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ENDING UP AT THE BEGINNING – TEACHING MATERIAL DRIVEN DESIGN TO ENGINEERING STUDENTS

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ABSTRACT
Material Driven Design, or MDD, is a new way of realizing products starting in the understanding of the material rather than the need-driven approach that can be used to describe classic product development methodology. While new, MDD has potential to encourage more sustainable products being developed and is a useful tool for new designers and engineers to learn. In this paper, the author presents some lessons learned from teaching MDD to students in design and product development at a Swedish university. These students have experience from design and product development projects but have not done material-driven projects before. In general, the author concludes that the students are remarkably well-prepared in terms of tools and knowledge to do MDD, but that course coordination can make the projects less efficient if this is not solved early on. In master thesis projects or courses with few in-process deliverables, the implementation seems easier and can give students another path to solve problems in industry.

Keywords: Material driven design, design education, NPD, engineering education

1 INTRODUCTION
The product development process has been described in multiple different ways, but in general it comes down to the process of transitioning from some kind of market opportunity into a physical product, sold and delivered to customers [1]. A part of this is the definition of the product itself [2], and physical products can be defined by their material, geometry, and the processes used to manufacture them [2]. In a typical curriculum for mechanical or design engineering students, all these three parts of the definition will be addressed to some extent, with different emphasis depending on specialization, traditions and other factors affecting course composition at a certain university. In this paper, the emphasis will be on the teaching of materials in products and specifically how decisions regarding materials in products can be made.
There are multiple perspectives that can be taken on material selection [3], and is something that is taught to engineering students. But can classical methods for material selection, or even classical product development processes, cover all types of projects that engineers will face? Given the vast number of development projects being conducted in industry at any given time, it is unlikely that all of them would fall neatly into one specific process description. While classical product development methodology is based on problem-driven challenges, there could be other reasons for starting a product development project, perhaps some sort of technology-push variant rather than the more classical market pull process. And even within the problem-driven approach, ideas like agile development can be argued to alter the way a product development project is done. Agile development originates from software development [4] but has been adapted to the development of physical products as well [5, 6]. There is a need for teaching engineering students more than the classical approach to product development, and one of the interesting newer methods is Material Driven Design [7]. But what happens when Material Driven Design is included in an educational programme still centred around problem-driven development approaches? Can it be introduced without rewriting the whole curriculum, and can material-driven projects be run alongside traditional, problem-driven, projects?

2 MATERIAL DRIVEN DESIGN

Material Driven Design [7], (MDD), is a method for designing new products. While other, more traditional, methods for product development are based on a problem for a customer [8], MDD derives its name from the fact that the material to develop a product in is the first input into the process. Karana et al [7] describes four stages of the method: Understanding the material; Creating materials experience vision; Manifesting materials experience patterns; Designing material/product concepts, as can be seen in Figure 1. With regards to workload, stage 1 and 4 are more time-consuming where stage 4 contains much of what would be described in a traditional product development methodology model.

