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PRODUCT LIFE CYCLE DISPOSITION MODEL

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1. Introduction

Companies in the manufacturing industry acknowledge that certain steps are required to realise an intention towards a ready, physical, desired product. Furthermore, companies understand that information is required to achieve these steps. What seems to be challenging is to recognise the inter-relationship and interaction between product characteristics and its product life cycle characteristics. Some of the challenges come from the fact that these relationships are often logically indirect and durations in time are long. Also the involvement of different functional areas in PD organisations result in difficulties to depict the relationship flows through out a product life cycle. These inter-relationships between product characteristics and product life cycle characteristics are called dispositions. The term disposition is often linked to Olesen's definition of dispositional mechanisms [Olesen 1992]. In this paper this definition is applied with a difference in the method of depicting dispositions.

This paper aims to provide an explanatory model Product Life Cycle Disposition Model (PLDM), for understanding these inter-relationships and interactions between product characteristics and product life cycle characteristics. It is a conceptual framework to explain integrated product and production development system in the manufacturing industry. The hypothesis is that by combining artefact knowledge and its relationships to its bigger context, it is able to form more thorough understanding of how products and especially product development behaves in different situations. PLDM is a practical framework to support decision making during concept development phase in design process. This kind of knowledge is beneficial for the academic and for the industry. Based on the experiences of the model, in the future, a methodology is structured to support systematically product development projects.

2. Research Approach

The primary objective of this paper is to introduce an explanatory model for understanding dispositions through out a product life cycle. This objective is transformed in to a following research question: what kind of elements a disposition model consists of?

This research applies Design Research Methodology (DRM) and is specifically part of the Descriptive Study I [Blessing and Chakrabarti 2009]. The preliminary concept for PLDM is gathered from a literature review, which is then tested and further developed in a pilot study with a Finnish manufacturing company.

Scope of the research is on the development processes of existing products, also known as brownfield products [Lehtonen et al. 2011]. These products have a possibility for design knowledge reuse unlike new product development, which starts from scratch. This research also investigates product life cycle, however the scope in this paper is limited to beginning of product life cycle including product development and production, and middle of life cycle including distribution, use and maintenance of a product.

3. Literature review

3.1 Theoretical Background

This section covers the theory basis of PLDM. Systems thinking is a natural starting point within this research context as it fits to its purpose to rationalise systems in which humans are involved and specifically PD processes. After this Theory of Dispositions is introduced, as understanding dispositional mechanisms of products are argued to have a positive impact on PD [Olesen 1992]. Product structuring [Andreasen et al. 1996] is an important way to understand the behaviour and functions of the product thus contributing to the mindset of dispositions. Theory of Properties and finally Property-Driven Development provide a way to explain decisions behind a PD process.

3.1.1 Systems Thinking

In this paper, Systems Thinking is the consideration of the whole system and its context within a human system, and follows Checkland's interpretation of Systems Thinking [Checkland 1985], [Checkland and Haynes 1994]. According to Checkland and Haynes [1994], Systems Thinking evolved from organismic biologists who argue that the ideas that biologists had developed could also be applied in other systems. From this General Systems Theory (GST) was introduced to which Ludwig von Bertalanffy has been an influential contributor. According to Checkland and Haynes the basic aim of GST is to achieve cross-disciplinary application by employing a common language to express and share problems of many disciplines.

The more recent Systems Thinking movement started from the study of systems ideas and, as such, evolved from GST to problem solving in real world situations before moving on to research of "Hard" and "Soft" systems [Checkland and Haynes 1994]. Hard Systems Thinking, including for example Systems Engineering (SE), is based on goal seeking and assumes that the problematic system can be named unambiguously and its objectives can be defined precisely, allowing it to be engineered to achieve objectives. This also implies that any human activity could be regarded as a goal-seeking system [Checkland and Haynes 1994]. According to Checkland and Haynes [1994], SE has been an effective approach for dealing with technological and social components of problems. However, they continue, that as a methodology where objectives of system can be defined with precision, social aspects in SE become resources. This does not take into account the complex nature of real human activity systems which is a combination of different worldviews from different interpreters. Soft Systems Methodology (SSM) was developed to this dilemma [Checkland and Haynes 1994].

