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DESIGN TO CONNECT: CREATIVE TOOLS TO DESIGN JOINING METHODS IN PRODUCTS

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Abstract: Creativity is the main force behind design and innovation. Joining methods play an important role in product design and 'how to join parts' still is an important challenge today. For designers, joining goes far beyond selecting the right method. They design connections as an integral part of the total product. However, different forms of fixation can occur, which can preclude the creation of new joining solutions. Existing tools that consider connections are not optimal to stimulate the creativity of designers. On the other hand, existing creativity tools are holistic and do not focus on joining methods. There is an opportunity to create creative and inspiring tools that focus on the design of connections. Two inspiring and useful tools are introduced in this paper: First, a technique called 'product crossing', based on forced analogy, and second, a set of 46 tool cards to consider a joining situation from different viewpoints. Both tools were tested with a relevant sample of design students.

Keywords: *product design, fixation, creativity tools, joining methods*

1. Introduction

Almost all products are created by using multiple parts and joining methods. This is for different reasons (Messler, 2004): to achieve functionality, to facilitate the manufacturability of a product, to minimize the cost or to provide aesthetics. The connections also have an influence on the different phases of the complete product life cycle: the assembly, the use and maintenance and the disposal of the product at the end of its life. Various ways in which parts and materials can be joined were developed throughout history: from beautiful wood joinery over high end welding processes to invisible adhesive joints. During the design of products, designers can rely on a comprehensive assortment of known connections. Sometimes, these solutions do not meet the requirements and the designers are bound to explore new solutions. New materials and production processes create new possibilities for designers and lead to new joining methods. How to join parts and materials remains an important challenge for designers today.

Previous studies have demonstrated that people tend to think in patterns to solve problems, which can be an obstruction to come up with new ideas (Bilalic et al., 2008; Purcell & Gero, 1996). First, fixation can occur due to previously acquired knowledge. A problem is solved in a specific manner even though more appropriate methods exist. In literature, this phenomenon is defined as the 'Einstellung Effect' (Bilalic et al., 2008). Second, fixation can occur by seeing existing solutions. This phenomenon is defined in literature as design fixation (Purcell & Gero, 1996). In the context of designing connections, designers can be fixed by joining solutions they used in past projects or by seeing existing joining solutions in similar products. Several solutions to overcome fixations are described in literature. Physical prototyping and group work for instance have a positive effect on preventing design fixation (Youmans, 2010). Three ways to deal with the ‘Einstellung Effect’ are given: (1) using defixation instructions, (2) using analogies or (3) finding new ways to frame the problem (Bilalic et al., 2008). This paper provides an overview of existing methods to design connections, and challenges and opportunities to create more creative and inspiring tools. Furthermore, two ‘creative’ tools to design connections are introduced based on (2) using analogies and (3) reframing the problem.

2. Existing tools to support the design of connections

2.1. Joining method selection tools

Ramalhete (Ramalhete et al., 2010) gives an extensive overview and critical analysis of existing digital material selection tools. One of his conclusions is that the majority of the existing material databases lack information about aesthetics and surface properties. This limits most material databases as a source of inspiration for designers. Several tools have already been developed to select the best suitable joining process (Esawi & Ashby, 2004; L'Eglise et al., 2001; Lae et al., 2002; LeBacq et al., 2002). These tools are very structured and methodological. The conclusion of Ramalhete can be extended to joining selection tools, since the latter too lack information about aesthetics. Furthermore, each database only contains a limited number of joining processes, which can be very helpful during the engineering of products but they do not stimulate the creativity of designers. These tools were developed for mechanical applications. Joining methods like zippers and stitching are frequently used in consumer products but are not considered in the existing selection tools. Joining in product design goes beyond selecting the right method. These tools do not help designers to overcome fixations and to think up new joining solutions.

