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Creating the Virtual: The Altered Role of 3D Models in the Product Development Process for Physical and Virtual Consumer Goods

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Creating the Virtual: The Role of 3D Models in the Product Development Process for Physical and Virtual Consumer Goods

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Abstract. The role of 3D models has substantially changed for companies that focus on the creation of consumer goods. For manufacturing and retail firms, virtual objects are today the predominant medium for product development and customization while virtual world and game developers not only build their entire products based on 3D models but found that selling virtual goods in games and virtual worlds can be more lucrative than selling the actual virtual environment. The objective of this study is to emphasize the role of 3D models in the product development processes and to identify similarities and differences between both domains based on a literature review. The results imply that 3D models are today prevalent in the entire value chain of both domains, while non-functional attributes of 3D models are of increasing value. A commonality is the growing importance of the user as source of knowledge for and creator of 3D models.

Keywords: virtual product, virtual good, product development, user creation.

1 Introduction

3D models are to date indispensable across a variety of industries and already being used in numerous fields of application, such as digital entertainment, cultural heritage, medical modelling, and architecture [1–5]. While companies in these industries utilize 3D models mainly as a mean to an end during the product development process or create products and goods for business customers, two domains rely on 3D models throughout the entire value chain for the creation of end consumer goods: manufacturing and retail firms and virtual world and game developers. Modern manufacturing and retail firms today draw on virtual products throughout their entire value chain, from sketching and manufacturing to resale and visualization [6]. For virtual world and game developers, however, 3D models are the essence to create their environments and gain revenue through virtual goods. Even though both domains thus heavily depend on 3D models, companies in these domains have long been considered to have only few points of contact, given that collaborations were mostly limited to branding and marketing efforts, e.g., in [7].

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But both domains are facing trends which might bring them closer together: For virtual world and game developers, the steadily increasing dominance of the free-to-play model [8] forces the providers of virtual environments to offer incentives and put mechanisms in place which induce the players to purchase virtual goods. Since the sale of the environment does not generate revenue, the free-to-play business model relies on the monetization through the items within the environment [9]. These in-game sales, although in most cases based on micropayment to make the player believe that s/he is not paying that much for a single transaction [10], to date established a multi-billion-dollar revenue market [11]. Market consumer goods to customers, however, is the core discipline of manufacturing and retail firms. Manufacturing and retail firms on the other hand identified virtual (VR) and augmented reality (AR) technologies as an opportunity to provide customers in online retail with the possibility to experience and customize their product in an enhanced and enjoyable manner [12] and leverage the technology for inhouse product development (e.g., [13, 14]). Vice versa, creating enjoyable interactive environments for users and virtual environments with complex dependencies and collaboration are core disciplines of virtual world and game developers.

Hence, the aim of this study is to investigate how the role of 3D models in the product development process changed in both domains due to these emerging trends and whether the processes show similarities and differences which in turn offer the opportunity for collaboration and exchange of knowledge and methods. To achieve these objectives, this study synthesizes literature from both domains in relation to the usage of 3D models in the creation process for goods and products based on the literature review methodology (section 2). The findings from the literature review are illustrated in section 3 and discussed in section 4, leading to a preliminary model of the product development stages and intermediate 3D models. Lastly, limitations and future research are described in section 5.

2 Methodology

A systematic literature review is conducted to identify, synthesize, and discuss publications in the manufacturing and retail firm and the virtual world and game developer domain regarding the application of 3D models in the product development process. To ensure the integrity of the results, the literature review process includes all required steps recommended by Webster and Watson [15]. The search and inclusion process is illustrated in Figure 1.

2.1 Search

First, a pre-screening of literature in relation to the creation of digital 3D models were conducted to identify eligible keywords for the search process. Since the objective of the study is to identify literature on end consumer goods, the selected terms should represent 3D models that either are consumer goods or used for the creation of consumer goods. For the manufacturing and retail domain, the commonly used term for the development of consumer goods is “virtual product”, while virtual world and game developers refer to the goods created for and sold in virtual environments as “virtual good”, “virtual item” or “virtual asset”. Furthermore, the study focusses on the creation and development of end consumer goods. Hence, the terms were searched in combination with the words “creat*” and “develop*” in the title, abstract and keywords of publications, resulting in the search string: *(“virtual product*” OR “virtual good*” OR “virtual item*) AND (“creat*” OR “develop*”)*. Second, the databases Web of Science, ScienceDirect and IEEExplore were identified as eligible for the search due to their high reputation in the research field. The preliminary search process in the three databases resulted in 545 articles (Web of Science: 323 | Science Direct: 93 | IEEExplore: 129). Third, duplicates were removed from the sample (98), as well as false entries, retractions and publications that were not available (32). Finally, to ensure a high quality of literature, both keynotes and book chapters (8) as well as conference proceedings (198) were excluded.

