AGENT-BASED SUPPORTING SYSTEM FOR ENVIRONMENTAL ASSESSMENT OF PRODUCTS

EWA DOSTATNI, JACEK DIAKUN

ABSTRACT
The article concerns including of environmental aspects during design phase of households appliances. The assessment criteria for this kind of products from EU regulations have been characterized. Based on them additional set of indicators have been proposed. The indicators have been implemented into agent system that supports the designer during the design phase in the product lifecycle, thus enabling the assessment of influence of changes in the design on its ecological properties. The structure of the agent system have been also described.

KEY WORDS
agents, ecology, environmental engineering, design

INTRODUCTION
The environmental aspects of design is becoming more and more important. The necessity of fulfillment the environmental requirements causes decisions made by designers have the influence not only on typical attributes of a product, like functionality, appearance and manufacturing costs, but also on environmental of the product.

In order to perform this task effectively, the designer needs to be equipped with appropriate tools, which support him in this aspect of design. The paper presents an agent technology based computer system, which enables the designer to do on-line assessment of products, which are designed from the standpoint of ecological criteria.

METHODS AND TOOLS SUPPORTING ECO-DESIGN
Owing to increasing meaning of eco-design and EU restrictions concerning environment, several methods and tools have been drawn up that enables including environmental aspects into design process.

They differ from each others mainly level of complication and accuracy. Each of them support particular phase of eco-design. One can distinguish guide-books that help in eco-design [van Nes and Cramer, 2003; Lofthouse and Bhamra, 2005; Herrmann et al., 2006] and also tools for identification and assessment of product influence on environment. One of them is QFDE (Quality Function Deployment for Environment), which is the modification and extension of QFD [Quality Function Deployment] from the standpoint of environmental protection [Sakao et al., 2006]. Checklist is created for quality assessment of selected ecological parameters connected with the product. It could be i.e. gas emission, energy consumption, using of particular materials or ease of assembly [Schischke et al., 2010].

One of the most widespread method is LCA (Life Cycle Assessment), which „is the process of assessment of effects that particular product exerts the influence during its whole life cycle” [Kowalski et al., 2007]. The result of the analysis is the list of used resources and emitted contaminants connected with its existence.

Another group of tools are indexes. They are single values that represent the impact of product or material on environment, i.e. MIPS, recycling level or eco-indexes. Eco-indexes are the attempt to modeling
of wide scope of influences on environment. Each of them reflects another aspect and requires individual interpretation. The selection of eco-index and set of them depends on individual features of the product, manufacturing method and location, consumers, etc. [Goedhoop and Spiersman, 2000; Lewis et al., 2001].

In the literature one can indicate the attempts of selection and identification of methods and tools that support eco-design. Calow et al. (2001) propose two categories that can be used to categorize these tools: qualitative and quantitative. In [Knight and Jenkins, 2009] the authors proposed another classification of methods. They distinguished three categories [Knight and Jenkins, 2009]:

1. Guidelines: defined here as: providing broad support, with little detail, but applicable either across the whole product development process and life-cycle (…);
2. Checklists: defined here as: providing in-depth, but narrow, application at selected stages of the product development process or lifecycle,
3. Analytical tools: defined here as: providing detailed and/or systematic analysis at specific stages of either the product development process or lifecycle e.g. eco-indicators; environmental effect analysis; environmental impact assessment; life cycle assessment; material, energy and toxicity (‘MET’) matrix; life cycle cost analysis”.

Each of the methods listed previously may be assigned to one of the criteria mentioned above.

The development of IT technology enabled computer implementation of method supporting eco-design. Dedicated software are mainly databases that contain information useful during eco-design. One can number among them such tools as: EDGE [EDGE, 2010], ECO-it [ECO-it, 2009] and others. Eco-indexes and other methods of product assessment concentrate on selected aspects of environmental impact. Even the most universal method LCA (mentioned before) does not generate complete and holistic results. Calculating the value of the index gives the information on current state; it enables to assessing and identifying of necessary ways of further development. Product development is an iterative process, thus the values of each index change after every stage. Monitoring of their values gives useful information about the effect of activities being taken, but is laborious. The automation of these activities is one of the reasons of development of methods supporting eco-design.