2.2. Design for X principles

Design for X (DfX) is an integral name for a collection of design guidelines and methodologies. The best-known DfX principles that consider connections are Design for Manufacturing and Assembly (DfMA) and Design for Disassembly (DfD). These principles are structured and methodological. DfMA is a methodology that helps optimizing the assembly and manufacturing process. Boothroyd et al. (Boothroyd et al. 2011) defines Design for Manufacturing (DFM) as the design for ease of manufacture of the collection of parts that form the product after assembly and Design for Assembly (DFA) as the design of a product for the ease of assembly. DFMA is a combination of both. Boothroyd & Alting (Boothroyd & Alting, 1992) defines Design for Disassembly (DFD) as the design for ease of disassembly. DfD considers the future needs to disassemble the product. This is for repairing the product or for re-use and recycling. DfX principles are very interesting and helpful, however, they mainly focus on optimizing an existing design and are not optimized to design new connections and overcome fixations. Each principle also focuses on only one stage of the PLC. Other, more user-based requirements like the usability and aesthetics of the connections, which are equally important in product design, are not considered.

2.3. Creativity tools

Creativity tools are used to stimulate the creativity of designers. According to the Innowiz (Howest University, 2009) methodology, the creative process can be subdivided into four main phases: the problem definition, the divergent phase or idea generation, the convergent phase or idea selection and the idea communication. The online Innowiz tool gives an extensive overview of existing creativity tools classified under the four creative phases. Most creativity tools are holistic and applicable for various types of problems. Creativity tools like the TRIZ methodology (Mann, 2002) and the morphological matrix (Pahl & Beitz, 2007) are developed for more technical problems. However, there still is an opportunity to create creative tools that are optimized for designing connections in products and to overcome fixation.

2.4. Online inspiration and blogs

The internet provides designers with much information and inspiration. Design blogs and image databases are filled with inspirational products and ideas. These can be very inspiring for designers, however, they are not at all structured. Furthermore, design blogs are mostly holistic and do not focus on connections. Online inspirational sources that focus on joining methods in product design are very rare. Therefore, it is difficult to find useful 'joining' inspiration on the internet owing to the overload of available information.

2.5. Need for creative tools to design connections

Figure 8 presents an overview of the four groups of tools and techniques discussed in this paper. A distinction is made between holistic applicable tools and tools specifically developed for designing connections. This is represented on the vertical axis. The horizontal axis indicates whether the tool is structured and methodological or more unstructured and inspirational. As can be seen on the graph, there still is an opportunity to develop more creative and inspiring tools that focus on the design of connections. The three tools presented in this paper try to stimulate the creativity of designers and try to overcome fixation. The first tool is based on (2) using analogies to create new solutions, the second tool is based on (3) reframing the (joining) problem to create new solutions and the third tool focuses on finding online joining inspiration more efficiently. The tools can be applied in the conceptual stage of the design process.

