production may deplete natural resources and energy and increase a quantity of post-manufacturing and post-use waste. That is why legal and economic environmental requirements (e.g. enforced by the legislation of the EU[8,9,10,23]) were imposed on manufacturers, forcing reorientation of companies' business processes on issues related to recycling, disposal and recovery of materials or components[14,15]. For example, manufacturers of electrical and electronic equipment, according to the WEEE directive[8], are especially obliged to reclaim or recycle a specified quantity of produced goods.

Consequently, designers are challenged with new tasks and must take into account the environmental issues at the early stage of the product design in order to design environment-friendly products[14,15]. The introduction of environmental aspects into an early stage of the design process is called ecodesign.

Ecodesign is a new approach to the design of products. It is based on identification of environmental aspects of a product that must be considered in the design process at the very first stages of development. This approach is also referred to an environmental design and design according to the principles of sustainable development[14,15]. Authors analyzed a number of definitions of the ecodesign term in their previous work[12].

There are various reasons motivating companies to implement ecodesign. The main determinants have been divided into internal and external factors and described in authors previous papers[12,16]. Briefly, the internal factors include product quality, cost reduction, stimulation of technological innovation, sense of responsibility, improvement of company and product rating and increase of employee motivation. External factors include the cost of waste, government policy, market demand and competition, commercial and industrial organizations, and finally environmental criteria of awarding prizes for projects. Most often companies are driven to implement ecodesign by a combination of both external and internal factors[16]. Research shows that companies do not follow ecodesign systematically[3,28]. The main cause is "the lack of systemic approach to the existing practice and lack of tools that support ecodesign"[2,3,4,7,12], and "no interest in including product development based on eco-innovation into the business strategy"[2,4,12,25,27].

Very important factor in the strategy of sustainable design is prevention and reduction of negative environmental impacts of all activities related to the production of a new product during its lifecycle. The earlier the environmental aspects are considered in the design process, the more effective it is[12]. The ecodesign of a product's life cycle requires a number of principles to be observed (e.g. saving natural resources, design considering recycled materials, design for disassembly, environmentally friendly production, reduction of materials that cannot be recycled)[1].

Issues like recycling possibilities for a product are determined during the design phase, through selection of proper materials and types of joints between parts. For example, designer should be familiar with compatible materials. Incompatible materials affect the quality of the recycled product. The most effective way is to use only materials which together form a compatible combination in the process of production. Designer can use the compatibility tables (e.g. for metal alloys, for plastics, for thermoplastics) and define which materials may be combined to make recycling as simple as possible. It is also crucial to minimize material diversity to reduce the probability of material incompatibility issues. It is also important to consider the manner and type of joints to be used in the product. The joints should be designed to ensure quick and smooth disassembly, particularly when the use of incompatible or hazardous materials is unavoidable due to functional reasons[11,13,16].

In conclusion, a designer must consider not only the criteria of product functionality, its durability, quality, and cost, but also the issues related to product disassembly, environmental impact of all of its elements, marking of the materials, materials compatibility, and types of joints to be used. Some of these are skills that need to be acquired.

The paper is focused mostly on methodology of improvement of the skills and knowledge of future designers in the field of ecodesign. Recycling requirements were included in the phase of product design[14,15]. In details, ecological-oriented product assessment during the practical tasks of the design process was implemented in CAD environment[12].

In order to enhance the effectiveness of the training of designers, authors decided to use immersive VR technologies that are more and more often used as advanced training systems. Paper briefly describes the analysis of the recycling of selected product designed in the CAD 3D system with the support of VR systems. As the example of the immersive training of recycling-oriented virtual product design that was based on the recycling product model (RpM) and the agent technology[12,14,16], case study of the design of small household appliance is presented.