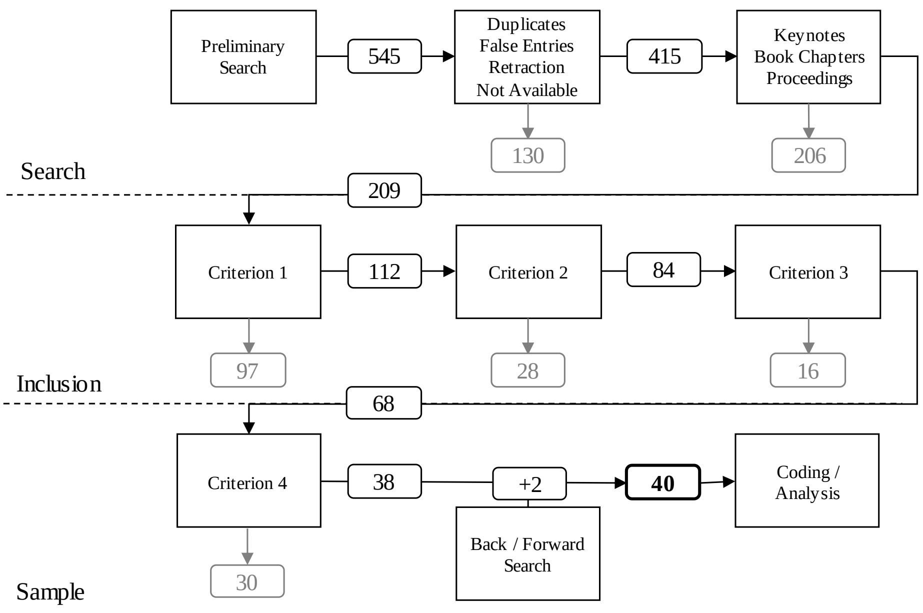

Figure 1. Search and inclusion process

2.2 Inclusion Criteria

The titles and abstracts of the remaining 209 publications were read and evaluated regarding their suitability for the research objective. Since the study focusses on digital 3D models, publications that use the term “virtual” in relation to digital goods (e.g., eBooks) and the virtualization of hardware components (e.g., virtual server) were excluded (criterion 1). In addition, other domains, and industries, such as architecture or digital entertainment, rely on 3D models for their processes but are not in the scope of the study. Thus, 28 publications were removed from the sample because they did not focus on either of the two domains in scope (criteria 2). In a last step, the full-text of the remaining publications was read. In this process, publications regarding the distribution of goods and products were removed from the sample if the papers did not contain contributions or implications for the creation of the good (criteria 3). Finally, 30 publications addressed the creation of tools that facilitate creation processes (e.g., Computer-Aided-Design software) rather than the actual development process of a good or product and were thus excluded from the sample (criteria 4). Subsequently, a back and forward search was conducted [15] which lead to the inclusion of 2 publications. Hence, the final sample consists of 40 studies (Table 1).

Table 1. Coding of literature

<table>
<tr><td rowspan="6">Manufacturer and Retail Firms</td><td rowspan="2">Prototyping</td><td>Virtual Prototyping</td><td>[13], [14], [16], [17], [18], [19], [20], [21], [22], [23]</td></tr>
<tr><td rowspan="2">Virtual Collaboration</td><td rowspan="2">[24], [25], [26], [27], [28]</td></tr>
<tr><td rowspan="2">Production</td></tr>
<tr><td>Virtual Fabrication</td><td>[29], [30], [31]</td></tr>
<tr><td rowspan="2">Distribution</td><td>Virtual Product Experience</td><td>[12], [32], [33], [34], [35]</td></tr>
<tr><td>Virtual Customer Integration</td><td>[36], [37], [38], [39], [40], [41], [42], [43]</td></tr>
</table>