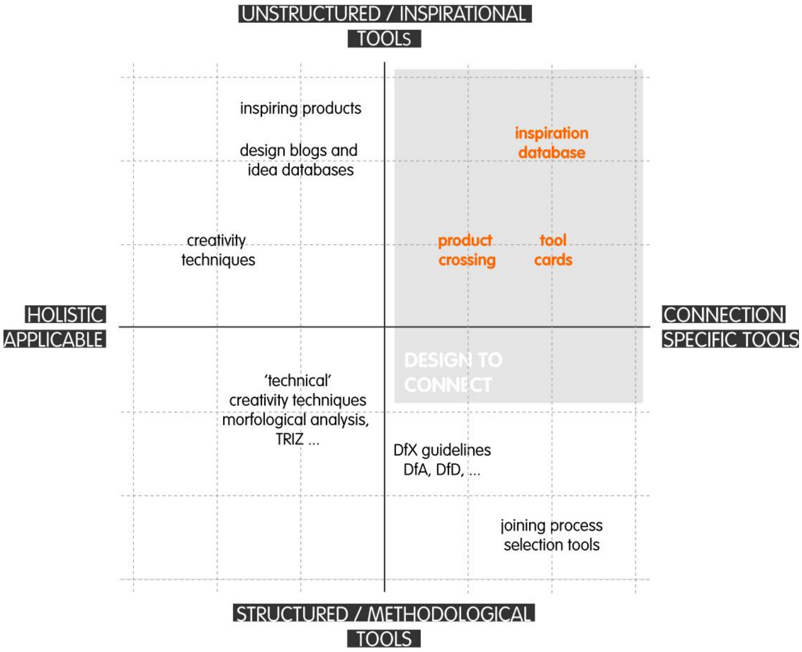


Figure 1. overview of existing tools for designers

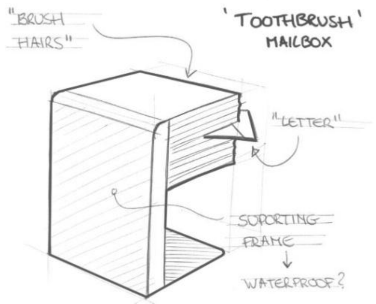
3. Using analogies to stimulate creativity: product crossing

Product crossing is a technique based on forced analogy (Slocum , 2006). The term 'product crossing' is based on the term 'plant crossing', which is the art and science of combining properties of two plant species to create a new variety. In 'product crossing', designers combine aspects from an inspirational product with their own context. It can be applied during the ideation or embodiment of product concepts.

The technique will proceed as follows: The design team gets a physical product as inspiration during a brainstorm session. They must focus on this product and its properties to design their own product. It is important that a real product is used and not an image of the product. A real product conveys much more information in a very concentrated way. Basically, it makes no difference which products are used as inspiration. The best results were obtained with products that meet the following three conditions: First, none of the products deal with the context of the case. It is better to choose a product from a completely different context instead of a similar product, otherwise design fixation can occur. Second, the products are composed of multiple parts (max. ±20 parts). Third, the products can be (partially) disassembled and contain different joining methods.

This technique was applied and tested in an exercise with a relevant sample of students in a previous study (Bleuzé et al., 2011). This was done three times; each time with students from a different educational background: master students of Industrial Design, bachelor students of Product Design and master students of Civil Engineering. Each time, the students were divided into groups of three. Each group received a design case (mailbox, coat rack or planter) and they were asked to explore ideas based on their inspirational product and combine these in one product concept. The results of the exercise were analyzed and compared with existing benchmarks of the products from the three cases. Two criteria were used to compare the concepts with the similar products, the embodiment of the product and the used connections. The technique resulted in new and surprising product concepts. There was no obvious difference between the students of Civil Engineering and the students of Industrial (Product) Design. Figure 5 shows two concepts for a mailbox generated by using this technique. The first one was created using a toothbrush, the second one using an Atoma notebook. In both cases, new joining methods and product structures were created for constructing a 'mailbox'.

Inspirational product | **Product concept generated by students**



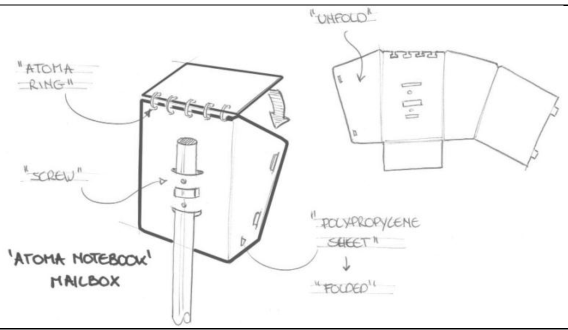


Figure 2. concepts generated by students using the 'product crossing' technique

4. Reframe the joining problem: Design to connect (D2C) tool cards

The second tool discussed in this paper is based on reframing the problem to overcome fixation. The tool cards were created based upon the Elementary Design Properties (EDP). The EDP are: materials, production process, function, shape and connections. "*With these elementary design properties as the only means, the designers should fulfill all the requirements set on a product by giving it the necessary internal and external properties"* (Johansson, 2008). By changing one of these properties, other joining possibilities can be created or connections can be avoided. The EDP are all related to each other. When one property changes, it influences the others.

