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Rapid Concept Evaluations in Product Development using Modular Construction Systems

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Abstract (300-500 words)

This paper presents how modular construction systems are used in product development projects for mechanical engineering students to rapidly generate and evaluate different concepts. Additionally, the method can be implemented in the industry for the same purposes. The method is demonstrated with LEGO for two applications –a foldable bicycle and cup holder. Several concepts were built and evaluated for each of the three applications.
The possibility to evaluate each concept with a physical prototype increased the information that the students had when they chose which concept they would develop further. One drawback was that some students required a few hours of LEGO handling to feel confident when they assembled technical solutions.

Keywords: Guides, instructions, author's instructions, conference publications

1 Introduction

The concept generation and evaluation phase of the product development process is extremely important since much cost is committed once a concept has been chosen (Ullrich and Eppinger, 2008). Therefore, modeling, simulation and optimization, is often used to increase the knowledge about each concept at an early stage. Whereas it is cheaper and often faster than performing physical experiments, it has some drawbacks. Table 1 presents advantages and disadvatages with Modeling and simulation compared to physcial testing.

Table 1. Comparison of Modelling and Simulation versus Physical Prototypes

Modeling and Simulation	Physical Prototypes
+ Fast to perform repeated evaluations	+ Tests the real phenomena
+ Safe	+ Can discover unanticipated phenomena
+ Cheap	+ Excellent learning tools
+ Flexible	
- Includes modeling errors	- Expensive

- Must be verified and validated	- Occupies workshop time
- Difficult to describe the concept to other people	- Potentially Hazardous

The main detterent from building prototypes is usually the cost since they usually are much more expensive than the final products. Therefore, it is unrealistic for airplane manufacturers to build more than a few fully functioning prototypes.

Another option would be to use Virtual Reality (VR). Ottosson (2002) wrote about how VR can be utilized in product development. However, he states that model-aided design (MAD) should be used before or at least in conjunction with VR. This is probably still the case, even considering the advancements in VR during the last decade.

For a student, it is an important experince to get the opportunity to construct the products that they develop during student projects. This is one of the main pillars of the the CDIO concept (Crawler et al. 2007), which is a widely used education approach. It puts a heavy emphasis on design-implement exercises in engineering education. Crawler et al. (2007) state that:

"A design-implement experience is a series of events in which learning takes place through development of a product, process or system. The key criterion for such an experience is that the object created is designed and implemented to a state at which it is operationally testable by students. In this testable state, students verify that the product, process or system meets its requirements. Then they identify possible improvements."

This statement also highlights the importance of prototypes in product developemnt, especially for inexperienced engineers.

This paper suggests to remedy the resource drawbacks with prototyping by using modular construction systems such as LEGO Technic and FAC. This is mainly useful in the conceptual stages of the product development process, when the different concepts should be evaluated and compared to each other.

2 Prototypes and Modular Construction Systems in Product Development and Education

Ullrich and Eppinger (2008) devote an entire chapter in their book to the topic of prototypes. Physical prototypes are divided into comprehensive and focused prototypes, where the first are close to ready for market. The focused prototypes implement one or a few attributes of a product. Furthermore, Ullrich and Eppinger suggest creating two protypes – one "Looks-like" and one "works like". The purpose of the later is to reanimate the mechanisms of a product or attribute and this is where modular construction systems can be used.

Hallberg (2013) based his licentiate thesis on protypes in engineering and especially in education. He claimed that low cost demonstrators are especially useful when the product development includes new or unfamiliar technologies.

Bruseberg and McDonagh-Philp (2001) present research concerning product development that includes user experience. They use LEGO as a 3D-modeling tool which the product developers can use to build their ideal products.

The LEGO method (Danielsson and Löthman, 2015) was developed in a master thesis at Luleå University of Technology and also presented in a product development book from Luleå (Wikberg-Nilsson et al. 2015). It stands for Laborative, Exploration, Grading and Optimization.

