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WASTE IN DESIGN AND ENGINEERING

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ABSTRACT

The purpose of this paper is to shed light on the feasibility of using waste drivers to explain waste in a design and engineering setting. Waste drivers are defined as the mechanisms that have the capacity to create waste, under certain conditions. The waste can occur in design and engineering, and as a consequence of design and engineering. Waste include, e.g. reduced build ability and usability, with increased costs, time, and quality. The distinctiveness of the engineering process has been central when attempting to identify the waste drivers. The complexity associated with waste in design and engineering may indicate that the conventional manufacturing wastes do not suffice in the context of identifying waste in design and engineering. Based on researched literature and a case study, a list of waste drivers was identified. This paper should contribute to the understanding of design and engineering processes. Thus, potentially making design and engineering processes more predictable.

KEYWORDS

Waste, mechanisms, engineering, design, management.

INTRODUCTION

Design and engineering (DE) processes play an important part throughout the product life-cycle. Typically, the design phase accounts for a small portion of the total product cost, however, it can impact the life-cycle costs significantly (Verma and Dhayagude, 2009). The increased market competition as a result of globalization and the higher level of complexity in projects calls for more efficient and predictable DE processes. Consequently, it becomes important to ensure that time is spent on value-adding activities, providing value to the customer within budget and in a timely manner. In order to achieve this, it is necessary to identify the mechanisms that lead to waste in DE.

Several studies have been conducted in an effort to conceptualize waste in DE. An extensive amount of literature and research has been written on the topic of waste in manufacturing and construction. However, it appears to be limited focus on the mechanisms that lead to waste in DE. It seems like previous literature and research has been stuck in a loop trying to relate the wastes of DE to the seven conventional

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manufacturing wastes described by Womack and Jones (2003). More often than not, researchers end up adding their own categories in an effort to cover the waste drivers of DE. To some extent, previous research fails to consider distinctive elements of DE, such as creative processes, motivation, and social relations. Furthermore, DE is a learning process (Kalsaas, 2011), which adds an additional layer of complexity when trying to define, identify, and eliminate waste. These elements need to be addressed in the aforementioned context. Based on this background the following research question was explored:

What are the mechanisms that might lead to waste in design and engineering?

The scope of this study is limited to the conceptualization of waste in design and engineering, with an emphasis on the mechanisms that has the potential to lead to waste. This includes waste which is realized in the design and engineering processes and waste these mechanisms might generate in processes further down-stream.

The selected approach was constructive research design, which is a procedure for developing constructions that can contribute to theory in the field of research (Lukka, 2003). This included gathering data from multiple sources, such as literature and a case study. The majority of the source material consisted of literature on topics such as lean, engineering, design, management, and learning. The findings from literature were supplemented with the collected data from a case study. The case company studied is a subcontractor for the oil and gas industry. The findings were used to present a generic representation of the waste mechanisms in DE, thus, they are meant to be applicable to DE in different industries and organizations.

During the process of investigating the characteristics of DE, several topics and theories were considered relevant to the research question. The emphasis on the elimination of waste is a central element in lean (Womack and Jones, 2003), which led to investigating the concepts of lean, including lean manufacturing and lean construction, and the Toyota Production System (TPS). A lot of research on waste in DE has been conducted by LAI at MIT. These studies were used as a starting point for this study. Several hundreds of papers, articles and books were read, especially papers from the International Conference on Engineering Design (ICED) and the International Group of Lean Construction (IGLC) were investigated.

This paper covers some basics about the nature of DE, and then there is an overview of some previous ideas of waste. The possibility of using previous ideas of waste in a DE setting is explored. Lastly, a suggestion for a possible conceptualization of waste in DE is presented.

THE NATURE OF DESIGN AND ENGINEERING WORK

Human beings are central actors in DE. Thus, one can argue that it is important to consider additional aspects, when compared to manufacturing or conventional production processes. From the researched literature, several authors suggested that information is the product of DE processes, such as Bauch (2004). Bauch (2004, p. 1) states that “Product development […] can be understood as some kind of information creation factory”. Due to the relevance of information in DE, the aim of analyzing and improving the processes in DE can be considered an analysis of the generation of different information types, as well as their respective qualities (Vosgien, et al., 2011). This differs from manufacturing, where the products are physical objects. Simon (1996, p. 138) goes as far as to suggest that "The proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated man." Even though one does not need to agree with this statement, it is plausible the knowledge of technical systems and analysis does not suffice in order to understand what leads to successful and efficient design. The design process is a complex cognitive endeavor, and it is critical to understand these cognitive processes in order to improve existing design methodologies (Pahl, 1997; Dym, et al., 2005). Creativity and innovation are important in order to generate good solutions, this is often accomplished through experimentation (Ulrich and Eppinger, 1995). In this context, creativity can be seen as the process of coming up with novel ideas that have value. Innovation can be seen as the process of realizing these ideas. Without creativity in design it is impossible to have innovation, and it is mandatory to have innovation in order to improve quality, create new markets, and extend the range of existing products (Verma, Das and Erandre, 2011).

