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CHALLENGES IN CONCEPTUAL DESIGN OF FENCING SYSTEMS, STUDENTS VIEW

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ABSTRACT
A systematic engineering design process is recommended for use in industry. Still many design teams tend not to follow it and consequently their designs are not adapted to a customer needs. Even when used, such a process needs to be applied properly in order to produce desired results. Following the first training in application of systematic engineering design process, it was clear to the mechanical students at City University how to use it for generating concepts of mechanisms and machines. However, in the project which they performed for an industrial partner they were asked to conceptualise on a fence which was regarded as a structure. In this case students needed to apply different approach and to introduce more tools in extracting engineering characteristics.
The process was performed in two phases. Initially the research phase was carried out to define customer requirements, the objectives tree, engineering characteristics and to generate a QFD. However, generating a functional model as the basis for the morphological chart was not perceived as a trivial process. Therefore other alternative approaches for identifying functions were evaluated. In the second phase, the concept generation, this approach proved very useful and allowed generation of several novel concepts. This paper written by undergraduate students outlines details of this exercise. Students described their challenges in adapting to new processes and elaborated on suitability of using the proposed approach by the industrial partner.

Keywords: Engineering design process, value analysis, functional model, FMEA

1 INTRODUCTION

An engineering design process provides a structured set of tools to aid designers fully evaluate problems in a strategic manner. It involves a series of creative, corrective steps, as well as selection and evaluation methods. This is explained in detail in German standard VDI 2225 [7] and Value Analysis [2] . However, in some cases a standard structured design process may be difficult to follow due to the various technical and economical aspects of both product and company. The commercial and technical elements of the market for which a product is designed play a significant role in selecting tools suitable for design. In some cases, standard tools may not satisfy all the requirements of the design objectives and time constraints for a new design [4] . Thus, a systematic design process is often ignored by design teams who prefer using their intuition or experience to reduce time of design. Such an approach often ignores the fact that a systematic design process can serve as an optimisation tool and at the same time can channel creativity stemming from intuition and experience. It can systematically take advantage of experience by consolidating loose ideas and concepts into a common and reusable format, thus leading to reduced lead time through repetition. An effective product development process, supported by scientifically validated design theories and tools is an increasingly useful asset for industry [3] .
European Global Product Realisation (EGPR) is the engineering design project for final year students from across the School of Engineering and Mathematical Sciences at City University in London. The course is arranged in an academic virtual enterprise which includes an industrial partner [5] . The aim of the course is to use a holistic approach in order to develop the competencies of participating students [1] . The EGPR project is conducted jointly by six universities across Europe, namely Delft University of Technology, Ecole Polytechnique from Lausanne, University of Ljubljana, University of Zagreb, Technical University from Budapest and City University London [5] .

As the collaboration with other universities starts in the second semester, and in order to provide real life experience on industrial project, the team of students from City University collaborated with one of the UK's largest manufacturers of fencing systems, Jacksons' Fencing. The company assigned task for the design team to develop an alternative fence system which will meet requirements of a target market segment. In an attempt to follow the structured design process, the group started with developing an objectives tree, followed by the functional model and QFD. However they faced serious challenges in extracting an adequate amount of engineering characteristics from the developed functional model. The functional model could not be sufficiently detailed in large part because the functional model was deemed to be ill-suited to modelling an item that does not involve significant input of energy or material. For instance the function of a mechanism such as a compressor can easily be derived using a functional model [6] , but a stand-alone structure has no interacting parts and virtually no processing of material or energy inputs. This prompted a re-evaluation of the learned methodology which consequently led to use of more tools to extract engineering characteristics in addition to functional model.

This paper describes the process the student team used in the design of a novel fencing system and the experience of working as a team for an industrial application. The aim of the exercise was to test the effectiveness of systematic design procedures to design of structures. The team were also trying to assess the comparative effectiveness of the design process when applied to the design problems presented by SME's to the SME's own design methods.