The method presented here uses agent technology. It enables supporting eco-design on early phase of product life cycle (conceptual design, geometrical modeling), operates in distributed environment and automates product assessment from the recycling point-of-view. It gives the possibility of rapid assessment of influence of particular product variants on its environmental features. This way the designer can concentrate of engineering activity without having knowledge on legislative acts concerning ecology. The solution being presented may be also treated as improving the functionality of PLM-class solutions by incorporating into scope of engineering software another aspects than geometrical modeling (CAD 3D) and data management (PDM).

PRODUCT ASSESSMENT CRITERIA
TAKING INTO ACCOUNT ENVIRONMENTAL ASPECTS

Considering a system supporting an environmental engineering focused on recycling, current standards and directives which embrace requirements and regulations pertinent to environment protection have been collected and analysed. Standards, which define ways of including environmental aspects into product design and development, has been selected.

In recent years, the European community has implemented a number of changes in environmental protection law regarding electrical and electronic equipment. The list below contains the most important documents tackling the subject of ecological design:

• IPP – Integrated Product Policy [IPP, 2001];
• EuP (Eco-design of Energy Using Product) directive – environmental design of products consuming energy defines requirements describing influence on environment, exerted by electrical and electronic products in each phase of the life cycle [EuP, 2005];
• WEEE (Waste Electrical and Electronic Equipment) directive – describing the electrical equipment and electronics used – defines the requirements that electrical equipment and electronics should meet, as well as principles of handling used equipment and ways of limiting waste generated from used equipment [WEEE, 2002];
• RoHS (Restriction of Hazardous Substances) directive – limits the usage of some dangerous substances in electrical equipment and electronics RoHS, 2002].

Taking into account requirements expressed by the European Community regarding ecological and environmental design, the authors – within the scope of the presented paper – present coefficients and indices expressed in numbers which they have developed, helpful in assessment of a designed product from the viewpoint of recycling.
**Number of toxic materials – WT**

The number of toxic materials is one of the most important aspects of assessment in environmental design. Designers keeping with the idea and the good practice of design should proceed with designing in a way that uses as few toxic materials in the product as possible. In the ideal solution the ready-made product does not contain any toxic substances or materials. However, there are examples of products (in refrigerators, where Freon is a dangerous substance), in which such a solution is impossible to implement due to the loss of properties. Then, the designer has to design products in such a way that toxic material may be possible to remove in the product’s recycling phase. This coefficient takes a value reflecting at the real number of toxic materials present in the product.

**A number of different materials – WM (weigh of variety of used materials)**

The smaller the number of different kinds of materials, the easier the recycling is. If materials in the products are the same, then there is no need to disassemble it because materials can be recycled together. The situation similar to the above is when materials are compatible, in other words, the materials can be recycled without the need to separate them.

**Table 1. Weigh coefficient of variety of materials used**

<table>
<thead>
<tr>
<th>Percentage index of amount of various materials [%]</th>
<th>Coefficient</th>
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<td>5,0</td>
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Source: Authors elaboration.

Weight coefficient of a variety of used materials takes weight values defined on the basis of percentage number of different materials used to manufacture specific parts with relation to all materials used. For example, if a product contains 25 materials, while six materials are different, then the percentage index of a number of different materials is 24%, in other words, the weigh index is 1.5. It is one of the parts needed to calculate the recycling index (Table 1).

**Number of various connections – WP (weigh coefficient of variety of types of connections)**

The fewer number of different types of connections the easier and faster it is to recycle products and this, in turn, reduces the costs of recycling. Less variety of connections in the product makes it easier to disassemble it because there is no need to change tools very often. If disassembly is automated, the disassembly line does not need to be adjusted to a large number of different types of connections.

