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VALUE OF VIRTUAL PROTOTYPING – A STRATEGIC RESOURCE BASED VIEW

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ABSTRACT

This conceptual paper proposes how business value of virtual prototyping (VP) could be modeled in the context of manufacturing industry and engineering design. The strategic resource based approach mapped data from industrial studies to public value theories and models in order to synthesize and model how technological features and benefits of VP could contribute to value creation and capture during a product-service value chain. In the model virtual prototyping is positioned as a strategic asset within value network and value shop configurations that have their own logic and processes related to value chains. The resource based strategic value of VP model emphasizes role of virtual prototyping as a media for better organizational knowledge creation and learning, which is today one of the essential competences of enterprises. In future the proposed model will be used as a reference in empirical studies. It will be iteratively improved and concretized in industrial strategy development projects. Aim is that VP business value modeling facilitates better adoption of VP, and reduces incredulous attitudes in manufacturing enterprises.

Keywords: concurrent design, communication, virtual reality, value, business

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1 INTRODUCTION

This research is about investigating a concept called virtual prototyping (VP) in an industrial context. The wider mission of our research is to support implementation of VP, and improving utilization of it in industry as an enabler of improved product processes and business. Today companies are lacking understanding and knowledge about real value and significance of VP. Our aim is to gather knowledge about business and organizational value of VP, and thereby remove bottlenecks of VP investment decisions. The purpose of the paper is to propose a theory-based framework for assessing value of VP from business and organizational viewpoint.

Prior research (Leino and Riitahuhta, 2012) revealed benefits and opportunities of VP found in literature and in industrial case studies. Furthermore, Aromaa et al. (2012) described and categorized benefits as well as bottlenecks of VP in industrial case studies. They also modelled causal links between VP characters and main benefit categories, which are VP technology related benefits (like more natural user interface), benefits for designing (for instance better collaboration), and business benefits (like better product quality). Aromaa et al. (2012) also indicated need for interpreting the benefits as more business related assets for companies.

The scope of this research is on manufacturing industry where typical products are heavy machines and systems, which are partially in configure to order and engineer to order mode. This type of business is facing design and performance issues as their environments, markets, products and service offerings, and stakeholder relationships have become more complex (Allee, 2009). The products are relatively expensive customer investments with long lifecycles. Additionally, a trend is that manufacturing companies intend to expand their business models towards product-services. Therefore design for lifecycle is an essential approach. Particular object of the research is in integrated new product development, which engages product designing, productization[1] , production, and stakeholders during the product life. The focus is especially in productization phase of the product development, i.e. preparation new products or modules for serial production. This is detailed later in the paper.

The review of Leino and Riitahuhta (2012) described how the concept of virtual prototyping has been proposed to enable more agile and collaborative product development approach, and knowledge transfer capability which takes account of system and life-cycle perspectives especially from human factors viewpoint. Nevertheless, a problem is that most industrial companies do not know real holistic business and organizational value of virtual prototyping. Mainly partial virtual prototyping case studies have been published, and they are mostly very technically oriented (Leino and Riitahuhta, 2012) lacking the business value approach. Scientific knowledge about VP business value is scarce. Moreover methodology for assessing the value of virtual prototyping is narrow as well.

1.1 Virtual Prototyping

Virtual prototyping (VP) attempts to streamline product processes among other things by decreasing need of physical prototyping and improving decision making power. The industry has been gradually adopting it since VP technology has become increasingly mature enough. For instance automotive and aviation industries have exploited VP significantly. Though, terminology of this relatively new engineering discipline is not yet stabilized. Therefore conceptual definition by (Wang, 2002) is espoused in this paper: "*Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analysed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping*". Secondly, VP is an umbrella that covers several types of methods and tools such as simulations, CAE and virtual environments. In this research virtual environments (VE) and virtual reality (VR) technologies are employed. The VR technology combines multiple human–computer interfaces to provide various sensations (visual, haptic, auditory, etc.), which give the user a sense of presence in the VE (Seth et al., 2011). A virtual prototype is hence a model that represents structure, functions and properties of a technical system, and virtual prototyping is an activity which supports transformations (see Hubka and Eder, 1988) during designing.