2 METHODOLOGY

The research phase directed the team to clarify the design objectives and establish the user requirements through the objectives tree analysis. This was followed by the functional analysis in order to establish the engineering characteristics and functional requirements. The conceptual design phase focused on performance specification through the use of QFD. This helped in setting target values for the engineering characteristics and customer requirements. The morphological chart was developed for systematic generation of solutions for individual sub functions which were then combined into a solution set to derive new concepts. As a result, four concepts were developed and presented to the management team of the industrial partner. The selection of the optimum solution was performed by use of the decision matrix, in which the derived concepts were individually rated against the key customer requirements.

3 DESIGN PROCESS

The classical approach to the design process shown in Figure 1 is what the team were familiar with due to prior use in an academic setting. The process was however seen to be less suitable for a project involving the design of a fence system. The main obstacle for the team was the fact that no functions could be defined in order to develop the structure. The team was therefore prompted to explore alternative methods outside the boundaries set by the standard academic curriculum.

The aim of the first phase of the design process is to establish customer requirements through the objectives tree analysis and to define engineering characteristics through the functional model. However, while extracting the engineering characteristics from the functional model, the team realised that the functional model analysis did not offer a sufficiently extensive evaluation of the functions of a fence structure. The team then looked for alternative methodologies that could be used to aid the extraction of functions and engineering characteristics. Two such methods were proposed. Firstly, Failure Mode Effects analysis (FMEA) [9] was applied in order to identify failure modes, engineering characteristics could then be extracted based upon the parameters [3] that would impact the severity and occurrence of the failure mode, with the relevant mitigating options also catalogued. For example, oxidation and corrosion were

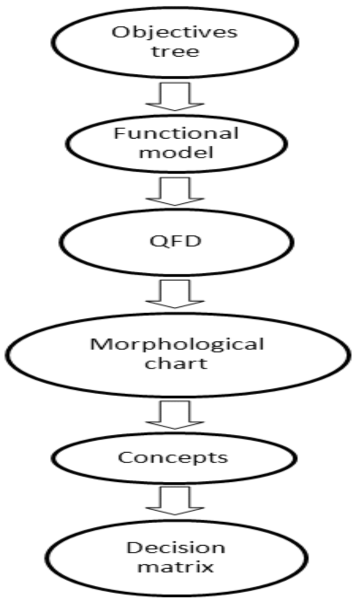

Figure 1. Stages of the design process

identified as one of the key causes of the failure of the fence to maintain functionality throughout its lifetime. The engineering characteristics impacting on corrosion were identified to be surface treatment and material manufacturing method. Appropriate action was further suggested as the application of galvanization, paint, or polyester powder coating during treatment. **Error! Reference source not found.** gives an example of the derived FMEA for the fence structure.

Table 1. FMEA on a fence panel

Component	Potential Cause	Potential Failure Mode	Action
Panel	Excessive human induced force	Panel Break	Higher strength material , monitoring of premises
Panel	Excessive force of large object (e.g. motorised vehicle)	Panel Break	Monitoring of premises
Panel	Oxidisation	Significant weakening of the structure	Paint/galvanizing/ppc
Connectors	Oxidisation	Connector break	Paint/galvanising/ppc
Connectors	Excessive human and animal induced force and forced entry	Connector break	Hidden connections
Pillars	Excessive force (car impact, human and wind force)	Structure failure	Deeper foundation for stability and material selection to withstand force, less surface area in contact with wind
All components	Poor installation and assembly	Weak structure	Simple design with installation information, less number of components.

Secondly, the team continued to reiterate the design process in order to further evaluate and identify other functional requirements of a fence structure, and realised that the value engineering or value analysis method [2] might help in identifying the requirements for conceptualisation since cost was one of the most important customer requirements [7]. Value engineering is aimed at maximizing the value/cost ratio, hence providing the opportunity for optimum commercial return [1]. Value analysis involves asking the following questions about an existing design:

1. *Eliminate:* Can any function be eliminated altogether? Are any components redundant?
2. *Reduce:* Can the number of components be reduced?
   Can several components be combined into one?
3. *Simplify:* Is there a simpler alternative or shape? Is there an easier assembly sequence?
4. *Modify:* Is there a satisfactory cheaper material?
   Can the method of manufacture be improved?
5. *Standardize*: Can parts be standard? Can dimensions be standardized or modularized?
   Can components be duplicated?