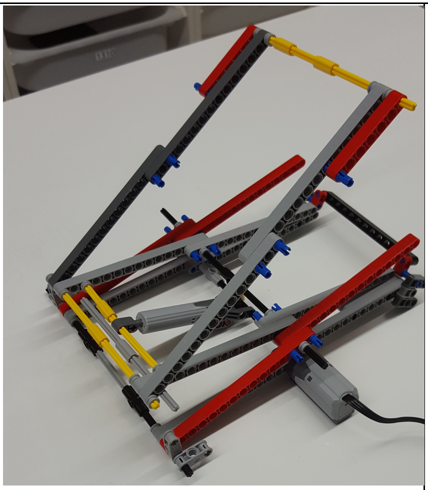
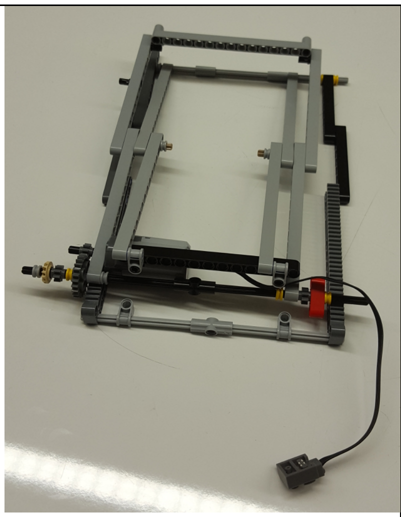
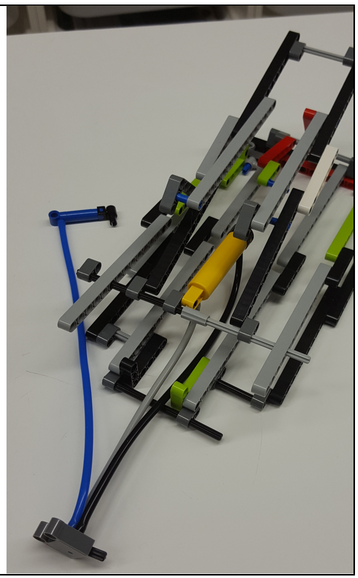
LEGO has been used in the education at Linköping University in several projects. Two of the most promising were the development of a foldable bike (Ahlbeck et al. 2017) and a lifting mechanism for a mobile industrial robot platform (Lindkvist et al. 2017). Mechanical engineering and Design and Product Development students conducted both projects during the fifth year of their educations. Both projects used LEGO Technic to construct and evaluate different concepts.

The evaluated concepts in the bicycle project are displayed in Table 2.

Table 2. Three different concepts for a foldable bike. Pictures taken from Ahlbeck et al. (2017).

The concepts from the lifting project are displayed in Table 3. All three are variants of scissor lifts, but

Table 3. Three different concepts for a lifting mechanism.

3 Overview of Modular Construction Systems

There are several modular construction systems that can be used in product development. Table 1Table 4 describes a few of the more promising, both plastic ones such as LEGO and metal based such as the FAC system (FAC, 2018).

Table 4. Overview of different systems that can be used to create prototypes

System	Material	Disadvantages	Advantages
FAC	Steel	Expensive Long time to assemble	Large torques can be transmitted
LEGO	Plastic	Only small torques and forces can be transmitted Large energy losses	Fast to assemble Cheap motors and batteries that fit well with the system
Mecano	Metal, Plastic	Medium time to assemble	Can transmit medium torques Motors are available
Strawbees	Plastic	The plastic straws cannot handle loads	Cheap motors and batteries that fit well with the system