Several tool cards were developed for each EDP. Each tool card contains one heuristic to design or prevent connections. An inspirational example is given to illustrate every heuristic. The heuristics are based on the experience of designers and on existing guidelines: DfMA guidelines (Boothroyd Dewhust, 2010), DfA guidelines and the 40 TRIZ principles (TRIZ journal, 2004). Not all tool cards can be applied in every case or context. The designer selects the cards that are useful to the specific case. An overview of the different tool cards is shown in table 1.

Table 1. overview of the 46 D2C tool cards

FUNCTION	STRUCTURE	MATERIAL	PROCESS	SHAPE	JOINT
1/ explore functions	6/ use gravity as an advantage	13/ homogenous materials	23/ automatic processes	30/ use asymmetry	37/ reduce variations
2/ merge functions	7/ design open box	14/ plastic deformation	24/ integrate by process	31/ use symmetry	38/ create feedback
3/ second life	8/ use counteraction	15/ flexibility	25/ think reverse	32/ integrate connections	39/ easy to use
4/ use gas and liquid	9/ create flat pack	16/ elasticity	26/ use only one process	33/ use alignment	40/ adaptable joint
5/ use electric signals	10/ use segmentation	17/ thermal expansion	27/ deform to avoid joints	34/ use a new dimension	41/ harm to benefit
	11/ modular structure	18/ discarding materials	28/ co process	35/ code your parts	42/ create personality
	12/ replaceable parts	19/ magnetic	29/ forming	36/ flexible interface	43/ avoid disassembly
		20/ surface			44/ hybrid connections
		21/ composite materials			45/ self-adhesive
		22/ smart materials			46/ avoid permanent

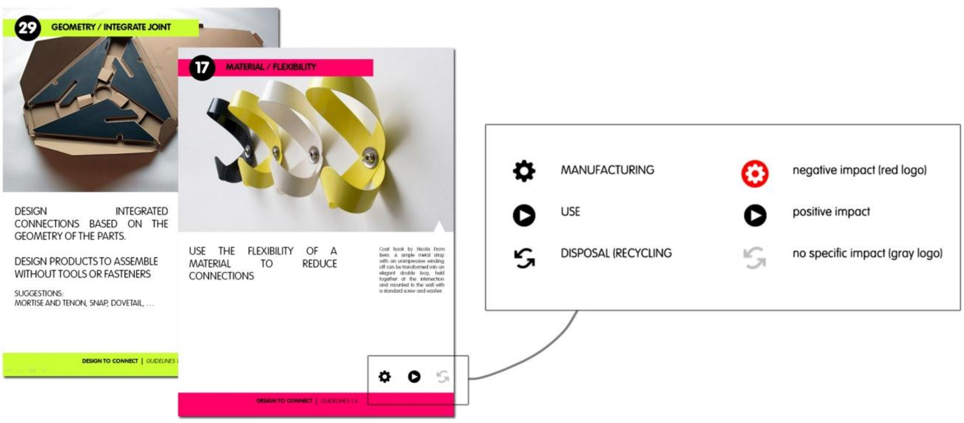


Figure 3. D2C tool cards

The cards also contain three symbols, which represent the three most important phases of the product life cycle (PLC) where connections have an influence: the first phase is the manufacturing and assembly of the product, the second phase is the use and maintenance of the product and the third phase is the disposal of the product, when the useful lifetime of the product is over. Then, the product is disassembled for recycling or re-use. These symbols indicate on which phase of the product life cycle the guideline has an influence. The symbol is red if the guideline has a negative influence, black if it has a positive influence and grey if it has no specific influence. The symbols are shown in figure 3. Note: the symbols are just quick indications. In reality, there are many other factors that determine whether a product has a positive or negative impact.

4.1. Test method

The tool cards were tested with a relevant sample of bachelor students of Industrial Product Design. The aim of the test was to evaluate the effectiveness of the tool. The 33 students were divided into teams of three. The students did two design exercises. The first exercise was done without using the tool cards. For this exercise, the students did not have any knowledge of the tool cards. In the second exercise, the tool cards were applied.