A number of the key features of design concepts were identified by use of value engineering. However, at the end of the exercise, it was concluded that this method alone could not be used to conceptualise. As the main aim of value engineering is to reduce the cost of a product in terms of its components and assembly, it was concluded that other important objectives might be ignored by sole use of value engineering [2]. As value engineering was deemed to be an un-exhaustive tool for extraction of engineering parameters, the team decided to evaluate possibilities to combine the two mentioned methods with a functional model.

The aim of the functional model is to establish the structure of the inputs and outputs, as well as the interactions performed within the device. Development of sub-functions in identified flows allowed for engineering characteristics of these sub-functions and flows to be extracted. For example, load transmission was detailed as an interaction in the system and through analysis of the load carrying parts, the connectors were determined to be a critical point of failure requiring greater attention for increase of the product lifetime. A similar exercise was performed by use of value analysis where the connection elements of a fence were studied from the flexibility and cost point of view. Figure 2 shows a part of the functional model detailing the energy transfer between panels and pillars.

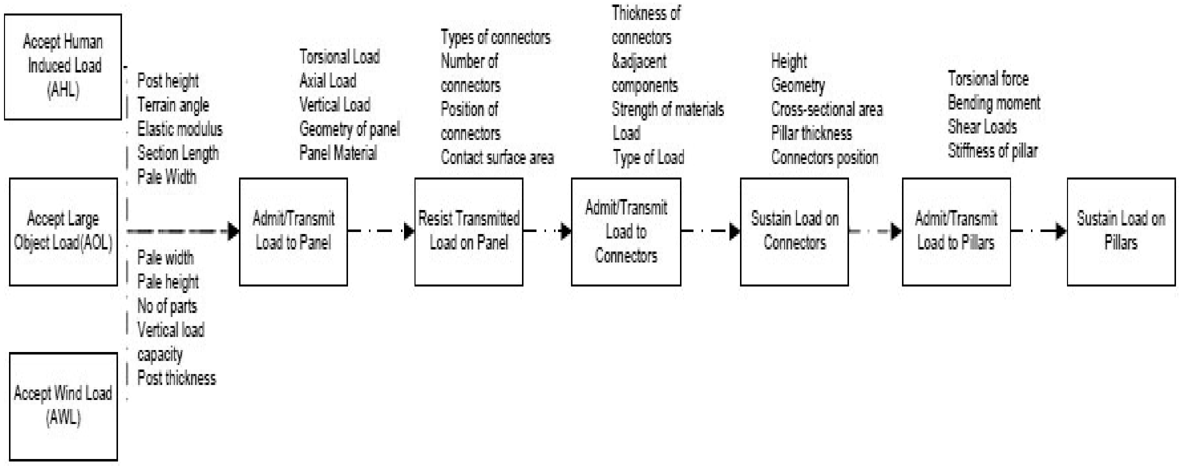

Figure 2. Section of a functional model

FMEA was used to determine other key system parameters where the functional model alone was inadequate. An example is environmental effects such as the occurrence of corrosion which the functional model alone could not be relied on to identify.
The approach the team used in solving the design task led to the integration of several tools in evaluating the requirements and functions of a new structure towards deriving an exhaustive list of engineering parameters. Hence the design process used for this project had a structure as shown in Figure 3.