SSM does not assume that the complexity of human activities can be captured in systemic models. SSM aims toward a systematic learning cycle within the organisation it is applied rather than to direct optimisation or satisfaction of the system considered. In addition, SSM concentrates to form a common understanding and 'accommodations' between the human participants of the system. SSM follows a model, which starts from finding out about a problem by modelling different worldviews of human participants and carrying on to organized Systems Thinking process. A debate about the situation is built by comparing captured models with insights of the real world situation. The aim of the debate is to find possible improvements that follow two principles; systematically wanted, and culturally reasonable in the situation [Checkland 1985].

3.1.2 Theory of Dispositions

Olesen [1992] introduces Theory of Dispositions, which is originally designed to help concurrent development, especially between product development and production development. In his research, Olesen ran into a problem whereby the product development theories, methodologies or tools of that time did not take other functional areas into consideration than those specifically being focussed on. Other functional areas were often only taken into account during the formulation of tasks and targets.

Dispositions are decisions taken within one functional area which affects the type, content, efficiency or progress of activities within other functional areas [Olesen 1992]. Dispositions are not just seen in terms of two activities, but in sequence phenomena. Thereby, a generic model of dispositions is valid for all the activities in such a chain. A complete picture of the design dispositions related to product and production are obtained by combining all the design activities with all the activities involved in the development and operation of the production system. Furthermore, dispositional mechanism, which is a more detailed application of how to use dispositional thinking in practice consists of:

- Two development activities from different functional areas, where one of the following are to be determined: concept, structure or details
- Data connection and dispositional connection between activities
- Objectives for both activities
- Rules for how the decisions can achieve the objectives
- Possible choices of design characteristics
- Calculation of the dispositional effects of particular design choices

[Olesen 1992].

3.1.3 Product Structuring

Andreasen et al. explain that product structure is the description of the interrelationships between product elements in a system model to create structure, based on a chosen point of view [Andreasen et al. 1996]. Here, a system model consists of elements and their relationships. Andreasen et al. describes four different point of views from which to realise product structuring, the activity to realise product structures, including: generic, functional, life-cycle-oriented and product assortment [Andreasen et al. 1996]. Due to the unique nature of the case study represented in this study, a relevant structuring point of view is the division of product structure into standard, partly configurable, configurable and one-of-a-kind components (see Figure 1). This results in specific behaviours to product life cycle [Juuti and Lehtonen 2006].