2. Computer-aided ecodesign

In order to enable the assessment of the environmental parameters of a designed product, computer tools aiding this evaluation has become necessary. Over the last few years a lot of methods and IT tools that aid designer in the decision-making process during pro-ecological design were developed. The authors analyzed the functionality of these methods and tools, e.g. Design for Environment (DfE) Matrix[38], Ecodesign PILOT[35], Environmental Effect Analysis[24,32], Environmental Quality Function Deployment (EQFD), Environmental Design Industrial Template (EDIT)[31], Life Cycle Assessment (LCA)[18,29], Ten Golden Rules[25], Alternative Function Fulfillment[33], Strategy wheel[34].

Methods and IT tools mentioned above support designer in the field of ecodesign and help to choose the proper method of recycling, eco balancing of products and materials and help to define the paths of disassembly. Sometimes there are integrated systems, joining together many modules. Databases contained within the software gather the information needed by designers. Depending on the software, this information is constantly updated, guaranteeing compatibility with obligatory requirements. In conclusion, application of these methods and tools to the design process allows routine control of the designed product, considering the ecodesign requirements.

Additional modules for CAD systems comprise another group of IT tools that support the ecodesign. For example, Sustainable Materials Assistant® (assisting in the selection of environmentally friendly materials) by Autodesk Labs, is offered and used together with Autodesk Inventor® 2009 software. It is a complex tool that assists decision-making in the selection of environmentally friendly materials, in order to reduce the negative environmental impact of products while ensuring appropriate operational parameters[12,37]. SolidWorks Sustainability is another example, that is part of the SolidWorks package. It is a practical application for implementing different strategies of sustainable development during the process of product design. SolidWorks Sustainability contains process models and life cycle assessment databases used in the GaBi software. The IT tool takes into account four key environmental indicators: carbon footprint, total energy consumption, and impact on air and water quality[22].

The examples briefly describe above show that developers of CAD systems have already noted the need to consider environmental aspects at an early stage of product design. However, the existing applications are made as additional modules closely tied to specific CAD software.

The method developed by the authors, supports the process of environmental design and is recycling-oriented. It belongs to the group of IT tools discussed above, but it allows designers to assess product recyclability whichever CAD system is used[16]. A detailed description of the methodology will be presented in the next chapter.

3. Method of recycling-oriented product assessment during design process

Effective use of CAD 3D systems allows the designer to carry out the geometry of the product as well as to develop its kinematics and wiring diagrams. The designer may also perform the durability calculations of the designed product, e.g. using the finite element method (FEM). However, standard CAD 3D systems lack tools used specifically to design recycling-related properties. The existing IT solutions that were briefly presented in chapter 2 – both autonomous software and the specific modules available in some CAD 3D systems – are mainly used to conduct a general environmental analysis (e.g. according to the LCA approach), or they are material databases of various types[13].

Method developed and proposed by the authors enables product recyclability evaluation conducted automatically during the design stage in CAD 3D system. Method is based on the *recycling product model* (RpM) and *agent technology* that are in details described in previous publications[13,16,17].

Based on the method, IT tool used for recycling-oriented analysis was created. The application has a modular structure. The first module is used to operate the RpM model in the CAD 3D environment. The other one operates the agent system (for conduction of product analysis, calculation of the evaluation measurements, collection and use of information and knowledge from previously completed projects)[13]. The recycling-oriented assessment of each product modeled in a CAD 3D system takes place according to the same procedures[11]:

- Extended product structure developing digital 3D models
- Extended material attributes defining geometric constraints for the designed assembly
- Developing the RpM
- Recycling-oriented product analysis

3.1. Recycling-oriented product assessment

According to the authors, recycling-oriented product assessment requires some additional elements to be introduced to the CAD 3D system, e.g. data on the recyclability properties of the designed product. The data, together with a standard geometric 3D model authors determined as a recycling product model (RpM)[11,13]. The RpM model consists of the following elements[11]:

- Extended product structure
- Extended material attributes
- Disassembly attributes (data on the disassembly process)
- Product categorization