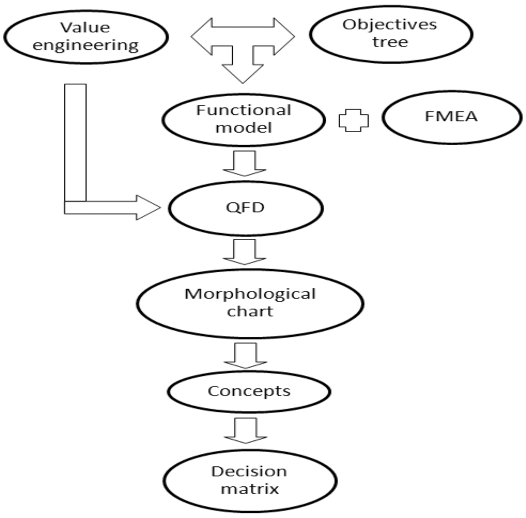

Figure 3. Design process used in this project

4 RESULTS

The fact that the process used to conceptualise the new fence structure included value engineering and FMEA allowed for a number of key issues to be identified which would not be possible by sole use of the functional model. Value engineering helped to realise that the assembly of vertical pales to the fence panel added extra onsite installation costs; hence helping to brainstorm on techniques or parts that would ease and speed up onsite installation. For example, the concept variant 3 shown in Figure 4 does not have connectors for pales and instead it uses sliding horizontal rails, thereby significantly reducing installation time without sacrificing structural integrity or product lifetime. Value engineering formed the cornerstone for maximizing the value/cost ratio for all concepts developed and was a major contributor to the creation of concept 3.
By use of FMEA, the key failure modes were identified and qualitative measures to prevent failure were recommended. For example, rust and corrosion were identified as a key cause of structural failure in fencing systems. FMEA was then used to categorize this problem and suggest mitigating measures. By so doing, a range of solutions were explored in the morphological chart, such as PPC coating and galvanization. Connectors were also identified to be susceptible to rust, corrosion or vandalism, and so they were conceptualised to be hidden and have minimum exposure to the corrosive environment.

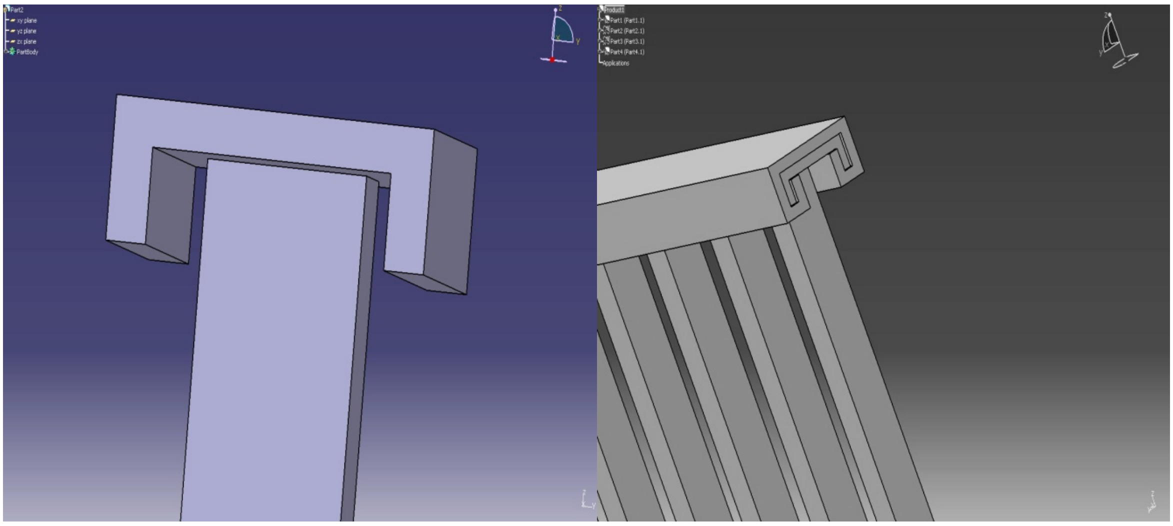

Figure 4. Concept variant 3

Solutions were assessed on the basis of their economic and technical feasibility. The four new concepts were compared with the two main competitors in the decision matrix and diagram of economical vs. technical values. Concept 3 shown in Figure 4 proved to be superior to other solutions both technically and economically. Further details on validation and selection of the optimal solution are presented in [8].

