INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

AVOIDANCE OF DESIGN ERRORS IN ECO-INNOVATION WITH RECYCLED MATERIALS

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Keywords: design errors, eco-innovation, recycled materials, furniture design industry

1. Introduction

The interest in finding alternative materials to conventional plastics derived from petroleum has arisen in response to the social awareness of environmental degradation and possibilities of reducing it by means of selection of products that are more environmentally friendly. In the search of a solution for this necessity an opportunity has been observed to obtain recycled materials mixing wastes of reinforced fiberglass in a polymeric matrix.

Thermostable composites offer great advantages in product design (low weight, high mechanical resistance, high corrosion resistance), but they are not mechanically recyclable. The excess of thermostable composites wastes makes necessary finding out a solution to re-introduce them in manufacturing. This paper contributes to a project whose objective is to study the applicability of fiberglass reinforced plastic wastes together with thermoplastic from the collection of urban solids wastes to the production of boards for furniture and panelling.

The search of new markets for recycled materials requires a significant inventive component, as well as more knowledge about their properties to reduce risks in their implementation. An objective of the project is to capture, organise, create -when necessary-, and facilitate knowledge about recycled plastic properties for its effective use in product design. Another objective is to develop an appropriate methodology for risk modelling that assists in the creation of eco-innovative solutions.

In the early stages of the product development process, the amount of available information is limited, and normally the designer is required to make experienced judgements when information is lacking [Swift et al. 2000]. Since there is little experience in the case of a new material, it is highly recommendable to assist the designers to make well-founded judgements.

It is a hypothesis in this paper that providing the means to be aware of the hazards of design errors and to efficiently manage knowledge regarding recycled plastics will contribute to assist the designers in the decision making, and therefore will assist in the eco-innovation of these products.

In order to know what type of knowledge about plastics and their applications must be captured to assist designers, first it is necessary to have a close look at how they work. The objective of this paper is, therefore, to study the specific characteristics of the design process in the furniture industry in Spain, making emphasis on understanding strategies for design errors avoidance and also to study the designers' need of knowledge regarding material properties, and the hazards which are avoided by means of having this knowledge early in the design phase.

2. Research approach

A first study has been undertaken in the furniture design industry since this is where the introduction of the new material is initially expected. The work has been done with the assistance of two Spanish

companies. The paper presents this first contact with the knowledge needed by designers regarding a new material. The project will continue with research on the characteristics of the new material, resulting from the mixing of wastes of reinforced fiberglass in a thermoplastic polymeric matrix, and their translation into an appropriate format for designers. This work will be made in close cooperation with AIMPLAS, the Technological Institute of Plastics in Spain.
In order to get useful furniture industry information to help in this research, a work on knowledge management supported by the Spanish Ministry of Science and Technology, project DPI 2002-04357-C03, realised by some of the authors of this paper [Castells et al. 2004] was considered. The most relevant information used from the knowledge management work was the analysis and redesign of the current design process of a furniture design company -realised by means of process modelling techniques- and also the informal model which was built up from the company’s product tacit knowledge.
Regarding risks, the damaging effects on human health of some manufacturing processes in the furniture industry have been published [Bovenzi et al. 2005]; general approaches to manage risks at the project management level have been described, e.g. Project Risk Analysis and Management (PRAM) [Chapman 1997]; and general methods that allow reliability performance measures to be assessed for product design early in the product development process [Swift et al. 2000] have been proposed, e.g. ‘conformability analysis’ [Swift et al. 1999]. However, little is published about the hazards of design errors specific to the furniture industry when a new material is introduced, such as unexpected changes of colour during product use due to unawareness in the design phase of the reaction to light of the chosen material.
During 2002-2004 AIMPLAS developed the European project called Craft Project Plastic-Recypallet "Development of a High Performance Plastic Pallet using Recycled Reinforced Fiberglass Polyester as Reinforcing Filler". This project proved that the properties of the new reinforced pallet with fiberglass are superior in rigidity to pallets made with recycled thermoplastic and that its use could reduce the amount of wastes in landfills. This contribution shows some of the studied problems in plastics design. However, the introduction of a new material in a market brings numerous design hazards, which need to be covered with new knowledge. The required new design knowledge for the introduction of recycled plastics in the furniture industry is explored in this paper.