The process of engineering design typically consists of the following five steps: formulation, synthesis, analysis, evaluation, and documentation (Verma, Das and Erandre, 2011). Creativity is especially important in the first two steps of the process, since new thinking or rearrangement of existing data is required (Verma, Das and Erandre, 2011). The process typically begins with the analysis of the product's intended usage and context. The analysis leads to a heterogeneous set of loosely related details, and possibly some insight to potential solutions. The design problem is initially structured and its solution defined through its implicit properties. The solution is further elaborated in relation to additional requirements, and if the context and requirements determines a distinctive solution, it may be derived algorithmically. Then designing is basically just the problem's transformation from its intentional to its extensional form (Takala, 1993). However, it is common that the algorithmic rules are unknown, or that the problem lacks specifications. This typically leads to an explorative approach of trial and error, which is usually not a random effort. The paradigmatic solution is compared against an increasingly maturing set of requirements, and modified as needed. In this aspect, design is described as the convergent evolution of solutions (Yoshikawa, 1981; Takala, 1993). Its progressive evolution may branch, and lead to detours and backtracking, which eventually will result in a path to the solution (Takala, 1993). Simon (1996) suggests that detours are a natural part of the design process. Even though a general notion of the goal is known, barriers that are encountered along the way call for a continuous adaptation in accordance to these obstacles. Ballard (1999) argues that design requirements and their respective solutions evolve as the process progresses. This is what Thompson (1967) depicts as reciprocal dependencies: relationships where output from one activity establish the next (Kalsaas and Sacks, 2011).

The design phase comes to a halt when the engineers run out of time (Reinertsen, 1997). This might indicate that the ideal solution cannot be achieved, and that decisions must be made in accordance to what is perceived as good enough (Bølviken, Gullbrekken and Nyseth, 2010). Typically, this is the solution that is most consistent with the original requirements.

Male, Bower and Aritua (2007) point out three challenges that are distinctive to design:

- Requirements are often subject to interpretation, since they tend to be vaguely formulated
- Problems become increasingly clearer as solutions evolve over time
- The design process is an interactive, multidimensional effort that represents the interests of several stakeholders

Kalsaas (2013a) suggests that these challenges are caused by the need for design to mature. Kalsaas (2011) conceives design as a learning process, where one develops and optimizes a solution. Thus, the aspect of learning can be seen as particularly relevant in the context of DE. Illeris (2007) divides learning into three dimensions: the cognitive dimension, the psychodynamic dimension, and the environment. The process of acquiring knowledge takes place in the intersection of the cognitive and psychodynamic dimensions, which subsequently interacts with the environment. According to Illeris (2007), there are different variants of learning in the cognitive dimension: assimilative, accommodative, and transformative. The general form of learning, which is termed assimilative, is the kind of learning that evolve progressively through encounters with new impressions and impulses, in everyday life. In DE, this learning can be in the form of acquiring additional knowledge and competence in how to use CAD software efficiently. Accommodative learning is described as the process of relating what is already known into situations that one cannot understand, e.g. applying knowledge to a different context than where it was originally used. Such learning requires creative efforts and is very important when attempting to improve existing work practices, e.g. continuous improvement (kaizen). Accommodative learning in DE can be the knowledge of dealing with uncertainties and how to apply it to different projects, even though the objectives and specifications may differ. Transformative learning is described as developing new mental models, and can be related to a state of crisis on the personal level.

The presented theories, as well as several others, have been central when exploring the mechanisms that lead to waste in DE.

WASTE IN DESIGN AND ENGINEERING

According to Morgan and Liker (2006), eliminating waste is the heart of TPS. Activities can be divided into value adding, non-value adding, but necessary, and non-value adding. True lean thinking does not focus on one-dimensional elimination of waste. It is necessary to understand that it is required to eliminate all the three types of interrelated waste, known as the three Ms, in order to achieve waste elimination (muda, muri, mura).