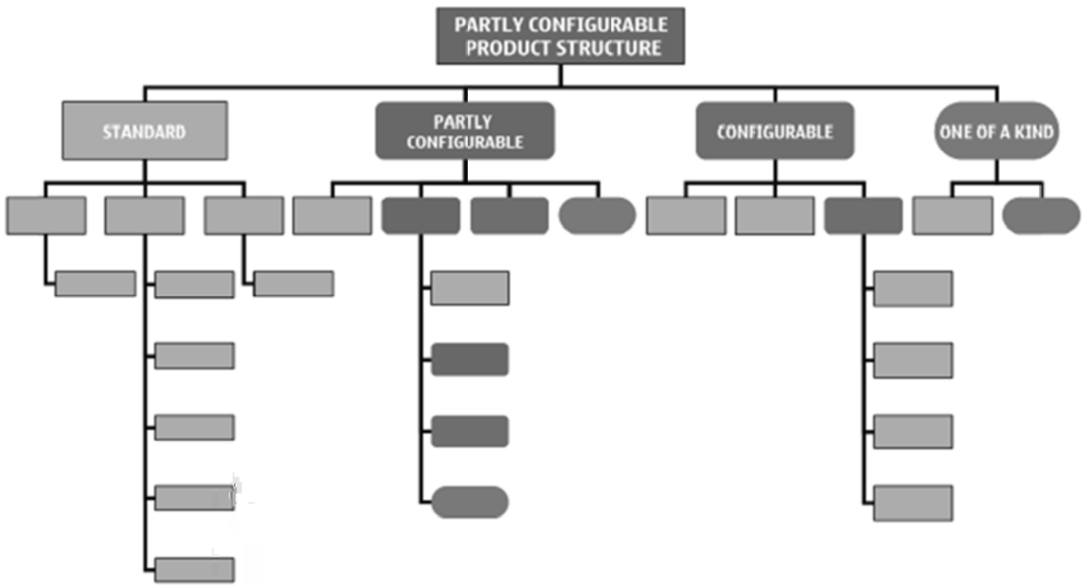

Figure 1. Division of product structures, the case of partly configurable product structure [Juuti and Lehtonen 2006]

3.1.4 Theory of Properties

Originally as an important part of Hubka and Eder's Theory of Technical Systems, Theory of Properties is based on a division between product characteristics and properties, two different concepts for describing products and their behaviour [Hubka and Eder 1996], [Weber 2012]. Similar product distinctions between characteristics and properties have been used in engineering design theories and methodologies for a long time, but with different terminology. In this paper, Weber's terminology for Theory of Properties is used. Hubka and Eder's definition of internal properties are equivalent to

Weber’s product characteristics, whilst external properties are equivalent to Weber’s product properties. Theory of Properties explain that both characteristics and properties are established by designing.
Characteristics are made up of a structure, shape, dimensions, materials and surfaces of a product. Engineers and designers involved in product development can influence or determine characteristics of a product. Conversely, properties define the product’s behaviour, such as weight, function, safety and reliability. Properties also describe a product’s nature e.g. assemblability, testability, costs and environmental friendliness. However, properties cannot be directly influenced by developers or designers. The influence only occurs indirectly through product characteristics [Weber 2012].

3.1.5 Property-Driven Development (PDD)

PDD, an explanatory model for understanding product development process phenomena [Weber 2012], sees product design and development as a process including several cycles of the following phases: 1. Synthesis process from Properties (Required Properties) to Characteristics, 2. Analysis process from Characteristics to Properties, 3. Determining individual Deviations comparing Properties with Required Properties, 4. Overall Evaluation of the results of the Deviations and choosing Properties to be addressed and methods for another Synthesis-Analysis-Evaluation cycle.
The first step, Synthesis, starts from Required Properties and moves toward the estimated Characteristics of the future solution. In practice, this can mean starting to work from existing, previous designs or, using tools and methods to achieve properties for a new product. As an outcome, updated characteristics are created for a product. The next step, analysis, sees how the characteristics contribute to properties. The third step is determining individual deviations. This means that results of the analysis (Properties) are compared with the Required Properties. As an outcome, Deviations are identified, describing the shortcomings of the current design. Finally, an overall evaluation is conducted and the main problems are extracted, as well as determinations on how to proceed further. In practice, this means choosing the Properties to be addressed in the next Synthesis-Analysis-Evaluation cycle. For the phases synthesis and analysis External Conditions are considered constraints. When proceeding from one cycle to the next, both the characteristics and the properties side of the product are updated. The analysis step more accurately predicts the behaviour of a product as the cycle continues [Weber 2012].

3.2 State of the art

This section presents a product life cycle modelling approach in general, which provides a way to support the understanding of a product and its behaviours through out its life cycle. Flow modelling again is another approach to model PD processes. However, in this research, Flow modelling is not seen just as a modelling practice but an inspirational way of thinking product development using the desired product properties as a starting point in rationalising a PD process.