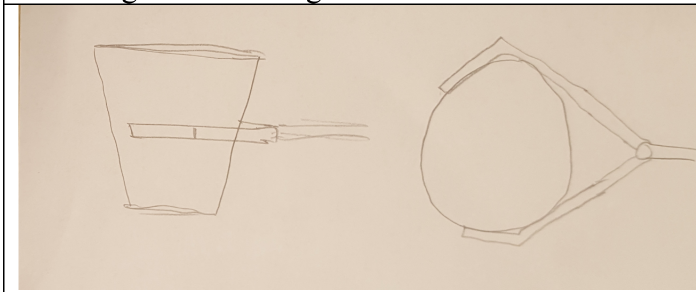
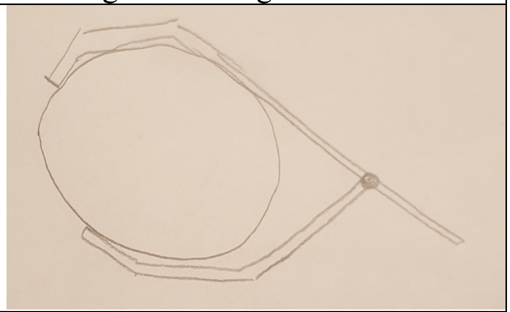
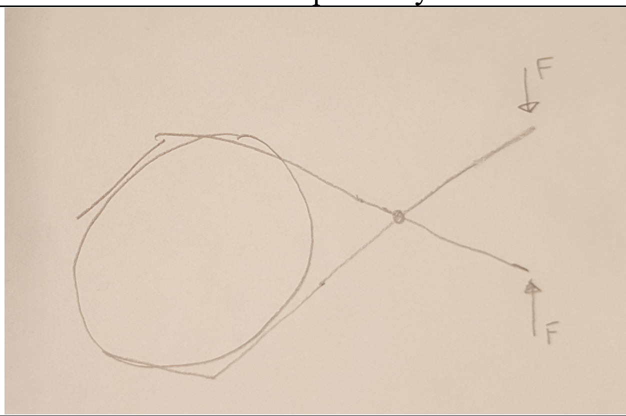
There are numerous webpages that exemplifies how the construction systems above can be used to teach basic engineering knowledge to youths. But some companies have also released suggestions for how their products can be used by adults.

One example is LEGO that has released Serious Play with the aim of improving the innovativeness of companies (Kristiansen & Rasmussen, 2014). It is a variant of brain writing, where each participant tries to represent his or her idea by assembling a few LEGO pieces.

4 Test Case – Gripper Mechanism

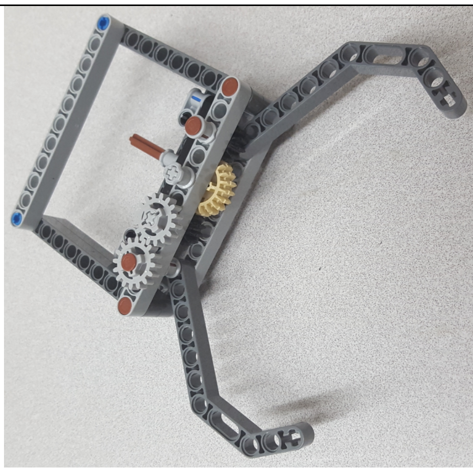
The modular construction system concept evaluation approach was used to evaluate different concepts for grippers that can grasp ordinary paper cups. An initial concept generation phase using paper and pencil resulted in three concepts. These are displayed in Table 5.

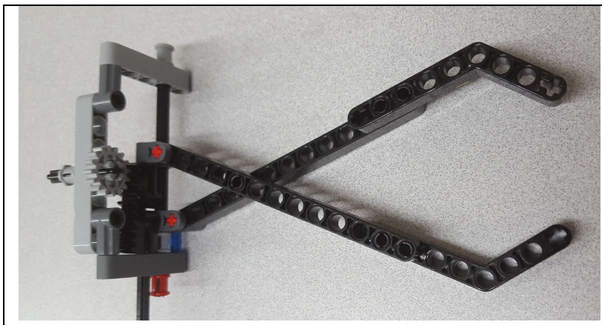
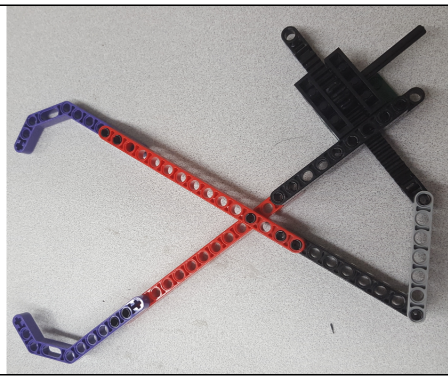
Table 5. The generated concepts for gripping mechanism for paper cups.