**Table 2. Weigh coefficient of variety of connection types**

<table>
<thead>
<tr>
<th>Percentage index of amount of various materials [%]</th>
<th>Coefficient</th>
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<tbody>
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<td>&lt;0–10&gt;</td>
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<td>(90–100&gt;</td>
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</table>

Source: Authors elaboration.

The best solution based on that sort, while all connections in the products are disjoint. Then, disassembly of the product is straightforward and uncomplicated. In case of the connections being impossible to detach the disassembly is usually not performed due to high costs. If connected materials are incompatible, the product does not qualify for recycling. For example in case of or glued connections, the paste between materials lowers the value of the material useful for recycling. Then, substances which amend the process are necessary because they improve the properties of the products of recycling.

Weigh coefficient of variety of connection types, similarly to the weigh coefficient of variety of materials used to manufacture the products takes weigh values. Table 2 shows the calculations of the coefficient for our products with 15 connections, where 10 connections are of different types. Then, the percentage index of the number of different connections equals 66%. The weigh index is 3.5. This result is a basis for calculating recycling index.

**Recycling and disassembly cost**

The cost of recycling, referred to in this paper as total cost of recycling (1), is one of the elements...
necessary to assess a product from the recycling viewpoint. The cost of recycling is important from the standpoint of manufacturers and processing companies. In order to be able to calculate the total cost of recycling one needs to define the cost of disassembly and the cost of recycling of the materials.

The cost of manual disassembly depends on the company carrying out the process way that disassembly is carried out. In time of disassembly is the key elements influencing its cost. The cost depends on the hourly rate of the company's employee. The type of tool used also influences the cost of disassembly. If it is an electrical hand tool another cost component should be taken into account namely the cost of electricity.

The cost of mechanical or automatic disassembly depends on the company and the kind of line used. The main parts of mechanical disassembly cost are: the cost of remuneration of the employee, cost of amortisation of machines, and the cost of electrical energy used. The cost of material recycling is another indispensable element needed to calculate the total cost of recycling. The most important criterion of calculation of recycling costs in a material is its weight, but also its purchase price, or sale price. The purchase/sale price depends on the type of recycled material, because recycling of some materials is costly, while for some, money is offered when delivered for recycling to special collection points.

The cost of recycling of materials present in the product is the difference between profit from selling those materials and other costs which had been borne. Profit is made on sales of materials useful for recycling, while costs is generated when such materials are stored and utilised. Negative result of recycling past signifies their loss, while positive result signifies profit.

The total cost of recycling is a difference between recycling cost and disassembly cost. Positive result means profit, while negative result means loss – in other words their company will have to pay up for recycling, utilisation, and storage:

\[
\text{Total cost of recycling} = \text{recycling cost} - \text{disassembly cost}
\]  
(1)

**Recycling Level**

Recycling level is an important indicator in product assessment from the recycling viewpoint. Electrical and electronic equipment manufacturers are obliged to reach a minimal recycling level [Act, 2005]. Principles of calculation of recycling level are spelt out in the appropriate regulation [Regulation, 2009].

Below is the formula to calculate recycling level:

\[
P_R = \frac{M_R + M_U}{M_Z} \times 100\% 
\]  
(2)

where:

- \(P_R\) – recycling level [%];
- \(M_R\) – is the weight of a waste generated by reprocessing of used equipment, regarding equipment from a given group, which has undergone a process of recycling [kg],
- \(M_U\) – is the weight handed back for a re-usage or parts originating from used equipment from a given equipment group [kg],
- \(M_Z\) – is the weight of used equipment, collected and transferred to a recycling facility registered in the files mentioned in article 6 of the Act of 29th of July 2005 on used electrical and electronic equipment [kg].