[1] Productize: "Make or develop (a service, concept, etc.) into a product. Productiazation; noun" (http://oxforddictionaries.com)

The virtual prototyping is widely seen as enabling methodology for intensifying product processes (see e.g. review of Leino and Riitahuhta, 2012). It has been claimed e.g. that virtual prototyping enables shortened product development cycles, reduced physical prototyping costs, better decision making power, and better quality of products. The virtual prototyping techniques also facilitate better concurrent engineering and communication among cross-functional teams. They enable engineers to consider product lifecycle downstream issues earlier in the product design phase, and to make design changes in the conceptual design stage.

1.2 Research approach

In this prescriptive and conceptual paper aim was to tackle a problem of unclear connection between existing virtual prototyping concept and industrial significance. Therefore the objective of this research was to reveal the value and impact of virtual prototyping from organisational and business viewpoint. The objective was derived as a research question: How value of virtual prototyping can be modelled in general? The Research approach was qualitative. The research question was answered by mapping data from industrial case studies to theories and models of public literature. Several interviews, workshops and simulation games were used in gathering data from the industrial cases.
The value of a product or service is created in a complex business environment, and ultimately realized by customers, which makes VP value a strategic business issue. Therefore a strategic approach was needed. The research is however very multi-disciplinary combining areas of engineering design, human factors, organizational sciences, management and economics.

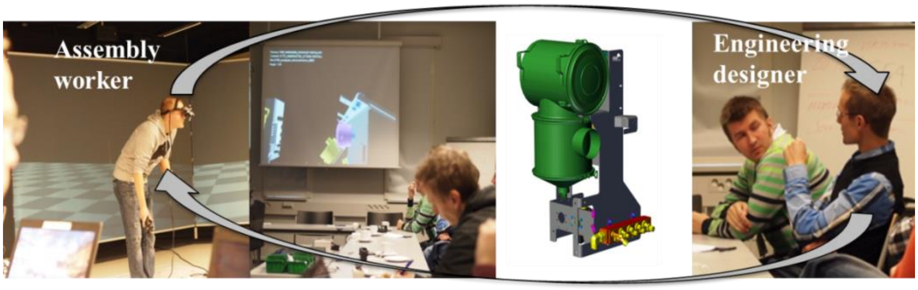

Figure 1. VP session of a new product module productization using virtual environments. The particular session was focused on assembly structure and maintainability of a new engine module. During the session a virtual prototype was studied in an immersive virtual environment, while issues and development ideas were discussed within a review board.

The case studies were conducted in several Finnish national research projects, and in a large EU-project called ManuVAR (see www.manuvar.eu) during six years. In these research projects goal was to develop support for designing better human-machine systems accounting integrated needs of business and product lifecycle stakeholders. In particular, manual assembly and maintenance work of mechatronic machines were in focus of the studies. Another specific goal was to improve utilization of 3D data among product processes and lifecycle support. The case studies were carried out in co-operation with a large company from manufacturing industry sector. The business models of the company typify configure to order concepts of product-services. Typical products represent heavy machinery and machine systems.
Figure 1 presents an example of one particular case model, which was built to describe a concept called virtual product design review. In the review, involved people of a review board come from several organisational groups and product lifecycle phases, namely product design, productization (i.e. preparation for serial production), production, product service and maintenance, marketing, product management, occupational health and safety, and project management. The involved individuals are designers, production planners, assembly and service workers, etc. They have very dissimilar background, knowledge, skills and ability to understand drawings and other more or less abstract product data.

1.3 Content of the paper

The next section describes the theoretical foundation for modelling value of virtual prototyping from strategic resource based viewpoint. The following section proposes how data from industrial case studies could be mapped to the public value models. Finally the resulting model is discussed and concluded.