3.2.1 Product life cycle modelling

Product life cycle modelling aims to support decision making in the early phases of product design and development. It is a functional approach for collaborative and interdisciplinary design approaches because its ability to enhance the understanding of interrelationships between a product and its whole life cycle.
Generally, product life cycle is a series of phases through which a product passes during its life span, however there exist many different approaches for distinguishing these different stages depending on the product type. In modelling purposes also customer requirements and product life cycle requirements are integrated into the product life cycle system. Customer requirements are seen as a feeder input to the system**.** The life cycle requirements are also seen as an input to the system, but are objects for change due to changes within the life cycle process. Although the divisions to life cycle phases include the whole life cycle of the product and the aim in life cycle modelling is to gain transparent look holistically, in most cases the life cycle orientation means focusing only on several life cycle requirements through design for X (DFX) [Kiritsis et al. 2003].

Quality Function Deployment (QFD) [Clausing 1994] has been widely accepted method to support effective product conceptual design and consideration of product life cycle requirements [Hepperle et al. 2011], [Lehtonen et al. 2012]. QFD is a matrix-based method traditionally used in analysing the relationships between customer requirements and product characteristics during the product's conceptual design. House of Quality (HOQ) and its follower extended HOQ, are modifications of the QFD model using a graphically house-like correlation technique to depict and analyse relationships between product characteristics, customer requirements and product life cycle requirements. These kind of graphical life cycle modelling approaches have been used successfully several times in the previous research done in the research group [Lehtonen et al. 2012].

3.2.2 Flow modelling in integrated product and production development

Fujimoto [2007] states that product development is the creation of design information whereas production is the transfer of this information to products. He proposes that product development and manufacturing should be considered as a continuous product creation process. Furthermore, this creation process should be modelled as a flow of knowledge. Fujimoto uses an automobile as a case study, where the starting point for creating a new automobile is intention. This includes the understanding of what properties a product should possess. Later on these properties guide the creation of new knowledge and eventually leading, if successful, to desired properties of a product [Fujimoto 2007].

Koskela represents similar kind of flow thinking in his doctoral thesis whereby product development and production is seen as a unified flow. According to Koskela, development as a flow process includes four stages at which information is divided into four different sections: transformation, waiting, moving and inspection. Transformation is seen as the only true designing when others are considered as waste which should be avoided [Koskela 2000].

Lehtonen et al. [2012] use this flow thinking in several case studies to reveal design rationale in decision making. In their Flow modelling, the transformation presented by Koskela is divided into four specific flows (Table 1). These flows are:

1. Knowledge/Information flow: Transformation and move of design information
2. Work flow: Working activities for value generation
3. Material flow: Raw materials and outsourced product parts
4. Control flow: Controlling events

Knowledge flow represents activities in transforming and moving design information. Documentations such as 3D models are an outcome from this flow. Work flow shows activities that increase product's value. Examples of this are manufacturing and assembly activities, which add value to the product. Material flow includes the flow of raw materials and outsourced product parts. Control flow represents activities for managing the timing and inspection with control events. It also answers the question of who is managing and controlling the element [Lehtonen et al. 2012].

3.3 Summary of the literature review

As a summary from literature review, a preliminary model for PLDM is created. This preliminary model consists of the following elements: artefact characteristics, artefact properties, Property-Driven Development elements, artefact life cycle characteristics and dispositions between artefact characteristics and artefact life cycle characteristics. Artefact life cycle characteristics at this context are understood through the Flow model using the 4 flows of information, work, material and control. Artefact life cycle characteristics are elements of the life cycle that can be influenced by the participants of a product life cycle for example designers.

4. Case Study Miksi esitetään case study jo nyt.

The case study was carried out with a Finnish manufacturing company. The case company is medium sized enterprise, operating in the Finnish manufacturing industry. The company's production approach is make-to-order products offering deliveries for international customers across continents. The manufactured products are big in size and require a lot of investment. As a project-oriented company, the products are partly configurable and include standard, configurable, partly configurable, and one-

of-a-kind components. The products have a typical lifespan of 30-40 years so the company also offers services such as maintenance for its products and for similar kinds of competitor's products.
The study aimed towards improving company's PD process and focus was also to consider the elements of the disposition model. The study was conducted by analysing company's current partly configurable product families. Data collection involved empirical observation within couple of workshops and company visits. Results were mainly an outcome from Company Strategic Landscape (CSL) –workshop [Juuti et al. 2007] and interviews with the company personnel. Also, informal discussions had a role in data collection. Information to depict product structure and product life cycle was primarily gathered using the CSL-model, to which all the information caught in the workshops was saved. Also, information was recorded in the form of notes from interviews and discussions. CSL-model collects important elements relating to company's business, which include product structuring, value chain structuring, operational structuring, strategy structuring and organisational structuring viewpoints.