Recovery level is calculated according to the following formula:

\[
P_O = \frac{M_O + M_R + M_U}{M_Z} \times 100\% 
\]  
(3)

where:

- \(P_O\) – recovery level [%],
- \(M_O\) – is the weight of a waste generated by reprocessing of used equipment, regarding equipment from a given group, which has undergone a process other than recycling [kg],
- \(M_R\) – is the weight of a waste generated by reprocessing of used equipment, regarding equipment from a given group, which has undergone a process of recycling [kg],
- \(M_U\) – is the weight handed back for a re-usage or parts originating from used equipment from a given equipment group [kg],
- \(M_Z\) – is the weight of used equipment, collected and transferred to a recycling facility registered in the files mentioned in article 6 of the Act of 29th of July 2005 on used electrical and electronic equipment [kg].

**TABLE 3.**  
**Recycling level weight coefficients for particular product groups**

<table>
<thead>
<tr>
<th>Recycling level reached [%]</th>
<th>Coefficient</th>
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<td>1</td>
<td>2</td>
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<td>3</td>
<td>4</td>
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<tr>
<td>5,6,7,8</td>
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<td>&lt;75-80)</td>
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<td>&lt;80-85)</td>
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</table>

Source: Authors elaboration.

Recovery level in the system supporting environmental design is defined separately for each group of equipment indicated in the WEEE Directive [WEEE, 2002]. Each group is characterised by a different
minimum recycling level [Act, 2005]. If that designed product fails to reach a minimum level indicated by the Act, then the value of the coefficient will be 15 (this is information for the designer that the designed products does not meet requirements), whereas if the product reaches this level or exceeds it, then the coefficient will have weigh indices such as those presented in Table 3.

**Recycling index (WR)**

Recycling index depends on coefficients mentioned above. It is constituted of elements indicating the following:
- number of different materials,
- number of different types of connections,
- recycling level.

The recycling index is a sum of coefficients defining numbers of different materials, different types of connections and recycling level. The lower the sum of the better is the design of the project from recycling viewpoint.

\[
WR = WP + WM + WPR
\]

where:
WP – Weigh coefficient of variety of connections used,
WM – Weigh coefficient of variety of materials used,
WPR – Weigh coefficient of recycling level.

**Usage of agents technology in engineering design**

In the literature one can indicate several applications of agent technology for design process aiding. It concerns especially the areas of “collaborative engineering” and “concurrent engineering” [Liu et al., 2002; Mahdjoub et al., 2010; Rosenman and Wang 2001; Shen et al. 2000; Shen and Wang 2003; Wang et al. 2009]. The agents are used for collecting, storing and making available the design knowledge, suggesting potential engineering solutions and management of design process [Dostatni, 2008; Weiss et al., 2005].

**Requirements of environmental design aiding**

Environmental design requires information from different sources. The structure of the product containing identification data characterizing each element of the structure is a starting point. In order to carry out the environmental design analysis one must gather crucial information about the elements and of materials used. The structure of a product must be
compensated with information about the way specific elements are connected, which reflects the relationships between elements and character of those relationships. A designer, selecting connections or joining together materials, analyses of the economic aspects of possible solutions, and chooses the best option. In ecological design, the economic analysis takes into account factors which do not appear in traditional approaches. Those include the influence of the product onto the environment during its usage, and the phase after usage has been concluded, labour consumption during disassembly, recycling or utilisation costs, and legal limitations. A designer may often not have enough information about it, because it is not his/her area of competence, and he/she has to contact appropriate personnel. For example, material purchase costs should be available at the department responsible for supplies, while recycling costs or utilisation data should be available from that person who has been in touch with an appropriate outside company.

Recycling indices and coefficients mentioned above have been implemented in environmental design aiding system focused on recycling, and constitute measures according to which one may assess a product from the viewpoint of its recycling capability. Coefficients and indices developed to assist the designer in real time about the effects of decisions being taken. The results of the analysis are presented to the designer and, at the same time, are further analysed, in order to point at major areas influencing the fitness of the product to recycling. The structure of the system has been designed in such a way that basic goals are met (Figure 1), and agents which are its basic constituent parts have been programmed.