2 THE CONCEPT OF VALUE

The following section describes the theoretical foundation for the study. This research is about value of virtual prototyping in industry and business context which will guide the theory review. Firstly value is studied as a universal concept and as a concept in product and service context. Secondly, found value theories and models within business strategy that fit to the research scope are introduced.

There exist many definitions of a concept called value, and the definitions are strongly context and phenomena dependent. Generally value theories aim to understand how, why and to what degree people value things. In other words value of a thing is a measure of how much it is worth. In the context of products and services generally, value can be defined as equal to the cost of the product plus a subjective part of the value (Neap and Celik, 1999). This is alike the approach of classical economists. They made distinction between use value and exchange value (Bowman and Ambrosini, 2000). Neap and Celik (1999) also listed different value situations: exchange value, esteem value (prestige or appearance), and use value (i.e. function of an item), other value situations like aesthetical, judicial, moral and religious. Salvatierra-Garrido and Pasquire (2011) summarized characteristics of value concept: objective (measurable attributes), subjective (stakeholders personal judgements), relative (opportunity to use), context dependent, and dynamic. Allee (2000) categorized value creation sources as a) goods, services and revenue, b) knowledge (for instance strategic information, technical know-how, collaborative design knowledge), and c) intangible benefits.

The above definitions of value give a good basis for modelling value of virtual prototyping. Anyhow, a challenge of this research is that methods for holistic value evaluation of VP specifically are lacking in literature. Instead of that, there are interesting publications about modelling and evaluation of information technology (IT) value. There has been similar problem in the general IT domain namely how to evaluate the value of IT and how to show link between IT and organisational performance or profit. This is often called "Productivity Paradox" (see e.g. Lee, 2001). Though VP must not be seen just as an IT technology matter, models and methods for IT value evaluation could be a helpful approach.

The IT value has been soundly modelled based on theories which emphasize organizations as set of resources, and when the resources are valuable, rare, imperfectly imitable and substitutable they are competitive advantage of firms (Bowmand and Ambrosini, 2000). These theories are generally called resource based view of a firm (see Melville et al., 2004) which combines the rationale of economics with an organization centric management perspective (see Melville et al., 2004). Bowman and Ambrosini (2000) introduced an integrative model of value creation and value capture which combines several theories. They explain finely how resource investments create new use value when using labour wisely, and how this value can be captured as exchange value from the customers.

2.1 Value configurations

In order to study business value of virtual prototyping, the context, i.e. business must be modeled as well. Porter (1985) pioneered conceptualizing and modelling business as a value chain. In the widely accepted model, primary value chain activities deal with concrete (physical) products, and are directly involved in creating and bringing value to the customer, whereas so called support activities enable and improve the performance of the primary activities. The generic support activity categories of the value chain are: procurement, technology development, human resource management, and firm infrastructure. The generic activity categories of value chain are not the same as organizational functions, but they can span several organizational functions from a competitive advantage perspective. The designing and product development are the functions which are part of product manufacture, and they should be seamlessly integrated with marketing and production (Olesen, 1992).

Although Porter's value chain is versatile and widely accepted, Stabell and Fjeldstad (1998) proposed two additional value configurations. Besides value chain models, business organizations can be modelled as value shops where value is created by mobilizing resources and activities to resolve a particular customer problem, and the value network models that create value by facilitating a network relationship between their customers using a mediating technology (Stabell and Fjeldstad, 1998).

The value network analysis combines business management practices where human interactions and relationships reside in one world of models and practices and business processes and transactions reside in another (Allee, 2009). The value network analysis offers a way to model, analyse, evaluate, and improve the capability of a business to convert both tangible and intangible assets into other forms of negotiable value, and to capture greater value for itself (Allee, 2008). The value shop schedules activities and applies resources in a fashion that is dimensioned and appropriate to the needs of the client's problem (Stabell and Fjeldstad, 1998). In the value shops, the evaluation of firm-level relative value advantage is more difficult than the evaluation of cost (Stabell and Fjeldstad, 1998) because relative cost of an activity and its relative value contribution are not necessarily related (Porter, 1985). Learning is an integral and explicit part of the problem-solving cycle of the shop (Stabell and Fjeldstad, 1998).