Ōno (1988, p. 54), who is considered the father of TPS, explains that *"waste refers to all elements of production that only increase cost without adding value"*. Macomber and Howell (2004) state that waste is commonly understood as anything that is not value. They elucidate that waste is the expenditure of effort or resources that do not generate value. Similarly, Koskela (1992) explains that waste is activities that takes time, resources or space, while not adding value. Several of the authors refer to waste as something that consumes resources without adding value, thus the resources that can be wasted in DE should be identified. The seven conventional waste categories describe waste through, e.g. rework, waiting, and overprocessing (Morgan and Liker, 2006). However, these categories do not explicitly describe what is actually wasted. Sugimori, et al. (1977, p.554) state that TPS works on the assumption that “anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises the cost”. Thus, the unnecessary use of resources can describe what is wasted. Bauch (2004) identifies and describes the factors that are wasted in DE. He divides the waste into primary and secondary waste types, where the underlying causes are the waste drivers. The primary waste types affect the flexibility, and impacts: quality, time, and cost to market. This include, e.g., the constructability and usability of the product. Instead of using what Bauch (2004) refers to as secondary waste types, the authors of this paper rename it to resources. Resources include man-hours, time, money, et cetera. Thus, waste of resources can, e.g. be spending more time on a given product, compared to what is achievable with a more effective and predictable DE process.

In addition to the resources that can be waste in DE, it is important to emphasize that DE processes can generate waste in processes down-stream as well. Thus, it can differ between what is wasted in DE, and what is wasted due to DE. The wastes that occur due to DE will be context dependent. For example, the downstream process can be a construction process, which arguably can have different waste than a manufacturing process. However, the waste in downstream processes is likely to impact the time, cost and quality to market of the product, in a similar fashion to the waste generated by the DE process.

Based on the provided definitions of waste, and the suggestions to what is wasted in DE, a proposed definition can be made. Waste in DE might be defined as resources spent on activities that negatively impact the cost, time or quality to market of the designed element. The market includes both internal and external customers.

CATEGORIZING WASTE IN DESIGN AND ENGINEERING

According to Vosgien, et al. (2011), defining waste is essential to increase process efficiency. Slack (1998) concluded that the primary manufacturing wastes could be applied to DE. However, due to the complexity associated with DE, the set of categories was not considered all inclusive. Furthermore, several other publications (Slack, 1998; Womack and Jones, 2003; Bauch, 2004; Morgan and Liker, 2006; Oehmen and Rebentisch, 2010) have addressed this issue, and it typically involves transposing the seven manufacturing wastes to the area of DE, often supplementing with additional categories, such as Koskela’s (2004) making-do (Vosgien, et al., 2011). Macomber and Howell (2004) discuss the force-fitting of the seven manufacturing wastes, and based on observation they introduce what they call the two great wastes: not listening and not speaking.

It is also worth pointing out that several of the manufacturing waste categories will be a natural part of the engineering process, and it may depend entirely on the situation if these activities should be defined as waste or not. As an example, if information is stored deliberately to enable reuse in later assemblies, then it might be considered value adding (Oehmen and Rebentisch, 2010). In manufacturing, overproduction is considered the most important waste, this cannot be defended regarding projects that are one-of-a-kind, like a design project often is (Koskela, Bølviken and Rooke, 2013).

SELECTING A DIFFERENT APPROACH

Bauch (2004) tries a different approach. Bauch (2004) uses the seven manufacturing waste categories. He also builds on these by adding three additional categories[4]. Bauch (2004) refers to the categories as drivers, since they describe why waste is happening, and not what waste is or what is wasted. In addition, he divides the categories into sub-drivers. The authors of this paper found this interesting, and wanted to explore these ideas further.