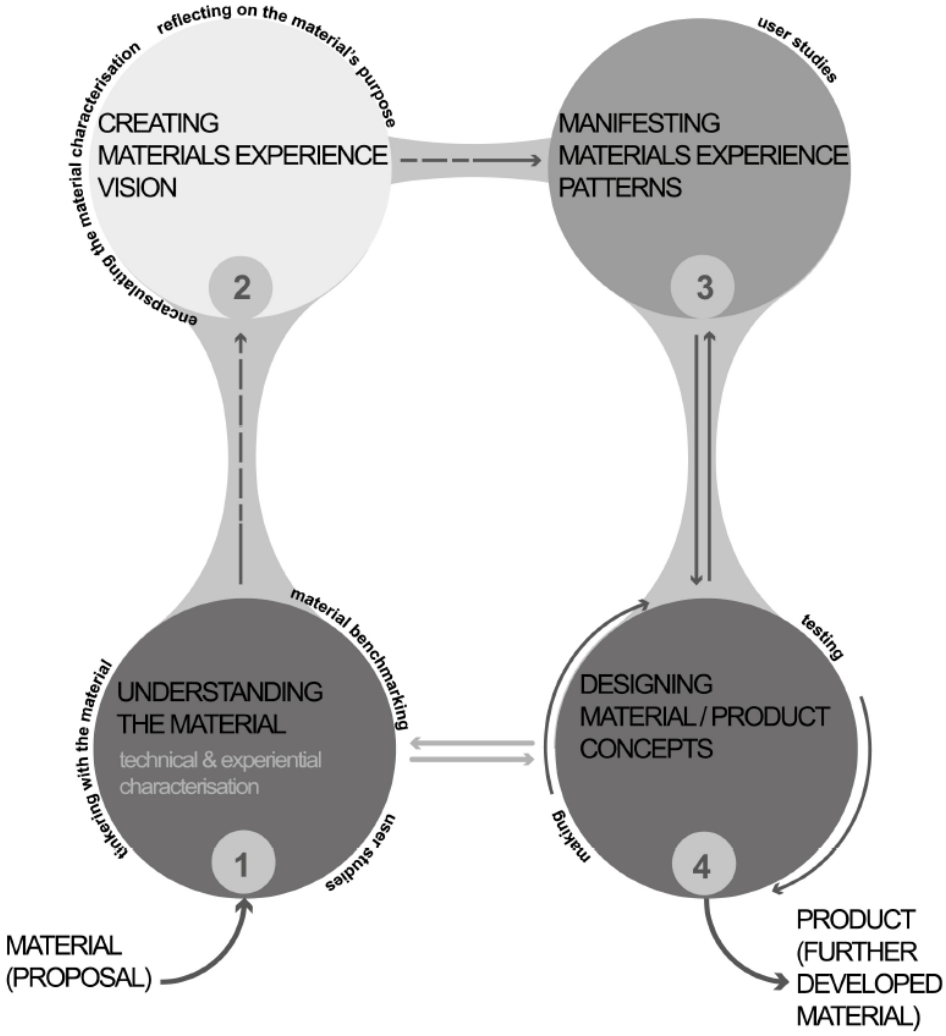

Figure 1. The MDD Method, figure from Karana et al. [7]

While a problem-driven product development process like Ulrich and Eppinger [8] or Pahl et al [9] would implement something similar to Ashby's material selection method [10] for selecting materials in a detail design stage, MDD both starts with a material and centres around the material properties rather than the product requirements [7]. It can be argued that these methods are not made for the same kinds of products, but even if replacing Ashby with something more focused on material experience, like Karana et al presented in their tool for meaning-driven material selection [11], this still assumes that some design work has been done before the material selection is done and that there are product requirements (or sought-after experiences) that can be fulfilled by selecting the appropriate material. MDD turns this around by finding the correct product for the material used in the project [7]. MDD thus should be viewed as a method for setting up the whole development process, and not a tool to select a material.

3 STUDY SETTING

This paper covers experience from the teaching of Design and Product Development students at Linköping University. Material Driven Design was introduced in the curriculum on the third year of a combined bachelor's and master's degree programme in 2017. Since then, the topic has been covered as a part of a general course on materials and their role in design, as well as in bachelor thesis projects, project courses in later years and master thesis projects.

In general, the Design and Product Development programme curriculum emphasizes on a combination of classical engineering skills and holistic design knowledge, and the capability to both analyse and create services and products [12]. Looking at the general course on materials and their role in design in particular, the emphasis is on understanding how material structure affect material properties, and how these material properties affect product properties [13].

While both the general course on materials and their role in design and the master thesis projects are unstructured in terms of fixed dates for deliverables, the bachelor thesis project and later year project courses utilize some form of simplified stage-gate model inspired by Cooper's description [14], intended for course coordination. This means that the students have fixed dates for delivering planning documents, pre-studies, concepts, and developed solutions. These courses do not have clearly defined definitions of what pre-studies, concepts or developed solutions could entail, especially not for material-driven projects, but rather guidelines that can be adjusted somewhat to fit a specific project.

In total, approximately 10 projects are studied, totalling 50 students. Of these, five projects are directly material-driven (defined as the main goal in the brief) and the other 5 are projects from courses where students are free to choose between problem-driven and material-driven project approaches and (as approximately 10% of the total course class) have included material-driven design approaches to some extent, sometimes in a hybrid fashion with traditional product development approaches and sometimes as including "MDD workshops" as an ideation tool. These projects have covered established wood-based materials as solid pine as well as novel, high-technology materials as flexible solar panels and graphene. In all the studied courses, problem-driven and material-driven projects are mixed so that both types of projects are done within the same course (but not by the same students).

4 OUTCOMES

The outcome will be divided into three parts; preparing the project (focusing on outcomes from writing the brief etc.), supervising the project (focusing on the execution of the project itself, and how supervision can be done), and analysing the outcome of the project (where the course coordination and grading of the project will be discussed). This section mainly covers aspects that can guide planning and implementation of material-driven projects in similar settings.

4.1 Preparing the project

Before the project is started, resource-allocation can differ somewhat from other projects since the students may require more time for experimenting with and experiencing the material early in the process. While experimenting is common in all design processes, the physical experimentation with materials can require more in terms of equipment, time and availability from experts.

For the preparation the project, the only main difference when writing a project brief for a problem-driven and material-driven project seems to be that the material-driven brief does need to be more clearly defined; the students will accept some higher level of uncertainty in the problem-driven brief than in the material-driven. This could certainly be due to experience with problem-driven briefs vs. inexperience with material-driven briefs, but other's experience would be much welcome to further analyse this.