<table>
<tr><td rowspan="4">Virtual World and Game Developers</td><td>Prototyping</td><td>Virtual Prototyping</td><td>[45], [46]</td></tr>
<tr><td>Production</td><td>Virtual Production</td><td>[9], [10], [47], [48]</td></tr>
<tr><td rowspan="2">Distribution</td><td>Virtual Entrepreneurship</td><td>[49], [50]</td></tr>
<tr><td>Virtual Customer Integration</td><td>[49], [51]</td></tr>
</table>

2.3 Coding

The studies in the final sample were analyzed and coded in relation to generic product development processes and the approaches in the publications to use or integrate 3D models in the development process (Table 1). The identified generic processes are *prototyping*, *production* and *distribution.* The two domains manufacturing and retail firms and virtual worlds and game developers were preliminary set. In the manufacturing and retail firm domain, most publications focus on concepts of how to use 3D models to allow for spatial sketching, haptic interaction with a prototype, an enhanced immersion with the product and an evaluation of the design. Since these processes are needed for the creation and evaluation of prototypes, these publications refer to the concept of *virtual prototyping*. A small proportion of literature focus on the constraints between components of product which often requires the collaboration of multiple designers. The tool and platforms developed for this purpose are therefore summarized in the concept of *virtual collaboration*. Furthermore, two publications describe the actual use of 3D models for the virtual simulation of the production process (*virtual fabrication*). In addition, publications examine how the user can experience the product before and after the purchase or how customers can be integrated both in the creation and customization process of the products. Hence, the approaches for the former are referred to as *virtual product experience* and for the latter as *virtual customer integration*. In the virtual world and game developer domain, only two publications mention how virtual goods can designed prior to the distribution of the good (*virtual prototyping*). Furthermore, four publications focus on attributes that virtual goods may possess to be purchased by the user. Although the papers concern virtual consumptions, the implications in the studies affect how virtual goods should be designed and integrated in the virtual environment and are therefore assigned to the concept of *virtual production* in this study. Lastly, studies examine how users can be integrated in the product development process or create and sell their own virtual goods in virtual environments. Consequently, these studies belong to the concepts of *virtual customer integration* and *virtual entrepreneurship*.

3 Results

The results of the study are aligned to the outcome of the coding process in section 3. First, literature regarding the usage of 3D models in the manufacturing and retail firm domain is reviewed, followed by the analysis of publications in the virtual world and game developer domain. Reviewing literature from both domains reveals that publications in the manufacturing and retail firm domain mostly focus on the in-house prototyping (10 publications) and virtual collaboration (5 publications) while studies on the actual creation of virtual goods are sparse in the virtual world and game developer domain (2 publications). Publications rather focus on the virtual markets, i.e., the consumption and distribution of virtual goods which have implications on the virtual production of the virtual goods (4 publications). Both consider the user as integrational part of the development process, either as entrepreneur (2 publications), contributor (10 publications) or consumer (5 publications).