Bauch's (2004) idea of sub-drivers might have the potential to create a less ambiguous representation of waste in DE, and will perhaps even make waste easier to identify. Based on the sub-drivers created by Bauch (2004), and other literature, such as Oehmen and Rebentisch (2010) and Oppenheim (2011), a list of waste drivers was created. This was supplemented with findings from the case study and personal experience. The usefulness of creating a list of waste drivers is considered to be supported by Koskela, Bølviken and Rooke (2013), who tries to conceptualize waste in construction processes. They explain that the seven wastes stem from a manufacturing context. Hence, it does not cover the design aspect. They explore the potential of creating a list of waste drivers in construction. Koskela, Bølviken and Rooke (2013, p.3) explain the benefit and purpose of such a list: "Such a list would be instrumental in creating awareness on the major waste types occurring in construction, as well as mobilizing action towards stemming, reducing and eliminating them.". DE is part of the construction process, and as a consequence, the statement by Koskela, Bølviken and Rooke (2013) should be relevant in this context as well. The purpose of waste drivers in DE could be to create awareness about the mechanisms that potentially contribute to waste. Managers and employees could benefit from such a list. Knowing what contributes to waste could enable people to eliminate it. Terms like rework and overproduction are too ambiguous in a DE setting to provide a sufficient image of waste in this context. The waste drivers are an attempt to provide a better image of waste in DE.

A table was created in order to evaluate if the waste drivers should be sorted into the conventional seven waste categories. The purpose was to categorize the drives in accordance to the seven manufacturing wastes. However, the process of categorizing the drivers was time consuming and challenging. The relationships are complex, context specific and, thus, very much open to interpretation. It became apparent that many of the waste drivers could be tied to multiple of the conventional categories. Thus, sorting waste in this manner was perceived to not serve any significant purpose. This was much due to the aforementioned issues. It should be noted that the waste drivers could be related to each other. Still, they should be more distinguishable in the context of DE, compared to the conventional seven categories. Furthermore, the waste drivers are more specific, which makes it easier to identify measures that can mitigate or eliminate waste.

Based on Bauch (2004) and Kalsaas (2013b) waste drivers is defined as a mechanism that has capacity to create waste and to be hindrances of workflow, under certain conditions. The definition of waste drivers used in this paper is similar to Bauch's (2004) definition of sub-drivers. Furthermore, the seven manufacturing

[4] Limited IT-resources, Lack of System Discipline and Re-invention

waste categories are not defined as drivers like Bauch (2004) does. This is since the authors of this paper do not perceive the manufacturing wastes as drivers in the context of DE. For example, rework is a value-adding activity, and not a mechanism that generate waste. Rather, rework is a result of such mechanisms.

The three aforementioned authors (Bauch, 2004; Oehmen and Rebentisch, 2010; Oppenheim, 2011) are perceived to use different resolutions when describing the waste drivers. Thus, it was tried to determine a fitting resolution, in order to adapt the previous concepts. The main objective was to make the waste drivers identifiable and manageable, in the context of eliminating or reducing waste in organizations. In order to accomplish this, a fitting resolution had to be chosen.

It was tried to find somewhat a golden path between high and low resolutions. While many of the drivers are connected, one of the main criteria when creating the list was to avoid overlapping, to the extent possible. However, this was not completely achieved, since the waste drivers are highly context dependent. Also, no drivers should be effects; the drivers should be the mechanisms that might lead to waste. This interface is a bit ambiguous, as several drivers can be effects of others, depending on the context. Even though many of the drivers can be effects, all of them are mechanisms that lead to waste. In relation to DE, the authors argue this is an improvement compared to using the manufacturing waste categories. An expansion of the list might include sub-drivers of each driver, and categorizing the drivers in a sensible manner. An overview of the suggested waste drivers is provided in table 1.

*Table **1**: Overview of Suggested Waste Drivers*

Waste Driver	Description
Ineffective Verifications	Include ineffective testing, prototyping, approvals, and transactions Example: tests that are more costly than the risk they are trying to mitigate, or information is dispatched without sufficient testing
Poor Coordination	Poor planning, scheduling, prioritizations, unsynchronized processes Example: Tasks completed in a sequential order, when they should be performed concurrently
Task Switching	Interruptions that forces a person to reorient themselves Example: unnecessary hand-offs
Capacity Constraints and Overburdening	Interruptions of workflow as due to unavailable resources or exceeding the capacity of an entity Example: tasks are hampered due to unavailable staff, tools, and equipment
Lack of Required Competence	Not possessing the skill or knowledge required to conduct the task in question Example: ineffective use of IT tools, such as BIM, due to limited skill
Unclear, Goals, Objectives, and Visions	Misaligned goals, objectives, and visions in relation to, e.g., customer requirements Example: employees pulling in different directions, reducing the efficiency
Information Overload	Large batch sizes, and distributing and storing information that is not needed Example: excessive information can make the relevant information harder to access
Unclear Authority and Responsibility	Unclear expectations in relation to performance and organizational roles Example: overlapping competencies and responsibilities
Insufficient Means of Communication	Means of Communication that are insufficient to handle the reciprocal interdependencies of the DE processes, or means that demand excessive time and effort, without adding additional value Example: not utilizing the Big Room (BIM rooms) when it would be beneficial
Interpretability of Information	Information represented in an ambiguous manner, resulting in misinterpretations Example: Lack of standardization of documentation
Accessibility of Information	Information cannot be accessed when needed Example: missing input, leading to, e.g. making-do
Underutilization of Resources	Allocating resources in a less effective way than possible Example: inappropriate use of competence