When looking outside of preparing the brief for the students, some extra time needs to be spent on explaining the concepts of MDD and what it can mean in terms of in-course deliverables to other involved teachers, since they can differ significantly from what they are used to from problem-driven development projects. This also applies to support infrastructure such as workshop access or laboratory environment; both timing and tasks can be differing from previous experience which can sometimes raise questions from support infrastructure personnel.

4.2 Supervising the project

During the execution of these projects, the supervision is not significantly different from supervising other projects for similar students. The overall work is very similar, as well as the distribution between problem-solving, motivational work, and enforcing the requirements set for the course, but the

distribution in time could differ somewhat from problem-driven projects since the crunch-points differ between the two types of processes.
In the early stages of the project, some encouragement to test can be needed. From our experience, the students can be hesitant to perform "simple" tests or tinker since it can be perceived as non-value-adding. This can usually be resolved with encouragement, but without some intervention the process can slow down while students try to design experiments "worthy" of the time spent instead of building experience and knowledge gradually.
At a certain point in the project, usually around the initiation of stage four in the MDD process, there seems to be a small "slump" where the students can express some sense of dejection when they realize that this is approximately where a problem-driven project starts; they feel that they have spent a large portion of the time available in the project only to ending up at the beginning of a project. The supervision usually must focus on motivating the students here, and after having pushed through the students often express surprise over how easy the decisions were in the later stages of the process since they already have worked through the ideas and formulated a clear vision and goal for the end product.
During the supervision, it can be beneficial to remind students of the different tools that they have learned in previous courses and discuss how these can be applied in a material-driven project. The author's experience is that the students have multiple suitable tools available, but that they can need some help to understand that they can apply them in a different type of development process as well. After the first two or three tools implemented in the project, this is usually solved.

4.3 Analysing the outcome of the project

On a general level, the outcome from these projects does not differ significantly from problem-based development project. The quality of the final products is similar, and the level of innovation is also similar: some projects have innovative potential, while others less so. This is while the starting point of the project types are vastly different, which at least indicates that the students can manage using MDD as well as traditional product development methodology as a tool to generate product concepts. MDD can also be said to fulfil the basic description of product development as described by Krishnan and Ulrich [1], so this outcome is not unreasonable from a theoretical standpoint.
No real conclusions could be drawn regarding student long-term learning from this study, but the students working in these projects does not seem to have any more issues fulfilling the course requirements in comparison to their counterparts in problem-based development projects. It can also be argued that including MDD should give the students another way of setting up a design project, which should help understanding the complexities of design and product development further.
One identified challenge is the course coordination and check-up throughout the course. Especially mid-way through the projects, the gate meetings and deliverables are complicated for both teachers and students to navigate. These gate meetings are reasonably-well-fitting to classical product development processes, and the deliverables are more clearly defined when the classical, problem-driven process is synced with the gates. Especially if there are multiple projects in a course and there is a mix of material-driven and problem-driven projects, this can create uncertainty among students and teachers that can affect the progression of the project. One example is the use of a concept gate, where clearly defined concept ideas were presented. In the material-driven projects, the definition of the concept was unclear and complex to translate to a point in the MDD process. This created some uncertainty among both teachers and students, that affected early projects in a negative manner.
When the project is finalized, the difference between a material-driven and a problem-driven project diminishes, so grading and evaluating the project is not usually a problem if the students have managed to design a product and going through all four stages in the MDD method. The author cannot vouch for the ease of grading if the project is not as finished, since this could become more like the mid-way deliverables that are described in the previous paragraph.

5 CONCLUDING REMARKS

From this work, we can see that industrial design engineering students can produce innovative solutions with a high level of quality while using MDD for product development. The students themselves are also remarkably well-prepared for using the method, since most traditional tools, methods and activities used in design engineering can be used in an MDD process; the students already have a functioning "toolbox" for realizing products in this manner. What becomes the issue with this working process, instead, is to fit a material-driven project into a classic stage-gate model used for course coordination.

If suitable steps can be made in the course coordination to accommodate for the specific progress of an MDD project, the students seem to both enjoy the process and broaden their ability to tackle different types of industrial problems without having to relearn all new tools. This means that teaching MDD can be a resource-effective way to provide engineering and design students with another path to solving problems.

The author will continue to teach and use MDD as a tool in design and engineering education as of now, since there are industrial application of material driven design and since the students already have much of the knowledge needed to master the process. Thus, including MDD in the education seems like a small effort for possibly significant gains for the students.

For future work, the author sees the benefits of making a more structured implementation analysis, as well as studying the long-term learning outcomes from implementing MDD as a complementary method to classical product development work in teaching. After this has been done, the plan to continue teaching MDD mentioned in the previous paragraph will be re-examined.

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