4.1 Mapping product structure knowledge

One of the company's most common products was chosen for the case study. Mapping the product's structure involved listing the engineering bill of materials (EBOM), including the list of elements, or components it consists of and the different variables. To this an applied version of K- matrix presented by Bongulielmi [2003] was used to capture relationships between EBOM and customer requirements. In Figure 2, the EBOM elements in rows, list more than 150 components and variables. In the columns, customer requirements consist of different performance requirements for products and as such set direct life cycle requirements for different phases of the product. Relationships are indicated with colors (grey in the figure), in which green and yellow colors indicate a relationship and red indicate exlusive elements. In addition, every component and variable was categorised into groups based on whether it was a standard component, a configurable component, sub-contracted, or an order-specific component.
Altogether, this phase in the case study improved the understanding of product characteristics and relationships between product characteristics and product properties among the project members. This was seen as an important step for the project members to improve their product structuring capabilities. This was seen to improve the identification of dispositional mechanisms.

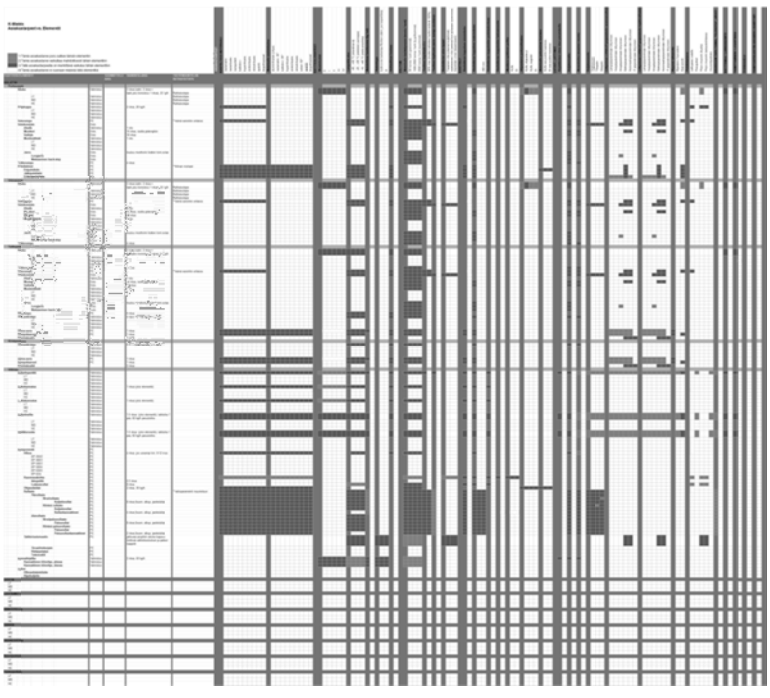

Figure 2. Modified K- matrix of engineering bill of materials and customer requirements

4.2 Mapping product life cycle

The next step was mapping the product's life cycle. In this the examination was limited to the product's order-delivery process. In here, Flow modelling was applied to capture information, work, material and control flows within different life cycle phases. Figure 3 shows one of the outcomes of the modelled order-delivery process.