Over-engineering	Adding features that do not add value for the customer Example: increased development and production costs as a result of exceeding requirements
Unnecessary Data Conversions	Avoidable data conversions occurring due to, e.g., use of inappropriate tools or a lack of standardization Example: re-formatting and re-entering data
Lack of Knowledge Sharing	Not exchanging information, expertise, or skills among entities Example: New projects starting below the potential starting point by not reusing previous solutions
Processing Defective Information	Processing information that is based on a valid need for information, but the need is not sufficiently fulfilled Example: defective information processed is not discovered and affects other processes
Changing Targets	While change is considered to be part of the iterative DE process, internal or external changes of requirements, that is not sufficiently compensated, can create waste Example: changes can lead to rework, especially when the changes occur late in the process
Cooperation Barriers	Includes transactional barriers, opportunistic behavior, risk aversion, et cetera Example: lack of ownership negatively affecting motivation, which could be mitigated by the use of Integrated Project Delivery (IPD)

CONCLUSION

Previous attempts at conceptualizing waste have typically involved transposing waste in DE into the seven manufacturing categories. However, it was concluded that this approach was not feasible, since it, to some extent, fails to account for the waste in DE. In addition, this approach does not provide enough information for employees and managers to actually do something about waste. This is because the approach does not explain why waste is happening. In contrast, the waste drivers presented are, in essence, explanations to why waste happen. Thus, it is possible to implement measures to mitigate or eliminate waste by using the waste drivers. Waste drivers are defined as mechanisms that have capacity to create waste and to be hindrances of workflow, under certain conditions. The waste can occur both in the DE processes, and as a consequence, where the waste is, e.g. reduced constructability and usability, or expenditure of resources such as, time and money.

The waste drivers were evaluated on usability, completeness, practical relevance, and generality. Generality and practical relevance might be considered high. However, the usability is hard to determine, since the waste drivers are not yet tested. The completeness is also debatable, since there are several theories and literature that might be considered relevant when conceptualizing waste in DE. Obviously, it was impossible to investigate all the possible aspects, but the waste drivers might provide an improvement compared to previous attempts at conceptualization. Based on the findings, the waste drivers presented in this paper is argued to be a theoretical contribution to the understanding of DE processes. Further analysis of the usability, and a purposeful categorization of the waste drivers, is suggested for future research.

REFERENCES

Ballard, G. 1999. *Can Pull Techniques be Used in Design Management?*: CIB Publication, pp. 149-160.

Bauch, C. 2004. *Lean Product Development: Making waste transparent.* Diploma. Technische Universität München, Munich, Germany.

Bølviken, T., Gullbrekken, B., & Nyseth, K. 2010. *Collaborative Design Management*. In: *Proc. 18th Ann. Conf. of the Int'l. Group for Lean Construction*. Haifa, Israel, July 14-16

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. 2005. Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, 94(1), pp.103-120.

Illeris, K. ed. 2007, *Læringsteoriens elementer - hvordan hænger det hele sammen?* Frederiksberg: Roskilde Universitetsforlag.

Kalsaas, B. T. 2011. The Last Planner System Style of Planning: Its Basis in Learning Theory. *Journal of Engineering, Project and Production Management*, 2(2), pp.88-100.

Kalsaas, B. T. 2013a. *Integration of Collaborative LPS-Inspired and Rationalistic Planning Processes in Mechanical Engineering of Offshore Drilling Contructions.* In: *Proc. 21st Ann. Conf. of the Int'l. Group for Lean Construction*. Fortaleza, Brazil, Aug. 31-2.

Kalsaas, B. T. 2013b. *Measuring Waste and Workflow in Construction.* In: *Proc. 21st Ann. Conf. of the Int'l. Group for Lean Construction*. Fortaleza, Brazil, Aug. 31-2.

Kalsaas, B. T. and Sacks, R. 2011. *Conceptualization of Interdependency and Coordination between Construction Tasks*. In: *Proc. 19th Ann. Conf. of the Int'l. Group for Lean Construction*. Lima, Peru, July 13-15.