A detailed description of the structure of the RpM model and the assumptions necessary for the proper functioning of this model in CAD 3D environment are described in authors previous work[11,13]. In short, the RpM that is developed during geometric modelling process, includes the data necessary for a comprehensive product recyclability evaluation already at the design stage. This approach allows designer to select appropriate solutions that facilitate future disassembly and to choose materials most suitable in terms of future recycling. The RpM has been implemented to the CAD 3D system and served as a basis to design an additional application that facilitates the design process taking into account the recycling aspects. The IT tool includes a knowledge base that store the knowledge and information from the previous projects. Based on the content of the knowledge base, application automatically generate suggestions for the designer relating to certain design solutions that can be used, taking into

account aspects of recycling. This is possible thanks to the use of agent technology. Agents follow the work of the designer in the CAD 3D system, monitor the changes made in the design, assess their impact on the parameters relevant to recycling, and provide suggestions of product improvements to facilitate its recycling[36].

In conclusion, It tool created by the authors enables automatic support for the recycling aspect of design process conducted in CAD 3D system. This is possible without having to re-examine the product structure, manually aggregate the parameters relevant for the adopted method of product recyclability evaluation, and to re-introduce them to third party systems[12].

A brief description of the application of the methodology for the recyclability assessment during the design phase with use of CAD 3D system will be presented.

3.2. Recyclability evaluation in the product design process

Application of the above presented methodology of recycling-oriented product assessment will be presented on the example CAD 3D model of a small household appliance made by one of the polish manufacturers of household appliances. The basic 3D model included various combinations of joints and has been updated with the assignment of extended material and disassembly attributes necessary for the recyclability evaluation. It was also possible (in its agent part) to conduct the calculation of recyclability evaluation measures for connected elements made of compatible and incompatible materials[12]. Figure 1 presents a product model in the CAD system.

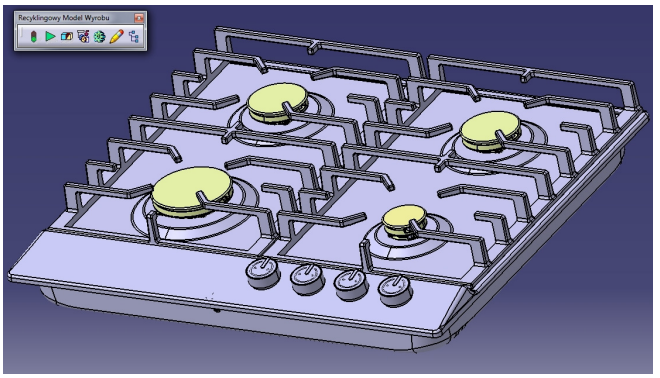

Fig. 1. CAD 3D model of the household appliance[12].

All possible combinations of joint type of the CAD 3D model were examined according to the following procedure:

- Development of a 3D model of all product components
- Development of the RpM model
- Recyclability evaluation (calculations of recyclability evaluation measures by the agent system)[12]

In the first step, geometric 3D models of the product elements were prepared. Then, necessary geometric constraints to determine the relevant geometric relations between the parts were defined. Based on the geometric assembly model of the product, the RpM model was developed. Within the RpM model the following were defined[11] possible combinations of joint type of the CAD 3D model were examined according to the following procedure:

- Product category (type)
- Extended material attributes
- Model of connections between the product elements

The RpM model is prepared in a CAD 3D environment through a graphical user interface (GUI) made in CATIA system[11]. The assignment of the product to a specific type (e.g. small household appliance, large household appliance, and other) is made in the project's global settings window. In the product type selection field the type (category) of the model uploaded to the CATIA system must be indicated. The database with extended material attributes must be also prepared and uploaded to the system. Materials database included the basic groups of construction materials and plastics. The basic material groups were listed and the compatibility matrix was defined. There is also a possibility to save additional information in the database, such as the set of tools needed for the disassembly process and the existing material "mixtures" (elements which cannot be recycled)[12].

As a next step, model of joints between the product elements must be created (connection constraints). The user must define to which group the given element of the product belongs (from the point of view of the role the element may play in the joints: connecting, combined, or connecting-combined element)[12]. After the completion of the process of definition of properties of all elements of the examined CAD 3D model of the product (assembly), user must specify the connection constraints between the elements (Fig.2). Each joint must consist of at least two combined elements, and the algorithm that verifies the correctness of data prevents the user from saving the information before this basic condition is met.