3.1 Manufacturing and Retail Firms

Virtual Prototyping. Today, virtual prototyping is a common practice for manufacturers to create first product drafts because the use of virtual instead of physical objects is associated with less costs and allow an easy configurability, variant support, the possibility to run several simulations on the same object [16]. Thereby, 3D models can already be used in the sketching phase. In [17], 2D and 3D sketching is compared in a virtual reality (VR) environment. The results show that users perceive 3D sketching to be superior to 2D sketching due to a better spatial thinking and inspiration. VR based approaches are also examined in the subsequent steps of virtual prototyping. To enhance the immersion with the 3D models, i.e. the desired product, VR allows the designer not only to develop but to interact with the product and other participants in the virtual environment, leading to higher success rates in the development process [13, 14]. In [18], the VR environment is further enhanced by semantic schemes which enable even unexperienced users to quickly adjust to the VR development interface. The resulting prototypes can also be assessed and evaluated in these VR environments which is found to be superior compared to 2D screen or even real prototypes [19]. While these studies provide impressive results for using exclusively virtual environments to enhance the virtual prototyping process, other approaches integrate 3D models into the reality. Since human interactions with products are difficult to simulate, haptic sensors can facilitate the virtual integration of human behavior. The sensors can capture the human movements during the physical interaction which provides valuable feedback on the usage behavior that can be integrated in the 3D model simulation [16]. In addition, haptics lead to more realism and interactivity with the 3D object in the prototyping process [20]. Given that the presence of the 3D model in the real environment is expedient, developers can shift to AR instead of VR applications. In [21], the authors utilize AR technology to place 3D models of the virtual product directly in the hand of the user. With the help of a marker attached to the user's hand, the product developer can manipulate the 3D model in the real environment which leads to an enhanced user experience and performance in the product evaluation process. Apart from the ability to interact with the 3D models, the dependencies of product components constitute a challenge in virtual prototyping. Due to the complexity of virtual products, systems have been developed which allow to handle these assembly dependencies and facilitate a collaborative product development process. Considering these assembly constraints in the prototyping phase is essential and has determined effects on the overall product performance and component alignment. Setting and testing the assembly features virtually bears the potential to identify difficulties in the interplay of components beforehand and thereby enhancing production efficiency [22]. In case that the assembly modelling is not well conducted, uncertainties occur that can lead to the failure of the overall product, for example in its function or size [23].

Virtual Collaboration. Often, several designers are included in the development of the same product, especially in the assembly of a product. Thus, concepts and tools are required to facilitate collaborative development. In [24], the authors describe basic characteristics for virtual collaboration environments: First, all assemblies should be designed as independent components, so that every developer can manipulate the object. Second, to avoid conflicts in the collaborative process, session manager systems are required that clarify which developer can access the model in which session. To extent this process not only to one developer team but to teams at different stages throughout the entire lifecycle of the product, the file format of the 3D model is essential [25] as well as creating an IT infrastructure that is able to communicate information about the 3D model [26, 27]. The file format must be accessible and modifiable by all involved parties and allow the transfer of the data. In turn, the comparability of file formats and the ability of data exchange between systems is tremendously important for the concept of virtual twins. The concept of the virtual twin goes beyond the initial product development process and aims on including the subsequent stages of the product lifecycle. Thereby, the product can be customized and modified after purchase. Often, the term virtual twin is used in combination with the term smart product which refers to the ability of the product to communicate its condition and other relevant information [28]. This allows for modifications of the product in use. However, these reconfiguration options are currently mainly limited to IT services since they can be added to existing hardware components by wireless connections and do not require a transportation of the product to a facility [28].

Virtual Fabrication. The 3D models designed in the collaborative virtual prototyping process are the basis to retrieve important information, such as the bill of materials or component functions, and to create repositories that provide these information for the fabrication of the product [29]. The production process can also be pretested in a virtual manner, i.e., by virtual fabrication. In [30], the virtual fabrication process is enhanced based on VR and AR technology. The technologies allow the users to work collaboratively on the 3D models meant for the production process and conduct a 3D model validation and verification directly at the shop floor. But 3D models are not only a medium to enhance the fabrication process of major firms. Today, the development in additive manufacturing systems enables even individual businesses and start-ups to manufacture their products based on a 3D design [31].

Virtual Product Experience. Apart from the ability to prototype and fabricate products based on 3D models, virtual objects can be the basis for product visualization and customization [32]. Based on software tools, users can change the design of a product, for example the color of a car, hence adjusting the product to their specific needs. However, the requirements for a 3D model used as a representation of the product, for example in an online shop, differ from the requirements of a 3D model used for in-house purposes. 3D models with the purpose of visualization and customization must be user friendly, provide design attributes and a high level of enjoyment [12]. A consideration of these characteristics leads to a positive attitude towards the website and presented product [12] and in turn towards the manufacturer or retailer offering the product. The virtual product experience is often divided in visual and functional control, while both have a positive effect on the perceived diagnostic and flow of consumers using online shopping environments [33]. In turn, the visual and functional control can be increased by AR. Seeing the virtual product in the real environment supports the user to make the right purchase decisions [34]. Recent VR based approaches even allow the developers to directly interact with the customer supported by sensory data to find perfectly fitting garments [35].