5 LESSONS LEARNED

The industrial partner on this design project has indicated that their current design process, although adequate, is not necessarily the optimum methodology for developing new products for new markets. They nonetheless mention that lack of time and resources are obstacles that prevent implementation of the full structured engineering design process. We argue that company culture and established practice can often stifle intuitive innovation, and the company may thus suffer in terms of reduced potential cash flow of products. The use of tools like the functional model and morphological chart provide an avenue to standardize and channel innovation and creativity across common platforms, and are therefore imperative to maintain innovation. As referred to in [8], a proactive market approach and innovation are primary drivers of market share expansion. The students also felt that the design process which includes the use of a single tool for extraction of engineering characteristics was not particularly well-suited to this project. It was therefore necessary to experiment with other tools, such as value engineering and FMEA. By use of these tools, parameters that would otherwise have been neglected in the functional model could be incorporated into the design process. The team found that extraction of engineering characteristics from the functional model was a difficult process especially in this case in which product did not perform a function by interaction of their constituent parts [6]. FMEA therefore aided the extraction of the characteristics by looking at the structure from a different perspective. It is therefore our suggestion that in future exercises of this nature, one of the first steps in the design process be reserved for research and analysis to determine an optimum combination of tools which will suitably aid students when attempting to design artefact which differ from standard machines or mechanisms.

6 CONCLUSIONS

The engineering design process learned at university courses may not necessarily be specific or adaptable enough to provide means of generating optimal solutions for every design problem. The use of design tools dedicated for development of mechanisms and machines which involve flow diagrams is not easily applicable for analysis of a structure. The design process must therefore be made adequately flexible so that it can be adapted to a specific task.

Utilisation of FMEA and Value Engineering in order to augment the functional model for extraction of engineering characteristics proved to be sufficient for solving the given design problem. The team felt that such changes need to be further explored and tools and methodologies adapted in order to allow flexibility within the design process for different design problems students may face.

REFERENCES

[1] A. Kovacevic, Competence Development in an International Product Design Course, *International Design Conference - Design 2008,* Dubrovnik - Croatia, May 19 - 22, 2008.

[2] D. Tate, M. Nordlund, A Design Process Roadmap as a General Tool for Structuring and Supporting Design Activities, *Proceedings of the Second World Conference on Integrated Design and Process Technology (IDPT-Vol. 3)*, Society for Design and Process Science, Austin, TX, pp. 97-104, Dec. 1-4, 1996.

[3] G. Pahl, W. Beitz, J.F Eldhusen, K.H.Grote, *Engineering design: A systematic approach*, 1999 (Springer)

[4] Nigel Cross, *Engineering design methods; strategies for product design,* 2003 (John Wiley & Sons, Chichester)

[5] I. Horvath, M. Wiersma, J. Duhovnik and I. Stroud, Navigated active learning in an international academic virtual enterprise, *European Journal of Engineering Education*, 24 (9), 2004, 505-519.

[6] L. Machado, M. Hashi, E. R. Gowree, G. Ondoa, R. Gaind and A. Kovacevic, Undergraduate project on conceptual design of a small screw compressor, *International Conference on Engineering and Product Design Education E&PDE2009;* September 2009, University of Brighton

[7] Verein Deutscher Ingenieure, VDI 2225 Blatt 1: *Design engineering methodic – Engineering design at optimum cost - Simplified calculation of costs*, 1997 (Beuth-Verlag)

[8] R. Ghazihesami, J. Verdeguer, A. Halai, S. Jeshani, E. Gowree, J. Valtera, A Kovacevic, *Use of a Structured Engineering Design Process in Expanding SME Market Share***,** Submitted for International Conference on Engineering and Product Design Education 2nd & 3rd September 2010, Norwegian university of science and technology, Trondheim, Norway.

[9] Evaluation of information requirements of reliability methods in engineering design, *International Design Conference 2010 – Design 2010,* Dubrovnik – Croatia, May 17-20, 2010.