2.2 Value creation, conversion and capture

The previous sections defined what value is, and what kind of value configuration models can be recognized in business. Anyway, the mechanism and logic of value transformations through those value configurations needs still clarification. The article of Allee (2008) describes a detailed framework with a system view that combines reasonably theory and practice for value network analysis that addresses the conversion and utilization of intangible assets. The framework provides dynamics approach of intangible value capture (turning a tangible or intangible value input into real benefits that contribute to the success of the participants and their organizations), interconvertability, conversion (the act of converting or transforming financial to non-financial value or transforming an intangible input or asset into a financial value or asset), and value creation (converting intangible assets into negotiable value).

In their research-based theory research (2000) Bowman and Ambrosini emphasized that especially perceived use value of an asset have both internal (enterprise) and external (customer) part. Perceived use value is the price customer is prepared to pay (Bowman and Ambrosini, 2000). They also state that tangible and intangible (e.g. information) are inanimate so they need to be activated by intervention of people in order to create new use value. Therefore labour is the only source of new use values which can be captured as exchange value, and profit. However, all labour is not source of exchange value and profit.

2.3 Competence and competitive edge

The previous sections explain theories about value transformations in different configurations, but what are the tangible and intangible assets that contribute to the business value and competence of a company? According to Prahalad and Hamel (1990) core competence of a company is delivery of value, which is improved by the collective learning in the organizations, especially how to coordinate (communication, involvement, commitment to working across organizational boundaries and many levels of people within all functions) diverse production skills and integrate multiple streams of technologies. The strategy formulation should start with the competence of people, because people are the only true agents in business (Sveiby, 2001), and value creation is primarily determined by the tacit/explicit transfer of knowledge between individuals and in conversion of knowledge from one type to another (Nonaka and Takeuchi, 1995). Therefore strategy building should emphasize enabling efficient knowledge transfer and conversion, i.e. labour's capacity to act (Sveiby, 2001).

Bowman and Ambrosini (2000) have categorized labour as generic, differential and unproductive. Differential labour is the most remarkable source of organization´s uniqueness and capacity. This asset can exist in explicit or tacit form. On the other hand labour can be even unproductive and value decreasing. This means waste in Lean thinking (see Womack and Jones, 2003) terminology. The waste can manifest for instance as producing scrap, unnecessary rework or repair work. In the Lean thinking value creation is connected with waste, and defined as meeting customer requirements while minimizing waste (Salvatierra-Garrido and Pasquire, 2011). The waste means unproductive and value decreasing activity.

2.4 Value in the Design Science

The concept of value in context of design research is corresponding to above described value definitions. The Theory of Technical Systems (Hubka and Eder, 1988) include following statements:

- By means of value of a technical system someone's needs will be satisfied or comfort or pleasure aroused.
- The total value can be regarded as the vector resultant of all values (technical, economic,

ergonomic, aesthetic, esteem, usage value), or of the measures of all classes of properties for a given product.

– The basic value realization factors include the abilities of the design team, design time, and the number of improvements. Value is related to concepts of efficiency (doing things right) and effectiveness (doing right things). Effectiveness can be defined as benefits of a process divided by expenditure for the process.

Universal Virtues (Olesen, 1992); costs, through-put-time, quality, efficiency, flexibility, risk, and environmental effects are general measurable quantities for assessing company's value creation and realization for all functional areas.

3 VALUE OF VIRTUAL PROTOTYPING

The above described value theories and models provide a good foundation for explaining the value of VP. As a result of this research, this section proposes a framework model to describe how the value is forming from features and benefits of VP towards value in respect to value theories.