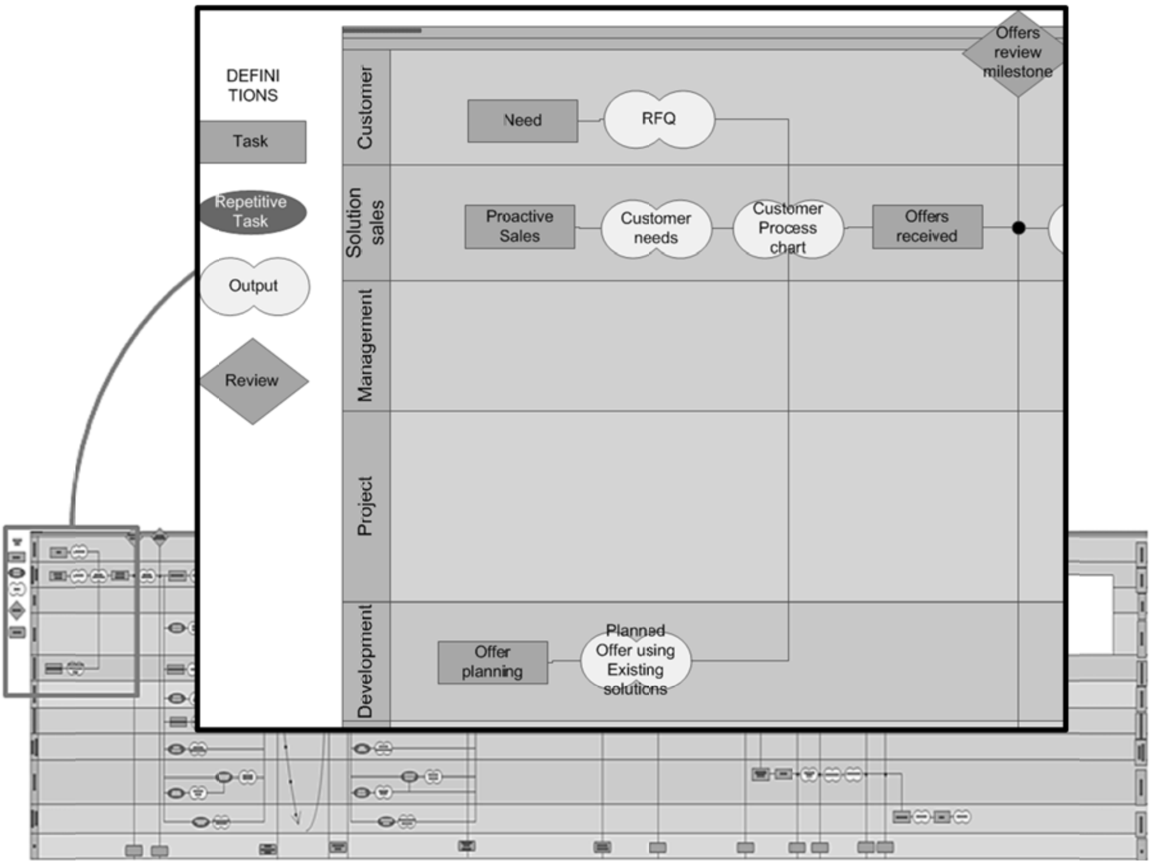

Figure 3. Product's order-delivery process

In the figure, the rows indicate different functional organisations involved in the product's life cycle. The order-delivery process includes work flow (tasks) and information flow (Output), represented with blue (rectangle and ellipse) and white symbols (cloud) respectively. The orange symbols (parallelogram) indicate the reviewing of tasks, which are the control flow elements. In addition, material flow is aimed to be depicted to the model, but was left out from this study.

The intention was to depict a desired PD project process which are compared with identified actual problems. Project manager, mechanical designers and a sales person took part to the mapping process. During the mapping process, the aim was to find a model that represents the common understanding of the participants of the PD project.