The list of elements which make up any joint can be viewed and edited. The user can indicate an element in the design which meets the following criteria:

- Its immediate parent element in the product structure is the element for which a joint is declared
- It is one of the combined elements
- It does not belong to the combined elements of the declared joint[12]

It needs to be highlighted that the minimum number of connecting elements required for a joint to be considered as correct depends on the type of the joint. Furthermore, information about tools needed during the process of disassembly of the joint was added as an additional attribute of the declared joint.

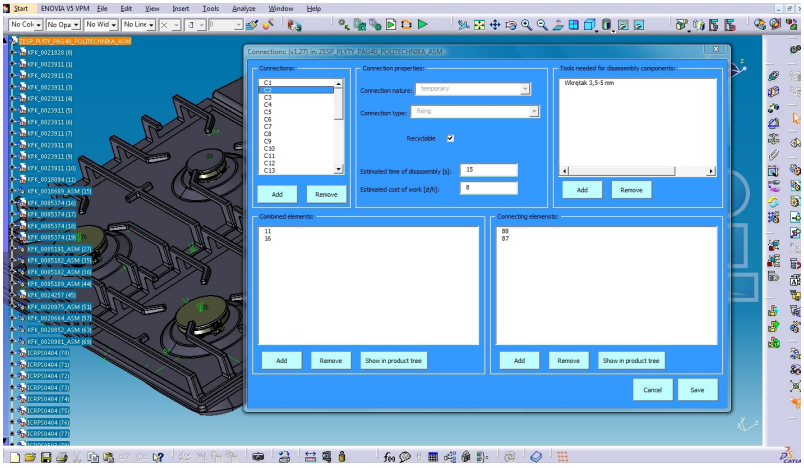

Fig. 2. Joint edition window[12].

Further analysis of the product are conducted with the support of agent system. RpM data is transferred from the CAD 3D system to the agent system with the use of data exchange interface. It is based on the universal data exchange format[12]. The agent system provides information on the values of product recyclability evaluation measures, e.g. the level of recyclability of each element (basic or complex) comprising the designed product (Fig. 3). The impact of each element or component on the ratio of entire product is also calculated[12]. If the agent system discovers errors during the analysis (e.g. inconsistency in the product structure), an appropriate message will be displayed on the user's screen.

In conclusion, the user can test numerous variants of the product model, with a change of the parameters that influence the results of recyclability evaluation (e.g. different types of joints or materials). This will allow designer to compare and assess the influence of the parameter change on the results of the recyclability evaluation (Fig. 4)[12].

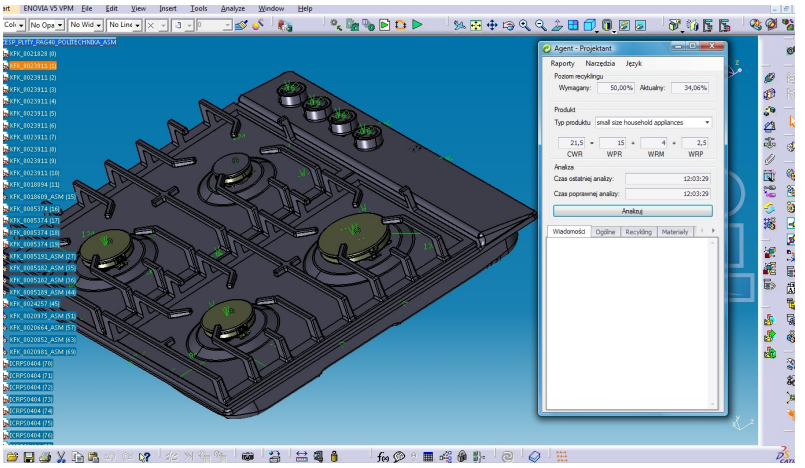

Fig. 3. (left) Cad 3D model of the product, (right) agent system interface – after the analysis[12].