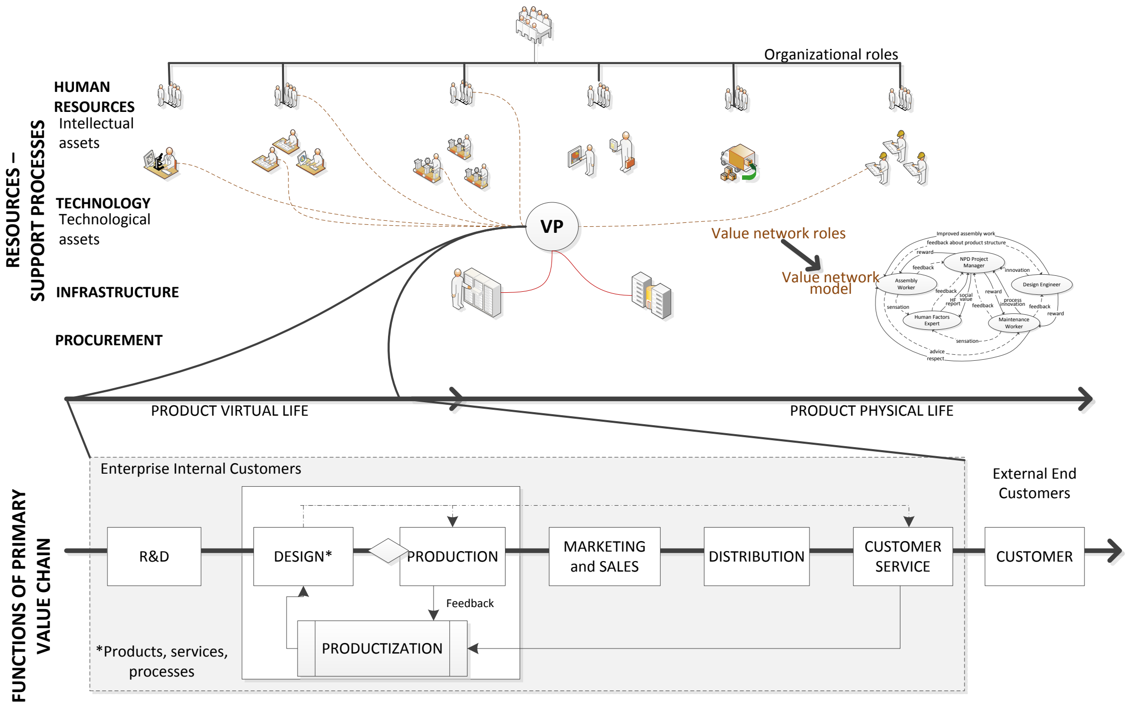

Figure 2. VP is positioned to Porter's value chain model as a technological asset that enables better utilization of intellectual assets in value networks. The asset supports the primary value chain e.g. by better problem solving capabilities in value shop configurations already in a product virtual life phase, e.g. related to productization problems

Apparently companies have often difficulties in understanding how virtual prototyping could contribute to business value, and where it belongs to in business context. Should it be considered just as another engineering tool or what? The value chain model of Porter (1985) helps positioning virtual prototyping in the context of business systems. It does not belong to the primary value chain, but is rather a supportive resource asset process with a different logic that combines humans, technology and infrastructure of a company or network. On the other hand it has also an impact to organizations, roles, technology and infrastructure. Therefore, it should be seen as a strategic asset that contributes to value creation but is simultaneously a remarkable investment when adopted in business.

In the model VP is manifested as a) media (technology and content) for communications within value networks, and b) enabler of problem solving in value shop configurations. Hence, VP is a strategic asset that enables better knowledge transfer and conversion, and therefore increased value in business. In the following sections the logic of VP value creation, conversion and capture as well as relation to competence and competitive edge of a company is detailed.