4.3 Identifying dispositions

The next phase was to identify the dispositions as they really occur in the company. To this several meetings and discussions were held to collect relevant data and form a common understanding for the participants. During this phase, the focus was in understanding the dispositions between the product characteristics and product life cycle characteristics. At this point, it was realised that the previously depicted order-delivery process did not represent actual situations, but the ideal situation from project management point of view. This was identified to be in conflict with dispositions identifed within the product life cycle. This was not questioned by the designers during the mapping process. During the discussions it was identified, that the

company's top managers and project managers were expecting product life cycle characteristics aligned with fully configurable products, which should consist of standard and configurable components. This was based on their current understanding of the product. Instead, from the information provided by the designers products were actually partly configurable, which included significantly unique components. To give an example of the identified dispositional mechanisms during these discussions, one of the major reasons for making unique components instead of reused components happened during the sales phase. Sales people, commonly project managers, possess some knowledge of the product's structure but have no experience in PD. They have the capacity to choose some of the specifications at the point of sale including standard parts, configurable parts, sizes and loads, in other words reusing the existing product structure knowledge. However, they lack the skills for more detailed, order-specific design at the point of sale.
At same time a catalogue of standard parts and of some configurable parts exists, but there is no documented product structure knowledge available, which would enable a complete design reuse. These circumstances result that during the sales phase, customers are being offered whatever is necessary to complete a successful sale. Thus, causing requirements that force in desiging new unique components instead of configurable components. Furthermore, these dispositional mechanisms continue through the information flow as the validity of the information documented at the end of the sales process (a successful offer) depends highly on the salesperson's knowledge and experience. This results again in growing numbers of order-specific components.
As a result of identifying dispositional mechanisms, it was realised that actions to improve the existing situation, changes were required both in existing product characteristics and in product life cycle characteristics. Thus, the final concept for PLDM was structured based on the knowledge gained from the case study.

5. Results

Based on the literature review on theoretical background, state of the art and the pilot study a concept for PLDM is structured. This is shown in figure 4. In the PLDM artefact is used as a general and an abstract term for an object made by humans or an object of doing. It is chosen to clarify and avoid confusions in what refers to the general description of the PLDM and what refers to a product in the case study.
The PLDM is an artefact-oriented approach, in which artefact is seen as a starting point for the continuous development process. The model uses PDD process [Weber 2012] as a central base for the process, including its main elements. The PLDM also includes artefact life cycle context and artefact life cycle characteristics as an essential part of the process. This is a significant extension to the PDD process, as the artefact life cycle is seen as an important force that continuously calls for reflection and updating the desired artefact properties and artefact life cycle characteristics.