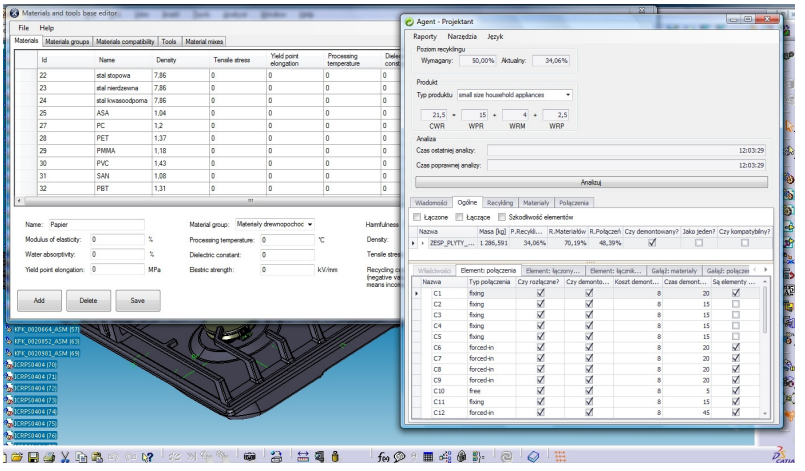

Fig. 4. Agent system interface at work– after the analysis[12].

In this way future designers can use this method and tools to improve their skills and knowledge about environmental aspects of the designed product [12].

In order to enhance the effectiveness of the training of designers, authors decided to use immersive Virtual Reality (VR) technologies that are more and more often used as advanced training systems. The user/trained person can explore Virtual Environment (VE) for educational and exercise purposes[5]. Immersive VR technologies are gaining wider use as engineering design tools to support the product design phase because of their ability to deliver an immersive and user friendly environment that can be used as digital test-bed for prototypes of the product[30].

4. VR for immersive trainings and educational simulations

As a form of instructional simulation, also called educational simulation, immersive simulation created in Virtual Reality environment can be a powerful learning tool. Immersive training requires trained users to complete tasks or to solve specific design problems within Virtual Environment (VE) that replicates the real work environments. Design tasks are centered on "realistic, job-related problems"[26].

The authors assumed that such a job-related problem to solve by designers is to design environmental friendly product. Educational simulations "result in the acquisition of complex and higher-order skills, as people learn by experience, made risk decisions, without bearing the costs of making mistakes"[6].

With a view to the above-described benefits resulting from the use of immersive simulations authors focused also on the integration of the hardware. For the purpose of creation effective training of virtual product design for recycling, authors decided to use the immersive approach, namely large stereoscopic projection system integrated with tracking and gesture recognition systems. Virtual Environment is a system consisting of an appropriate VR hardware and VR application that is always a heart of such a system. In the sense of programming, VR application should be defined as one, closed entity, containing virtual models of objects placed in a properly defined environment, ensuring the user with interaction and immersion.

Authors developed an immersive simulation of ecodesign with the support of VR technologies based on the methodology of VR application development, briefly described in authors previous work[20,21].

5. Example of immersive training application to support recycling-oriented virtual product design

As the example of the recycling oriented virtual product design, case study of the design of small household appliance is presented. Participants of the immersive training (students/future designers) have a possibility to design the product in the Virtual Reality environment (EON Studio software) and select the optimal variant (e.g. materials of parts or different types of joints), that meets all environmental requirements. Based on CAD 3D model of the product (household appliance), an interactive model was developed in Virtual Environment (Fig. 5).

Fig. 5. Virtual model of the product.

Graphical User Interface (GUI) was also developed. Creating user interface is an important stage of VR application development. The interface must be intuitive and allow easy launching of all the necessary functions of the virtual model. Almost always some form of GUI is in use, operated by either traditional input devices (e.g. mouse and keyboard) or by tracking systems, where movements of user's limbs are registered as input[19]. In most VR environments, 2D menu can be created using scripts written in one of the popular programming languages such as C ++, VB Script, etc. The EON Studio software allows creation of 2D GUI based on library objects – combo lists, as well as generation of a "3D menu" based on objects moving with the camera. The process of generating a 3D menu in EON Studio software was briefly described in authors' previous work[21].