**Possible scripts of action in the system (cases of usage)**

The system which has been developed can assist a designer's work on a new product, as well as when redesigning the existing product in order to make the design more efficient.

When designing a new product, data on structural elements of the products is introduced through the designer interface. Introduction begins from their highest level of the structure, then details of lower levels are clarified. Connections between elements and the ways of joining elements are defined right after introducing the data describing those elements. Such defining may come later, but in that case a designer has no access to results of further analyses.

The Designer interface agent displays then only information about elements not being part of any joint or connection, and about connections consisting of only one element, furthermore informing about their locations. If all connections have been clearly defined, the Designer agent displays information about current ecological parameters of the product and indicates factors which have the strongest influence on their values. The designer can retract his/her steps at any moment, and make an assessment of the influence of using different variants.

In the case of redesigning of a product which had already been introduced to the market, in order to amend its fitness to recycling, the existing structure of the product should be introduced to the system, including information about connections and joints between its elements. The system in its current version is not equipped with a mechanism allowing for these actions to be performed automatically. The next stage is designing proper, in other words, assessment of the influence of current status and looking for solutions. System operates then in the same way as in case of designing a new product.

The system also allows using an option of predefined patterns of designed products. A pattern contains information about the elements of the structure, and about connections and joints, typical or necessary within a given group of products. When designing using a pattern, one modifies existing data and specifies the details.

**System structure**

Environmental design depends largely on efficient gathering and processing of dispersed data. According to the requirements, the system should inform the designer in real time about the effects of decisions being taken. The results of the analysis are presented...
**Agent functions**

**InfoAgent – information agent – communications with the database**

All information on designed products is stored in the database. The database contains all information about product structures, connections and joints between elements of a given product, material properties, material compatibility, standard parts and normalised parts, as well as legal requirements of recycling.

**Figure 2.** Main designer interface window

- A) Structure of the designed product
- B) Structure of connections with other parts in the selected part
- C) Material properties of the selected part
- D) Graphic marking of the material

Source: The Authors.

Only InfoAgent information agent has direct access to the database. The role of designer interface is to introduce data about a product, displaying the data and administering the database. InfoAgent information agent modifies and makes the data available if asked by another agent. Having received a request for data availability of the agent acquires the data, puts it in the form used by other agents and sends to the author of the request.

**Interface agent. The designer, designer interface communications with the user**

User communication with the system goes through the designer interface and Designer interface agent. In the designer interface, the structure of the product is defined and displayed, and this is where the main attention of the designer should be focused. The interface agent displays results of environmental design analysis for the products in real time, in particular recycling level, reciting coefficient and information on factors exerting the largest negative influence on the general result for the product. Thanks to this information, the designer can quickly check the effects of decisions taken and compare different solution options. The number of designers can simultaneously work using the system, each one with their own initialised interface and Designer agent.

**Corrector task agent**

Corrector task agent analyses the product from the viewpoint of logical correctness of defined connections between elements and calculates and updates the weights of subsets in the database.

In the course of designing, information about the products is introduced into the system in sequences: first information about parts, sets and subsets is introduced, and then connections between them are defined. If all connections have not been defined, carrying out further analysis from the viewpoint of product fitness to recycling could provide information which does not reflect the reality. The remaining task agents would supply missing information with their own assumptions and suppositions, and this in effect could mislead the designer. This is why the Corrector agent blocks the analysis for that time span, simultaneously sending a message to the Designer agent about missing or ambiguous items of information. The designer, having read the messages can supply missing information requested, or ignore it, but in such a case she will be deprived of results of further analysis.

If an element is added or removed from the product structure, the weight of all superior elements will undergo change. Defining or removing a connection which has a weight (for example glued or pasted connections) also results in such changes. The task of automatic updating of the weights of elements has been given to a Corrector task agent. After each change in the database, the task agent calculates new element weight and sends the request to the information agent for modification of a given item of information. Updating this data is particularly important while calculating recycling level.