3. Data collection methodology

Data has been collected in two furniture companies, which are called company A and company B in this paper for confidentiality reasons. As previously mentioned, the data from company B had already been collected for the knowledge management project [Castells et al. 2004]. Here, the data is revisited.

3.1 Data collected from company A

Information about the design process of company A has been obtained through interviews and analysis of internal documents. The interview was designed on the basis of an internal document called "flow chart of a new product design or redesign" as well as of literature on risk management, risk analysis, and DFX tools. The purpose of the formulated questions was to clarify the design process and performed tasks in the design department, and the errors avoidance strategy during the design phase. Before the interview, the questions were sent to the interviewee, a designer of the company, to give her time for preparation. She checked the answer of some questions with the departments involved. Therefore, the collected information is enriched by diverse reliable sources of information.
The interview was developed in two sessions, which were videotaped and transcribed for their later analysis. The total duration of the two interviews was 5 hours. During the data analysis, five short interview sessions of 30 minutes were additionally made with the designer to clarify new questions.

3.2 Data collected from company B

For the previously mentioned project [Castells et al. 2004], a description of the knowledge management process in company B had been realised using the IDEF3 Process Modelling Method [Kusiak et al. 1994] with the software Prosim. Information was collected by means of interviews and questionnaires to the main experts and translated into the diagrams used by the IDEF3 method,

showing, in several levels of detail, all and each of the activities that are realised to design special products and the corresponding flow of knowledge.
For this same project, knowledge regarding the design of a piece of furniture made of particle boards, which belongs to the family of special products of the company, was also collected and introduced in the Catia V5 software. The MOKA ICARE forms were used [Stokes 2001] to collect and organise the information. They support five categories of knowledge: constraints, activities, rules, entities, and illustrations.
This information has been revisited for this paper. On one hand, the data regarding the knowledge management process is used to complete the data from company A, and thus to obtain more comprehensive knowledge about the design process in the furniture industry. On the other hand, the MOKA ICARE forms are studied to infer from them the type of knowledge regarding materials that the designer needs for the correct design of a piece of furniture.

4. Results

4.1 The design process in the furniture industry in Spain

The design processes of companies A and B have been depicted, and their strategies for design errors avoidance are discussed. Figures 1 and 2 represent the design processes of these companies respectively. The design process of company A describes the chain of activities to develop a new product that will be serially produced. The design process of company B is depicted from the point of view of the information flow generated to produce a customised (or special) product from the moment when a customer makes its order to its production. Although both design processes describe two types of products (serial and customised) and they are conceived from different perspectives (chain of design activities and information flow), they both reveal strategies of design errors avoidance.
In company A, diverse design phases are followed by design reviews where the design is checked against the customer's specifications and the company's expectations. These phases are: sketching of singular elements, initial data review, prototype of singular elements, overall programme definition, final data of programme, and first series production. This review system is a process of progressive assurance that the product can be made within specifications and that potential design errors will be marginal. The review of the first series consists of an incidences control process from the entrance of the first order of that series to the product shipment.
Company B has a knowledge management system that helps to identify, capture, store, and reuse in an unambiguous form all the design information generated at some point for a specific product. The system works with four types of product design data levels called: models, bulks, pieces and raw material. A model is the functional unit (e.g. a table); a bulk is the sales unit (e.g. a table is composed by two bulks, the legs and the board, which can be sold separately); the pieces are the items that compose the bulks including the packaging, the items manufactured externally (e.g. screws, hinges, etc.); the raw materials are the materials used to manufacture each piece.
There is a system of files that contain the information related to each of these categories identified by codes. The most generic file type is the one called "product file", which contains all the documents required to manufacture the product. This file makes reference to other file types: structure, model file, bulk file, piece file, raw material file, and price file. The structure file contains the names and codes of the model file, and the bulk, pieces and raw material files of a model. In the model of figure 2, the task "create new file" is decomposed in a group of activities whose objective is to identify similar products with model, bulks, pieces or raw material files potentially identical to the customised product being developed, and to create new files if these have not been created before. These activities also include the tasks related to drawing parts, Computer Numerical Control (CNC) programmes, input data into system and technical specifications. This computer aided system, enables the reutilisation of knowledge already created and involves a significant reduction of human errors. Therefore, this can be understood as a risk reduction strategy used in the furniture industry.