Koskela, L. 1992. *Application of the New Production Philosophy to Construction.* Stanford, CA: Stanford University, Center for Integrated Facility Engineering (CIFE).

Koskela, L. 2004. *Making-Do — the Eighth Category of Waste.* In: *Proc. 12th Ann. Conf. of the Int'l. Group for Lean Construction*. Helsingør, Denmark, Aug. 3-5.

Koskela, L., Bølviken, T. and Rooke, J. 2013. *Which Are the Wastes of Construction?* In: *Proc. 21st Ann. Conf. of the Int'l. Group for Lean Construction*. Fortaleza, Brazil, Aug. 31-2.

Lukka, K. 2003. The Constructive Research Approach. *Case Study Research in Logistics. Publications of the Turku School of Economics and Business Administration*, *Series B, 1*, pp.83-101.

Macomber, H. and Howell, G. 2004. *The Two Great Wastes in Organizations.* In: *Proc. 12th Ann. Conf. of the Int'l. Group for Lean Construction*. Helsingør, Denmark, Aug. 3-5.

Male, S., Bower, D. and Aritua, B. 2007. Design Managment: Changing the Roles of the Professions *Management, Procurement and Law, 160 (MP2)*. The University of Leeds, England: Institution of Civil Engineers, pp. 78-82.

Morgan, J. M. and Liker, J. K. 2006. *The Toyota Product Development System - Integrating People, Process, and Technology*. New York: Productivity Press.

Oehmen, J. and Rebentisch, E. 2010. Waste in Lean Product Development *LAI Paper Series "Lean Product Development for Practitioners"* Massachusetts Institute of Technology.

Ohno, T. 1988. *Toyota Production System.* New York: Productivity Press.

Oppenheim, B. W. 2011. *Lean for System Engineering with Lean Enablers for System Engineering*. (Vol. 82). New Jersey, USA: John Wiley & Sons, Inc.

Pahl, G., 1997. How and Why Collaboration with Cognitive Psychologists Began. In *Designers: The Key to Successful Product Development*. Darmstadt, Germany: Darmstadt Symposium.

Reinertsen, D. G. 1997. *Managing the Design Factory: The Product Developer's Toolkit*. New York: Free Press.

Simon, H. A. 1996. *The Sciences of the Artificial.* 3rd ed. Cambridge: MIT Press.

Slack, R. A. 1998. *The Application of Lean Principles to the Military Aerospace Product Development Process.* MSc. Massachuttes Institute of Technology.

Sugimori, Y., Kusunoki, K., Cho, F. and Uchikawa, S. 1977. Toyota Production System and Kanban System Materialization of Just-in-time and Respect-for-human System. *International Journal of Production Research*, *15*(6), pp.553-564.

Takala, T. 1993. A Neuropsychologically Based Approach to Creativity. In J. S. Gero & M. L. Maher (Eds.), *Modeling Creativity and Knowledge-Based Creative Design*. New Jersey: Lawrence Erlbaum Associates, Publishers, pp. 91-108.

Thompson, J. D. 1967. *Organizations in Action. Social Science Bases of Administrative Theory* 2003 Ed. New York: McGraw-Hill.

Ulrich, K. T. and Eppinger, S. D. 1995. *Product Design and Development*. Singapore: McGraw-Hill.

Verma, A. K., Das, L. K. and Erandre, A. S. 2011. *Creative Lean Design Process*. Paper presented at the Research into Design — Supporting Sustainable Product Development, Bangalore, India.

Verma, A. K. and Dhayagude, S. S. 2009. *Implementing Lean in the Design Processes — Validation Using Physical Simulation*. Paper presented at the Research into Design: Supporting Multiple Facets of Product Development, Bangalore, India.

Vosgien, T., Jankovic, M., Eynard, B., Van, T. N. and Bocquet, J.-C. 2011. *Lean Approach to Integrate Collaborative Product Development Processes and Digital Engineering Systems*. In: *Proc. 12th Ann. Conf. of the Int'l. Group for Lean Construction.* Helsingør, Denmark, Aug. 3-5.

Womack, J. and Jones, D., 2003. Lean thinking: Banish waste and create wealth in your corporation. New York: Free Press.

Yoshikawa, H., 1981. General Design Theory and a CAD System. In T. Sata & E. Warman (Eds.), *Man-Machine Communication in CAD/CAM*. Amsterdam, Netherlands.