Two equally difficult cases were selected for the test: a barbecue and a roof trunk for a car. In each case, five marked connections are to be designed. In the first exercise, five teams worked on the 'barbecue' case, whereas the other teams worked on the 'roof trunk' case. In the second exercise, when the tool cards were applied, the cases were switched. The teams had one hour to explore different solutions and create one final concept sketch.

To evaluate the effectiveness of the tool, the results of the two exercises were mixed and submitted to a group of experts. The experts were four skilled people: one design researcher, one professional designer and two lecturers Product Design with more than three years of relevant design experience. They received 11 anonymous concept sketches for both cases. The experts did not know that some cases were designed using the tool. They reviewed the concept sketches, focusing on two main criteria: first, they looked at the novelty of the used joining concepts and the construction of the product and second, they checked the feasibility of the concepts. Using these two criteria, the team of experts classified the concept sketches into four groups: (1) good, (2) OK, (3) moderate and (4) bad.

4.2. Results of the test

An overview of the results is given in figure 4. A filled dot symbolizes the 'barbecue' case and a plain dot symbolizes the 'roof trunk' case. The results from the first exercise are marked with a '1' and those of the second exercise with a '2'.

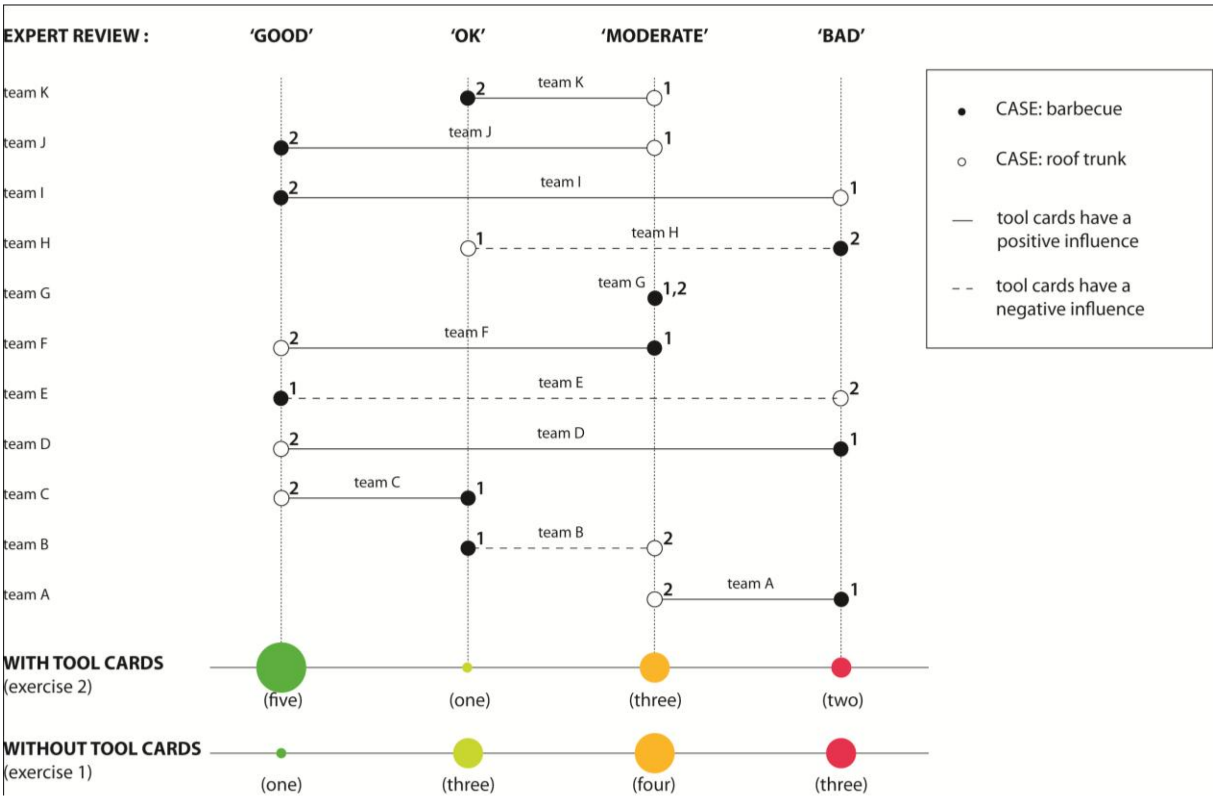


Figure 4. results of the test with students

Five concepts designed using the tool were classified in the group 'good by the experts. One was reviewed 'OK', three 'moderate' and two 'bad'. Only one concept generated without the tool was classified in the group 'good'. Three were reviewed 'OK', four 'moderate' and three 'bad'.

Seven teams (64%) improved their results by using the tool. Team D and I even improved their result from 'bad' to 'good' by using the tool cards. Three teams (27%) did not improve their result using the tool. This is illustrated in figure 3 by a dotted line. Team G stagnated. Both of their designs were reviewed 'moderate' by the experts.

4.3. Discussion of the test results

The concepts generated in the exercise were reviewed by the experts based on two criteria: the novelty of the connection methods and the feasibility of the concepts. Other aspects like performance, economy and ecology were not considered in this evaluation. The aim of the test was to evaluate whether or not using the tool leads to new joining solutions. According to the evaluation of the team of experts, 64% of the teams improved their result by using the tool cards. Five concepts in the group 'good' were developed using the tool cards. In most cases, the tool cards have a positive influence on fixation and they can help to creating new connections.