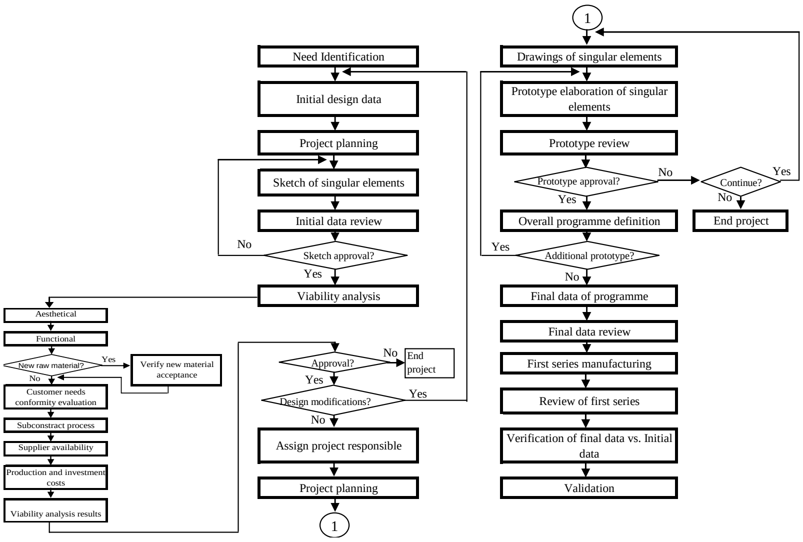

Figure 1. Chain of design activities to design a serial product in furniture company A