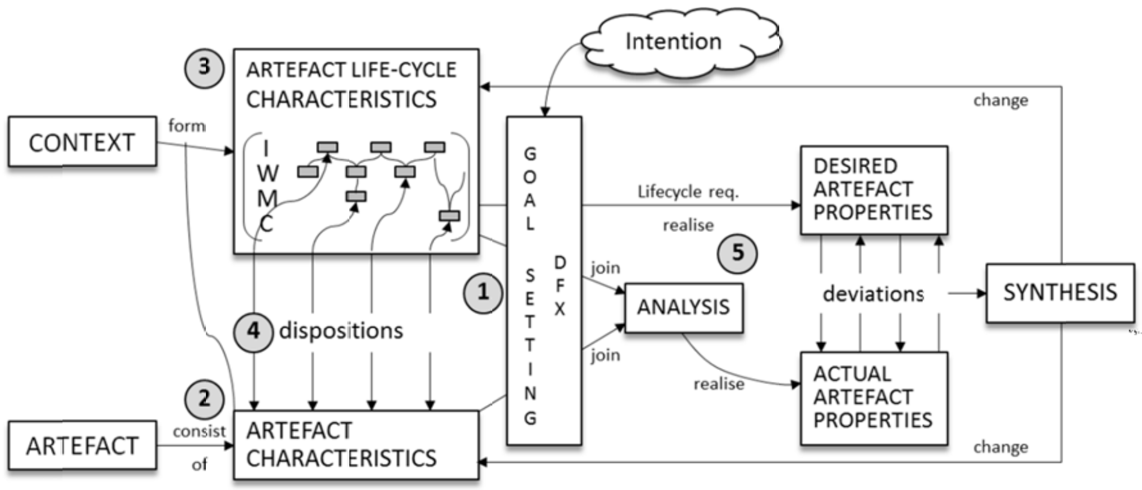

Figure 4. Elements and process of PLDM

In PLDM (Figure 4), the Property-Driven Development (PDD) process, consists of artefact properties defined by and artefact life cycle properties (in figure actual artefact properties). An analysis-synthesis process aims to affect the actual properties reflecting goals to desired artefact properties (5), by acting on artefact characteristics (2) and artefact life-cycle characteristics (3). The context is the environment in which the artefact functions and is examined through the Flow Model. Dispositions (4) are inter-relationships and interaction between artefact characteristics and the artefact life cycle characteristics and form a central point in the learning cycle. Artefact life cycle requirements effect the goal setting (1), or the catalyst of the model.

Goal setting is the first step, during which the targets of the learning cycle are determined. This includes choosing the DFX approach based on the requirements. Later the goal setting may be updated or changed as improved understanding leads to changes in the artefact characteristics or artefact life cycle characteristics. Structuring artefact characteristics and artefact life cycle characteristics is the next step in the learning process. Learning and acknowledging dispositions results in better understanding of the process. This may result in redefining the original goals and targets, and defining required actions. The final step is the analysis-synthesis process, during which the actions for change are evaluated. The actions can be directed to improving either the artefact characteristics or the artefact life cycle characteristics in order to achieve the defined, desired properties.

In the PLDM, the context refers to the environment within which an artefact interacts. In this context, artefact characteristics form the artefact life cycle, and the life cycle is seen through the information, work, material and control flows presented in the Flow Model [Lehtonen et al. 2012]. Artefact life cycle characteristics are seen as the actual realisation of the life cycle process, which consists of the elements of the four flows.

6. Discussion

The case study emphasized the importance of the industry's need to be aware and understand also alternative modes of operation and the possibilities for improved change. Manufacturing businesses might not realise the need for this knowledge, however for the case company, the improvement for their business operations was identified.

PLDM contributes to the design sciences by providing an explanatory model to understand dispositional mechanisms through out an artefact life cycle. In this study, the approach to depict dispositions differs from the approach Olesen represents [Olesen 1992]. Dispositions represent an inherent relationship and interaction between artefact characteristics and artefact life cycle characteristics. From a modelling perspective, this approach gives new possibilities to depict all of the elements of the PLDM into one model. This act as a promising future direction in the research. Being able to visually model dispositions, could facilitate the understanding of participants in a PD project.

The paper provides the initial conceptual framework, which is limited to the manufacturing industry and brownfield products. For the purposes of this research, one of the areas that do not get enough attention is the research done in design decision sequence, as the study does not reveal how the design decision path can be easily exemplified. However, as the pilot study revealed it is seen as one of the core outcomes of the PLDM model, therefore it should to be explored better in future research. The other area that requires more specific definition is the artefact life cycle, which combines a broad area of elements under one topic. It is reasonable in the future to define this area in more detail. Also the level of detail in depicting artefact life cycle characteristics should be considered as the pilot study revealed that easily a model can be left in too abstract level, and does not enhance the common understanding of PD participants as expected. The mapping process of artefact life cycle characteristics should be started from the resulting artefact characteristics of a PD process and depiction should be started from interviewing designers.

7. Conclusions

This paper introduces PLDM, which is an explanatory model to improve the understanding of dispositional mechanisms within PD to support the decision making process. The initial version of the model is constructed based on the literature review and further developed in a pilot study with a company from the Finnish manufacturing industry. As a result, a final concept for PLDM is structured illustrated in figure 4.

The case study indicates that the PLDM resembles situations as they occur in business within the area of study. The PLDM has the potential to describe the design decision secuence of a product, as long as the interpretation is supported with adequate description methods such as diagrams and graphs and a more specific methodology is defined to support the learning cycle. The PLDM is seen as a starting point to which a supportive tool could be developed, where integrated product and production development can be conducted using a chosen DFX approach. The improved understanding of the system can lead to improvements in both artefact characteristics and artefact life cycle characteristics.

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