“The hand”	“The claw”
Two fingers are closing in on each side	One finger is closing the hand
	
“Pliers”	
Both sides of the pliers move with a rack and pinion system in the back end	
	

These concepts were then constructed in LEGO Technic and the resulting prototypes can be seen in Table 6. It can be noted that the “Pliers” concept was developed into two variants. One with large pliers and one with small pliers.

Table 6. LEGO realizations of different gripper mechanisms.

“The Hand”	“The Claw”
	
“Small Pliers”	“Large Pliers”

The concepts were evaluated and then compared to each other. This was done using the datum matrix in Table 7.

- Precision specifies how precise the gripping mechanism can grasp the paper cup.
- Complexity is a metric that includes cost, number of parts etc.
- Space relates to how much space the gripper occupies from attachment to the gripped object.

Since the "small pliers" concept performed best it is the one that should be recommended for further development.

Table 7. Two datum matrices that try to find the best concept.

	The Hand	The Claw	Small Pliers	Large Pliers
Precision	Datum	-1	1	-1
Complexity		0	1	1
Space		0	0	-1
Total	0	-1	2	-1
Precision	-1	-1	Datum	-1
Complexity	-1	-1		0
Space	0	-1		-1
Total	-2	-3	0	-2

The usefulness in utilizing LEGO to evaluate each concept was investigated by the authors of this article. This compilation is presented in Table 8. Each characteristic was graded on a scale between 1 and 5 where 1 is abysmal/difficult and 5 is excellent/easy. For example, this means that the Claw was considered the easiest concept to explain and understand before any prototypes were assembled. The long assembling time for the Hand is also reflected in the Complexity value in Table 7.

Table 8. The authors' evaluation of how useful LEGO was to realize and develop each concept.

	The Hand	The Claw	Small Pliers	Large Pliers
How easy was it to understand the idea before using LEGO?	3	4	3	3
How easy was it to understand the idea after using LEGO?	5	5	4	5
How long time did it take to create your prototype?	50 min	10 min	10 min	30 min

Could your prototype move as intended?	5	4	2	5
How easy was it to adjust/ change your prototype	3	5	4	3

The statistical data for this example is too small to draw any general conclusions, but it shows that it took less than two hours to create moving prototypes for four concepts. Additionally, the advantages and disadvantages of each concept were easier to understand when there were prototypes that could be analysed.

A side-effect was that the concepts were developed further during the assembling since they had to be adapted so that the mechanisms worked as intended. This increased the knowledge about each concept and some alterations had to be made to them to make them work as intended.

The main drawback was that much effort was made to figure out how to create the concepts using the LEGO blocks.

5 Conclusions and Future Work

This paper demonstrates how modular construction systems, e.g. LEGO Technic, can be used for rapid concept construction and evaluation. This enables the construction of more prototypes, which can be used to increase the knowledge and understanding of each concepts advantages and disadvantages.

The experiences from the student projects and the test case in this paper suggest that unexperienced engineers and students can benefit greatly from creating physical prototypes of their concepts. Experienced engineers can usually tell at an early stage whether a concept is promising or not.

A drawback with modular construction system is that much time may be occupied trying to understand how a concept can be constructed using the particular system. This time could perhaps be better used elsewhere. On the other hand, the concepts are usually developed further during the construction of the prototypes since the goal is functioning prototypes.

A research direction for future work is to try to quantify how the increased usage of prototypes affect engineers with different experience. This would require interviews and workshops with many engineers to gather enough data.

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