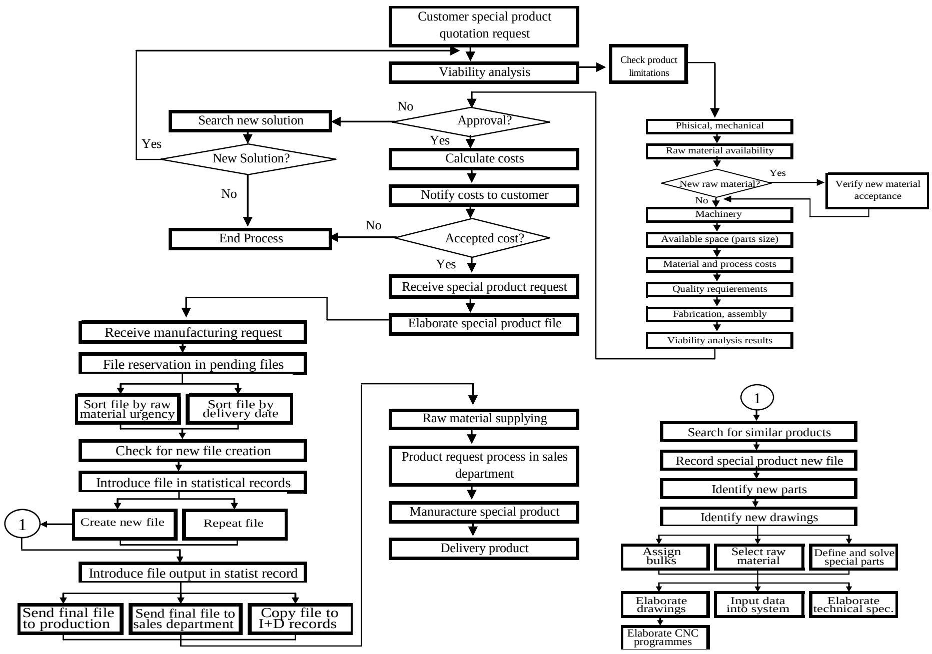

Figure 2. Information flow to design a customised product in furniture company B

4.2 Knowledge regarding materials needed early in the design phase in the furniture industry

From the MOKA ICARE forms created for the knowledge management project [Castells et al. 2004], the knowledge that designers need regarding particle boards for the design of a piece of furniture was inferred. There are five categories of MOKA ICARE forms, as was mentioned on the methodology description: (i) entities forms correspond to the parts that compose the product, for example, base, cover, door, etc. (ii) activities forms capture the design process elements for example "the activity to determine the width of the base entity”, (iii) illustrations forms register historic cases or empirical knowledge, (iv) rules forms present design conditions that have to be met by the piece of furniture and (v) constraints forms are related to the machine, material and supplier limitations including the UNE norms. To infer the knowledge that designers need regarding particle boards from the forms, the most useful category was constraints, of which kind there were 22 forms out of a total of 144. Table 1 shows an example of the MOKA ICARE form for the constraints category. The knowledge regarding material properties of particle boards is necessary to avoid design errors that could cause negative effects during the product life-cycle. The potential hazards can be deduced by collecting information that answers the question ‘why is this knowledge needed?’ This information has also been collected using the MOKA ICARE forms. Once the potential hazards were identified, speculations have been made regarding the corresponding knowledge that will be necessary for furniture design with recycled plastic. Table 2 shows: (1) type of knowledge, (2) knowledge regarding characteristics of particle boards required by designers, (3) hazards if this knowledge is missing early in the design phase, and (4) speculations about the knowledge that will be required regarding the new material.

Table 1. Example of MOKA ICARE form for category constraints

<table>
<tr><th colspan="3">MOKA ICARE FORMS: CONSTRAINTS</th></tr>
<tr><td>Name</td><td colspan="2">Thickness of low pressure melamine panels</td></tr>
<tr><td>Reference</td><td colspan="2">C_MP-1.2</td></tr>
<tr><td>Objectives</td><td colspan="2">Choose the right thickness of a piece that will be cut</td></tr>
<tr><td>Context, information, validity</td><td colspan="2">The thickness of the panels determines the maximum resistance and dimension that the wardrobe will have. The edge format depends on the thickness of the panel.</td></tr>
<tr><td>Description</td><td colspan="2">The thickness of the panels used in this company is: 19 and 30 mm</td></tr>
<tr><td>Linked rules</td><td colspan="2"></td></tr>
<tr><td>Related entities</td><td colspan="2">E1_BA.F1; E1_TA.F1; E1_CO_DR.F1; E1_CO_IZ.F1; E1_CO_ME.V; E1_TR.F1; E2_ES.V; E2_PU_DR.V; E2_PU_IZ.V; E2_CA_V</td></tr>
<tr><td>Related figures</td><td colspan="2"></td></tr>
<tr><td>Source of information</td><td colspan="2">Manager of the Product Department</td></tr>
<tr><td rowspan="4">Information management</td><td>Author</td><td>Ricardo Barbosa García</td></tr>
<tr><td>Date</td><td>27/10/03</td></tr>
<tr><td>Version number</td><td>1</td></tr>
<tr><td>Status</td><td>In progress</td></tr>
</table>

Table 2. Knowledge needed to design a piece of furniture made of a specific material

1	2. Characteristics	3. Avoided design hazards with this knowledge in particle boards	4. Recycled Plastic board
Material properties	Board dimensions	Designed parts of the required size cannot be manufactured.	Can regular size boards be manufactured? And with new sizes and shapes?
	Board thickness	Maximum resistance of board is not enough to comply with loads and flexion specifications.	Which thickness can boards be produced with? What is the maximum resistance/load of each thickness? Is space lost or gained?
Material properties	Company lay out constraints	Boards exceed maximum limit dimensions to be freely handled through available production plant space and equipment.	What are the dimensions of production plants access and transport limitations? Used to evaluate if boards can be handled properly.