3.1 Mapping case studies to the value models

In the Value network analysis of Allee (2008) organizations are modelled as networks of roles, transactions and deliverables. Figure 3 illustrates an instance of a simplified network in company's productization case. Roles of the model include assembly and maintenance workers, design engineers, project managers, and human factors (HF) experts. Transactions (i.e. activities) are depicted as solid (formal exchanges) or dotted (intangible flows of information and benefits) arrows between the roles. The arrows are labelled with deliverables, i.e. the actual things received during the transactions. The deliverables can be physical (e.g. document) or non-physical (e.g. verbal message), tangible or intangible. The deliverable may be piece of knowledge, expertice, advice, information, or a favour or benefit. It is helpful to explore value creation at the level of key roles (Allee, 2008) when an impact analysis shows whether a role is capturing value from the inputs it receives. In strategy planning it would be reasonable for companies to first model ”as-is” i.e. existing value configurations and value creation processes. After that potential ”to-be” scenarios where opportunities and impacts of VP could be revealed should be modelled. Figure 3 also illustrates position of productization value network within a value chain.

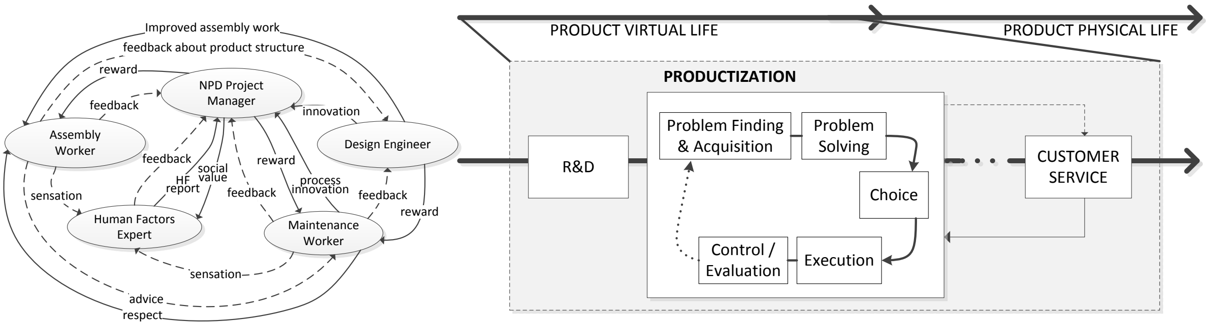

Figure 3. A) Value network model of the productization case including roles, transactions and deliverable; B) Consistent value shop configuration framework within a value chain

Value capture is the act of turning a value input, either tangible of intangible, into real gains, benefits, or assets that contribute to the success of the participants and their organization (Allee, 2008). Intangibles typically include favors that help keep things running smoothly. Figure 4 is an adaptation of value creation and value capture process by Bowman and Ambrosini (2000). In this VP value process the firms are not important, but the logic of value creation, conversion and capture between roles and parties of value network and value shop configurations during a product value chain. Figure 5 explains finally the position and benefits of virtual prototyping in value creation, conversion and capture by dint of a productization scenario.

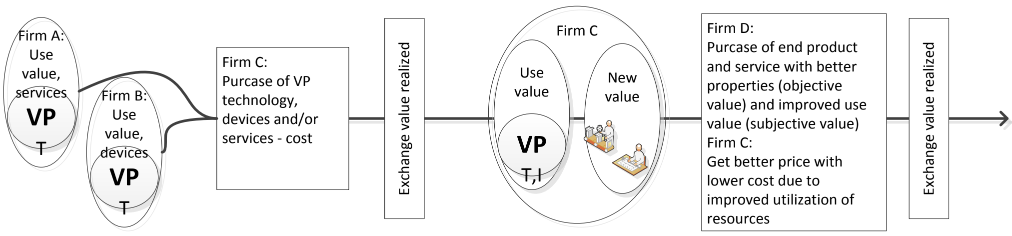

Figure 4. An exemplary schema of the VP value creation and capture within a value chain (adaptation of the model of Bowman and Ambrosini, 2000). First manufacturing company (Firm C) invests on tangible VP devices and services. The use value of VP is formed by value conversions using combination of intangible and tangible value elements adding new value to a delivered products and service. Value is finally realized by a customer (Firm D) as objective an subjective value, and by Firm C as better productivity