Some groups, however, did not improve their result by using the tool cards. This can be caused by various reasons. First, it could be possible that the 'roof trunk' case was experienced to be more difficult by the students. All the teams who did not improve their result in the second exercise started with the barbecue case in the first exercise (see dotted lines in figure 4). Second, the motivation of the students in the second exercise can have an influence on the results. Third, it is possible that some students have difficulties to apply the tool cards or prefer not to use creativity tools in the design process.

4.4. Example application

The D2C tool cards were also applied in a design assignment with master students of Industrial Design. The example application is not a test of the effectiveness of the tool, but rather an illustration of the tool. The students designed a picnic basket: 'Pique Nique' (see Figure 5). The production process of the chair RD Legs (Cohda Design, 2009) - designed by Cohda - was used as inspirational source. The final prototype is made of recycled PVC wires that are woven and melted together on one side. Several tool cards were applied to design the connections. According to the students, the basket was made symmetrical (card 31), which improves the manufacturing and assembly process. Personality was created by the joining methods (card 42): the woven and melted plastic. The students used the flexibility of the material (card 15) to facilitate the accessibility of the products stored in the basket. No hinges or closure systems were needed. They avoided permanent joints between different materials (card 46) and used permanent connections between compatible materials. These materials could be recycled without disassembly.

Figure 5. a. RD Legs (Cohda Design, 2009) / b. material tests / c. prototyping / d. final prototype

6. Conclusion and further research

Existing tools that consider the design of connections are not optimized to stimulate creativity. Hence, they could not be used to overcome fixations and to create new solutions. There is an opportunity to create creative tools that deal with joining challenges in product design. This paper presented two tools based on techniques described in literature to overcome fixations: the first tool, called 'product crossing' is based on analogies and the second tool, the D2C tool cards, is based on reframing the problem. Both tools were applied in student exercises to test their effectiveness. The results of the product crossing technique were compared with existing benchmarks. The results of the test with the tool cards were evaluated by a team of experts. In both cases, the tools have proven to have a positive effect on the design of new connections. In further research, the tools will be applied in real cases with design professionals. Another challenge mentioned in the paper is the lack of online joining inspiration. Further research will focus on the development and evaluation of an online inspiration database, of which a test version is already available (Bleuzé, 2010). The latter contains over 600 inspirational connections from different industrial sectors. The database is very visual and its users can search on material, geometry or function to obtain examples of various existing joining solutions. Several students and design professionals already use this tool. The database is constantly being adapted and improved according to the needs of its users.

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