	Tolerances of board thickness, length and width, board rectitude, perpendicularity	(a) Designed parts cannot be correctly assembled due to variations of material; (b) Ergonomic, aesthetic and functional requirements can not be fulfilled.	What is the supplier's production process like? Who can supply boards? What about material variations in boards? Used to evaluate if it is capable of designing parts that can be correctly assembled and also comply with aesthetics, ergonomics and functional requirements.
	Density and elasticity module of material	a) Material exceeds maximum weight allowed to be handled and transported. b) Designed product cannot achieve flexion and loads requirements.	What is the density and elasticity module of the new material? Used to evaluate if parts will comply with weight requirements and if final product will satisfy loads and flexion requirements.
	Thermo conductivity	Designed product gets temperatures out of customer expectations and it is probably causing functional problems.	What is the thermo conductivity of the new material? Used to evaluate if it is appropriate for the desired applications and/or to figure out how it can be better designed to comply customer requirements, e.g. design to keep or dissipate temperature.
	Pealing screw resistance	Unexpected disassembly of parts during product use (due to movements, loads, vibrations etc.)	How resistant the new material is to pealing screw? Other ways to assemble parts? Used to decide how parts can be designed, what types of screws should be used, or search for alternative ways to assemble parts.
	Heterogeneity	Insufficient resistance due to incorrect grain direction (wood is more resistant to flexion in grain direction).	What is the composition and distribution of thermoplastic and reinforced fiberglass wastes? Used to determine the variability of mechanical properties of the material.
	Reaction to light	Unexpected changes of colour during product use.	How does the new material react to light? Used to evaluate if light causes undesired changes on it.
Legal, safety, and ergonomic considerations	Toxic waste	Production process and/or final product generate toxic waste to operators, users, or environment.	What kind of waste is produced during production process? Are they toxic for operators, users or environment?
	Legal normative	Product designed does not comply with legal constraints (e.g. safety)	Which norms are applicable to this product design? Can they be accomplished?
	Edge	Product edges represent a potential accident for users.	How do edges in plastic boards affect product safety?
	Product stability	Designed product does not have stability; hazard of physical damage to users.	How will the new material affect product stability during transportation, installation, maintenance, and service?
Manufacturing Characteristics	Machine capabilities	a) Operations of designed parts (e.g. shapes, drills, profiles etc.) can not be manufactured by available machines. b) Board dimensions exceed the maximum limit to be introduced properly in available machines. c) Movement constraints do not allow performing operations according to specifications.	Can machines correctly process the new material boards according to specifications? What capabilities do machines have? Used to determine if board dimensions and properties can be processed by them and execute the required operations, and if new operations are available.
	Types of machine tools	Designed parts that require the use of special tools not commonly used by the rest of parts causing increase of production set-up.	Can available company tools be used to drill material according to desired specifications?

Manufacturing Characteristics	Manufacturing process performance	Designed parts and processes cause many stops and repetition of operations during manufacturing process that can be avoided improving the design and the manufacturing process.	How does the new material perform in each machine? Used to determine how parts and process can be designed to avoid repetition of operations.
	Process Planning	Designed parts can not be manufactured by the process sequence established	How do the new material restrictions affect operations of designed parts and process sequence required for product manufacturing? Used to establish the correct process sequence and to determine if specific operations (e.g. pivot operations) must be added on parts design to achieve a successful product manufacturing.
	Requirements of small components (joints, accessories, etc.)	Small components require operations that cannot be performed with available tools, or are new to the company, causing increase of production set-up.	What operations require the use of small components? Used to evaluate if these operations can be performed correctly on the new material.
	Need of cover on board	Product damages due to absence of covers.	Will the new material need protection? Used to investigate if existing covers dimensions are appropriate and if there is an appropriate process to attach them on boards.
	Type of finishing	Finishing selected to boards is causing aesthetics and functional defects.	What kind of finishing can be used on plastic boards? Will it cause aesthetic or functional defects?
	Types and specifications of covers	Available cover dimensions (width and length) do not match board dimensions.	If covers are needed, do available covers dimensions (width and length) match board dimensions?
		Selected thickness does not comply with final dimension expected in final product and/or to ergonomic requirements.	If covers are needed, will their thickness allow fulfilling final product dimensions and ergonomic and functional requirements?
	Type of packaging	Selected packaging of raw material or final product does not protect the material properly.	What type of packaging properly protects against potential damage during production process, transportation, distribution?
	Maximum weight allowed per operator	During production process there are parts that weight more than maximum value allowed.	What is the new material density? Used to assure that parts do not exceed maximum allowed weight or find a solution
Consideration of product application	Final product environment	Environment causes ergonomic, functional or safety problems to product (e.g. humidity, temperature, light).	How does the new material react to different environments?
	Users preferences	Customers do not like the material used in the product.	What is the customer opinion (look, smell, feel, etc.)?
	Installation and maintenance	Tools used to install and maintain the product damage it (e.g. scratches, cracks, deformations)	How does the new material perform regarding installation and maintenance tools? (e.g. scratches, cracks, deformations)
	Cleanliness	Product is hard to clean and material gets easily dirty	What method to clean and how easily it gets dirty again? Does it match expectations?