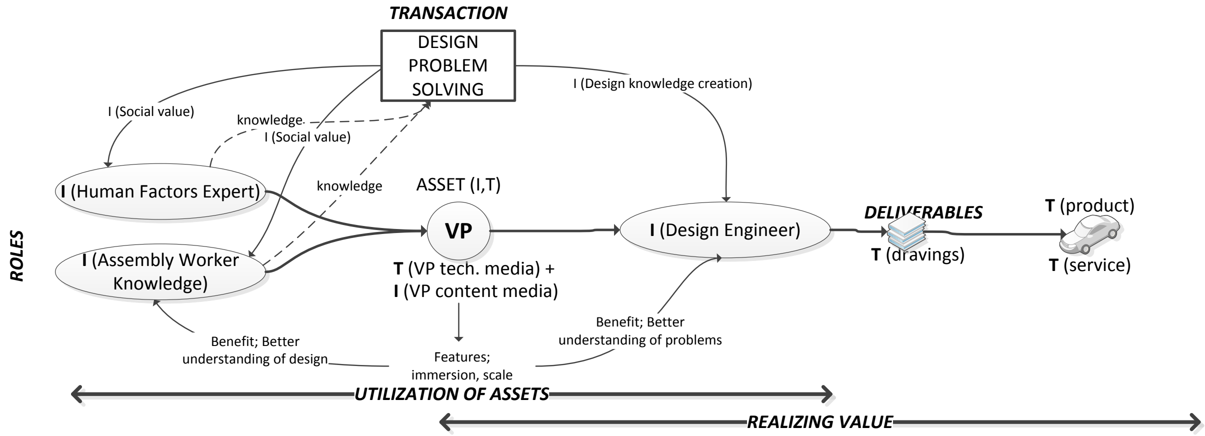

Figure 5. Simplified illustration of VP's role in value conversion; VP serves as a tangible and intangible asset providing benefit as a media for better understanding of design for assembly workers, and better understanding of possible problems for designers. Certain features of VP enable value creation by better learning and knowledge sharing within a value network.

4 DISCUSSION

As part of a larger research programme, purpose of this research was to propose a model for evaluating business and organizational value of virtual prototyping in general. This mission was initiated by adopting a strategic approach because that explains what actually contributes to business value. Generally assessing or measuring value is a challenging task because it's abstract nature and strong context dependency, including subjective and objective components. Thence, authors of this paper endorse the value models and theories that include intangible and subjective value elements into business value chain models, and highlight the value of human skills, knowledge, experience, motivation, etc. The literature on value of virtual prototyping particularly is either scarce or very old (1990's), or very technically oriented. On the other hand value is touched in many publications from other VP domains like training, learning, and psychology. "IT value paradox" and IT value models gave good hints towards analysing VP value as on resource based view to firms.

Ultimately companies must add more subjective value to customers than their rivals. Therefore they need some kind of competitive edge and core competence to value delivery. The value theory section revealed that people and their knowledge is the essential core competence of companies. On the other hand, value conversion is one of the most challenging questions for those trying to understand creating value from intangibles (Allee, 2008). The introduced theories and models are basically of great worth in explaining value configurations, conversions and sources, but without grounding to a specific industrial context they might remain even too theoretical. Similarly, the reputed common benefits of VP are actually dependent on characters like production mode of companies. For instance in serial production mode reduction of physical prototypes is an essential advantage, whereas VP could support building one-off products first time right. Our proposed model intends to build a more practical framework of VP business value on top of those theories and models.