**PRManager task agent**

PRManager task agent calculates recycling levels and product reciting coefficient and monitors the changes. Information on current values of those parameters, possible exceeding of the limits, on dramatic decrease or increase is transferred to interface agent. The functions of the discussed agent are fulfilled basing on internal knowledge database. The database contains information on compatibility
of types of materials, properties of types of connections, and about all projects analysed in the past. Fields of appropriate tables in knowledge database are presented in figure 5.19. The underlying names of fields signify the main table key.

Advisor task agent

Advisor task agent analyses of the product from a viewpoint of intensity of the influence of particular elements on recycling level and recycling coefficient, and indicates where critical spots are. Analysis input data consist of the structure of the product including information about connections and joints, as well as results of the analysis carried out by the task agent PRManager. The value of recycling level can be decreased by the existence of connections which are not going to be disassembled, and parts of such connections are not manufactured from compatible materials, and by existence of connections and joints characterised by weight. It is the agent's task to detect such spots in the structure of the products and pointing at the most important ones. The agent also quotes types of materials which are compatible with the material of the element in question.

The value of recycling coefficient depends on recycling level, variety of used connections, and variety of views to materials. A designer, naming the material in an element, or identifying the type of connection should bear in mind minimalisation of their variety. Therefore, the Advisor agents generates a numerical comparison of those factors for all sets in a product.

MatchMaker intermediary task agent

MatchMaker intermediary task agent mediates the communication between agents, and is the only agent with which the others communicate directly. It logs in new agents and logs out those agents who are finishing their activities. During the registration, information about agent capabilities is sent, namely what type of questions an agent can answer, and what type of tasks an agent can do. Every agent who needs specific information or requests a specific action sends a message to MatchMaker agent who confirms the content of the message with capabilities offered by other agents and sends the message to an appropriate agent.

It also has the task of monitoring the work on product design and controlling the operation of the system in such a way, that every project should be analysed by appropriate task agents, and that designers had access to current results of analysis which had been carried out. Necessary information about the status of the system and the status of projects is stored in internal knowledge database. Moreover, the agent stores changes in product design which might have significant influence on recycling level and reciting coefficient in the archives, and makes this information available on request of designers.

ANS (Agent Name Service) server

ANS server is an element of RETSINA MAS infrastructure. It operates as a register of information about agents, storing information about names and locations of the agents. It helps manage communication between agents, making available the mechanism of agent localisation. An agent who is “brought to life” logs onto the server, quoting their name, net address and port number. Thanks to the fact that the ANS server stores this information, agents can communicate even if localisation of any one of them changes.

Source: The Authors.
ANS server and MatchMaker agent play a similar role because they store information about agents and act as intermediaries in communication. They differ in the type of stored information and the way they operate. MatchMaker agent stores names and information about agent capabilities. Acting as an intermediary is based on matching queries and requests to capabilities. On the other hand, ANS server stores and makes available names and physical locations of the agents.

Agent system user interface

While working with agent system, the user communicates directly with Designer interface agent. The remaining agents operate in the background or work on another computer, and the user may even be unaware of their existence. After activation they don't display their own dialogue window, but an icon in the notification area.

Conclusions

The system aiding environmental design of products geared towards recycling can be used by designers as a supplementation of CAD system, extending its capabilities by aspects of related to later disassembly and recycling of the product. The system can assist designers in their work on designing products from scratch, introducing changes to an existing product or changing its outer appearance (so called “face lifting”).

Using of agent technology makes it possible to utilise the system in designing environments characterised by dispersed structures. A number of designers are able to work on a single design, although they may physically be in different locations.

In its present form, the system cooperates with one database on Microsoft SQL Server 2000 database server. Authors of the system had in mind the future extension of functionality and have designed the system in such a way that it can co-operate with other manufacturers’ databases. The system is also able to cooperate with a number of databases located on different servers.

References


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