5. Discussion, conclusions and future work

This paper highlights the tacit knowledge of designers related to current materials used in furniture design to avoid design errors, and the design processes of serial and customised products in two companies, which include design error avoidance strategies. Speculations are also made regarding the knowledge that will be required by designers when a new plastic material -a combination of reinforced fiberglass wastes and thermoplastic polymeric matrix wastes- is introduced. The identified knowledge needed by designers has been classified according to the categories: material properties; manufacturing characteristics; legal, safety and ergonomic considerations; and considerations of product application.

The broad range of knowledge required before embarking upon the introduction of a new material for well-founded decision-making in design and the fact that part of this knowledge is company-dependent indicate the suitability of having a strategy regarding transfer of knowledge to reinforce the adoption of promising new materials. In large companies, like those of the automotive industry, part of this new knowledge is produced in Advanced Engineering projects that run in parallel to Product Projects within an off-the-shelf-solutions strategy. In SMEs, the assistance comes from organisations like AIMPLAS that give support to a number of enterprises of a given sector (the plastic transformation sector, in this case). Whereas these specialised organisations have much to contribute to the production of the required knowledge, there are still unanswered questions regarding how this knowledge should be transferred. For example, it is necessary to know how the knowledge will be delivered to designers, and whether it is necessary to provide a methodology to evaluate the readiness of a new material to be introduced in a specific company product. Therefore, the identified need of knowledge should be the starting point not only to continue doing research on the characteristics of thermostable plastics wastes as a material for furniture design, but also on their translation into an appropriate format for the designers and managers to decide upon the readiness of its introduction.

Acknowledgement

We acknowledge the assistance of Marta Royo, Luis Piñón and Félix Lafuente designers of the companies studied in this paper, as well as of the students Mª José Castells, Ricardo Barbosa, and Verónica Peinado, who widely contributed to capture and model the data. Gratefully acknowledged financial support has been provided by the Spanish Ministry of the Environment, project 2.2-318/2005/2-A, and by the Spanish Ministry of Science and Technology, project DPI 2002-04357-C03.

References

Bovenzi, M., Vedova, A.D., Natalett, P., Alessandrini, B., Poian, T., "Work-related disorders of the upper limb in female workers using orbital sanders", Int Arch Occup Environ Health 78: 303–310, 2005, pp. 303-310.

Castells MJ, Barbosa R, Peinado V, Vidal R, Mulet E, Bellés MJ., "Gestión del conocimiento de diseño en la industria del mueble". Proceedings of Congreso de Ingeniería de Proyectos. Bilbao, 2004.

Kusiak, A., Larson, T.N., Wang, J., "Reengineering of Design and Manufacturing Processes", Computers Ind. Engng. Vol. 26, 1994, pp. 521-536.

Stokes, M., "Managing Engineering Knowledge. MOKA: Methodology for Knowledge Based Engineering Applications", Professional Engineering Publishing Limited. United Kingdom, 2001.

Swift, K.G., Raines, M., Booker, J.D., "Analysis of product capability at the design stage", Journal of Engineering Design, Vol. 10, No. 1, 1999. pp. 77-91.

Swift, K.G., Raines, M., Booker, J.D., "Case studies in probabilistic design", Journal of Engineering Design, Vol. 11, No. 4, 2000, pp. 299-316.

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