After completing a design task - change of connection type or construction material of the part, a user is informed of recyclability effects of his decisions. Current level of recycling calculated on the basis of the RpM model is displayed on the screen. If the level of recycling is lower than the required level, designer can use tips and

suggestions of changes in order to achieve a higher level of recycling. In this example, current level of recycling was calculated as 34,06% (Fig. 6). Agent system automatically generated a tip to change material of the knob (part was additionally marked with red color on the virtual model). Each change causes recalculation of the recycling coefficients and provides a new current level of recycling. Recalculation happens in background. In this way, a designer is kept informed about the potential impact of the designed product on the environment. In practice, change of material of the selected part resulted in increased recycling level (Fig. 7).

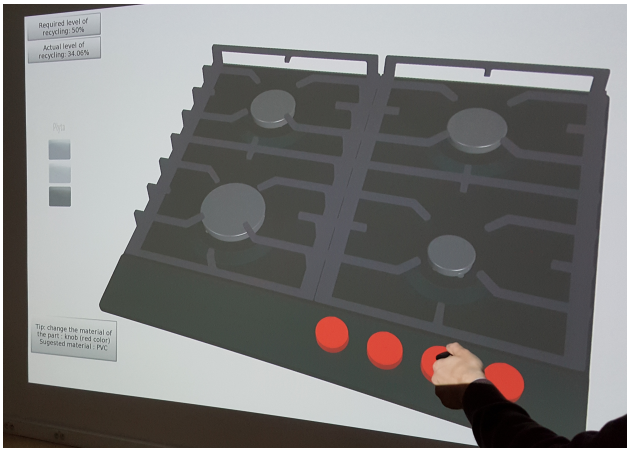

Fig. 6. Virtual product design for recycling – tips for the designer (for the purpose of this image, 3D view was temporary off).

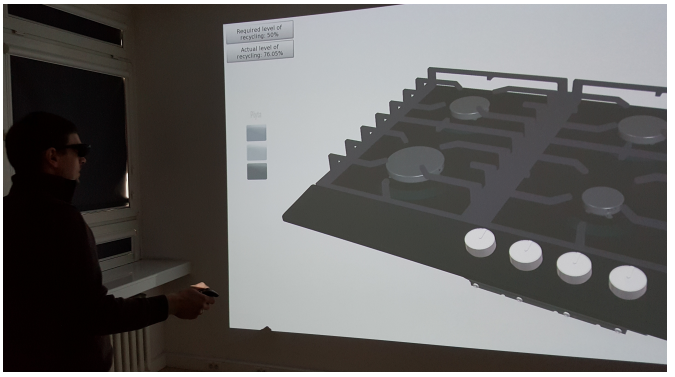

Fig. 7. Virtual product design for recycling – changes after the tips (level of recycling was increased).

Effectiveness of the immersive training performed in the VR system was tested using a sample of users (future designers) experienced with design techniques. A group of 30 people (students of mechanical engineering course) left their impressions in a survey study. It confirmed high effectiveness of the interactive training. The possibility of virtual product design with simultaneous feedback on the environment impact (the recycling level) of the product has been well received and evaluated as useful. Immersive aspect of the system was also valued very high – usage of the stereoscopic projection system with 3D glasses allowed to present the virtual product in more interactive way.

6. Conclusions

In order to improve the skills and knowledge of future designers about environmental aspects of the designed product, authors proposed the method of ecological-oriented product assessment performed at early stage of design process. A dedicated IT tool was created in order to enable automatic support for the recycling aspects of the design

process conducted in CAD 3D environment. In order to enhance the effectiveness of the training of designers, authors decided to use immersive Virtual Reality technologies. Students of mechanical engineering fields (as future designers) gained possibility to explore the immersive training of virtual product design for recycling. Paper showed that these noteworthy technologies can be used as innovative tools for educational simulations.

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