A core competence is difficult for rivals to imitate (Prahalad and Hamel, 1990). Understanding strategic value of VP and proper implementation of it into a company's processes and infrastructure could still be such a core competence accounting its role in improved knowledge transfer and conversion, and therefore better utilization of resources and intangible value. Therefore positioning VP within value network is essential. This includes also considering VP as an in-house core competence or out-sourced service. VP improves knowledge creation and conversion (tacit, explicit) because it provides a more natural media for communicating product data content. This is particularly important because only share of knowledge can be managed or controlled. Actually knowledge management should be seen rather as a process (Sveiby, 2001) than an IT technology and explicit information issue. For instance success of Japanese car manufacturers (Prahalad and Hamel, 1990) during past decades has been partly explained by oriental culture and understanding meaning of knowledge processes in decision making and problem solving. The added value of intelligent VP value network is derived from opportunity to make the mistakes and learning with immaterial prototypes based on intangible assets compared to trial and errors in conventional physical value chain. There VP facilitates needed human interventions.

An intelligent VP could support Lean thinking within value chain (i.e. cost cutting and removing non-value adding or even value decreasing mess), but above all it could contribute on adding more value by better capitalizing on the core competence of companies. The key to understanding the knowledge economy lies in understanding intangibles as assets, and how they are set into motion in unique configurations of relationships, interactions, and resources in value conversion networks (Allee, 2008). Setting the intangible asset into motion must be seen as a strategic investment which will produce income in the long run. The VP should be treated as such a strategic asset investment that includes holistic impacts also to organizations, processes, procedures and infrastructure in order to enable cost efficient VP. Furthermore, VP could even have impact and contribution to future business models. Anyhow, strategic investment must be justified by showing opportunities and logic of return and future income growth.

Future research will put this prescriptive model to field. Our intention is to test and develop the model iteratively in companies, i.e. simultaneously gather more data with the model and improve the model itself. One potential approach is to draw from an existing PLM Impact Analysis methodology (Leino et al., 2012) which is targeted to systematically recognize existing problems or future opportunities as well as to quantify and rank their business impacts with a scorecard tool. The principle of the scorecard is based on probabilities and criticalities of the selected matters. The future research will also extend theory by studying how the theory of dispositions (Olesen, 1992) could help explaining mechanisms where VP is an asset in identifying and communicating hidden issues within complex value networks. On the other hand disposition models could serve as means for recognizing critical VP targets, because it is self-evident that everything cannot be examined in virtual environments.

The next project will continue research more deeply in the same case company where VP is recognized as an opportunity for business value as well. The model will be utilized in other companies parallel in order to get wider validation for it. A demand for modelling maturity or readiness level of companies for adopting VP as a strategic asset was also detected during this research. Furthermore, need for more profound analysis of relation from technical VP features (like easy-to-use, functionality vs. visualization, model pipeline, etc.) to benefits and business value was identified.

5 CONCLUSION

This conceptual paper proposes how business value of VP could be modeled in the context of manufacturing industry and engineering design. The contribution was built on taking a strategic approach with a resource based view to modelling business value of VP. The approach mapped data from industrial studies to public value theories and models in order to synthesize and model how technological features (such as stereo visualization) and benefits (e.g. natural interface to product data) of virtual prototyping could contribute to value creation and capture during a product-service value chain. In the model virtual prototyping is positioned as a strategic asset within value network and value shop configurations that have their own logic and processes related to value chains. The resource based strategic value of VP (entitled henceforth ”VP-RESERVA”) model emphasizes the role of virtual prototyping as a media for better organizational knowledge creation and learning, which is today one of the essential competences of enterprises. Anyhow, VP value depends on enterprises business models, product types, organizations, maturity levels, etc. Therefore holistic and systemic value configuration modelling should be initiated firstly. In the future the proposed model will be used as a reference in empirical studies. It will be iteratively improved and concretized in industrial strategy development projects. Aim is that VP business value modelling facilitates better adoption of VP, and reduces incredulous attitudes in manufacturing enterprises.

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