Virtual Customer Integration. But users can not only be considered as consumers but as an essential asset for the product creation process itself. Working with users to co-invent and innovate new products have become an established mechanism for manufacturing companies. The user can be included in all phases of the development process [36]. In early phases, the user mostly functions as a feedback mechanism for the design of the product. To facilitate the integrations of the user in the product development process, virtual interaction tools help users to articulate their product needs and transfer these information to the product development team [37, 38]. 3D Models are used in this stage as a less cost and time consuming alternative to show potential users a prototype of the product, to evaluate the functionality and usability of the product and to gather knowledge about the customers' purchase intention [39]. For the product assessment, user control and media richness are drivers for the immersion with the product [40]. Since VR can increase both factors, the technology is applied in user integration processes. In [41], VR is used in combination with physiological measurements, allowing the developers to capture the users emotional assessment of the virtual product design. In the same vein, [42] use VR to measure the user impressions of different design variants. However, relying on 3D models in this early stage is considered risky because even slight changes in the final product may affect the initial impression [39]. Apart from integrating the user for product testing, companies rely on online communities to gather new ideas for product design [43], or let the user customize and evaluate variants of the product [36].

3.2 Virtual World and Game Developers

Virtual Prototyping. Literature on the virtual good development processes of virtual world and game developers is sparse. Virtual goods are intangible, mostly 3D models, and only exist and have value in the virtual environment they have been created for or in [8, 44]. Thus, they cannot be transferred and used in other virtual worlds or games. Most research on virtual goods do not focus on the creation of the virtual good but rather on the purchase and consumption of even such or the occurrence and role of different types of virtual goods. However, two publications describe the creation process of virtual assets that can be used as virtual goods. In [45], the authors adapted the quality function deployment (QFD) method, mainly used in manufacturing for the development of new products, to derive a QFD suitable for the development of virtual items which can match the user needs with the characteristics of the virtual good. In [46], the creation process of virtual goods is described from a user perspective, i.e. the user as the creator of the good: The virtual world Second Life allows users to create and assembly products and object parameters. Apart from shape, color, and texture, the user can write scripts that define the functionality of the virtual good.

Virtual Production. Despite these two publications, most studies do not focus on the creation of the virtual good but rather on determinants that influence the purchase of the good, i.e., how the good must be produced to be consumed by the users. However, one's conclusion could be drawn from the implications of these studies. Amongst others, user engagement, both behavioral and psychological (such as game satisfaction, game customization, and social interaction), is identified as a key criterion that leads to increasing virtual good purchase [47]. In turn, game developers are advised to maintain engagement at a high level when they intend to gain significant revenue. This is in direct contradiction to how game developers often design their games based on the freemium business model: creating weak user experience to force the user to access additional content [10]. Besides user engagement, social aspects are one of the main drivers for in-game consumption. Virtual world and games are self-contained environments that bear social hierarchies which are to some extend comparable to reality from a consumption perspective. As for physical possession, having premium accounts and specific valuable virtual goods can lead both to social distinction and discrimination against users which have neither [48]. This can be intensively observed for cosmetic, or non-functional virtual goods which do not provide the player with a competitive advantage. Even though non-functional items have no competitive advantages, user express themselves through these goods, for example by decorating their virtual rooms or dressing their avatars [48]. These non-functional attributes gained relevance in the past years because cosmetic goods can today be considered as the main revenue stream for most free-to-play games [9].

Virtual Entrepreneurship and Customer Integration. The role of the user as creator or contributor to virtual good creation differs in virtual worlds and games. In virtual worlds, the user has the possibility to not only create both functional and non-functional virtual goods, but act as a virtual entrepreneur and sell the created goods directly to other participants in the virtual world. In most game environment, this is not the case. The approaches are defined in [49] as bazaar versus cathedral standard. The former facilitates the ability of the user not only to be involved in the creation but distribution process of the virtual goods, for example in Second Life, while the latter exclude the user from these processes, leading to markets governed by the provider, for example World of Warcraft. Based upon these results, the authors explicitly examine "virtual entrepreneurship" in the virtual worlds [50]: In virtual worlds, self-accomplishment or reputation and social features are the main drivers for a user to become a virtual entrepreneur. In addition, virtual entrepreneurship spurs the virtual economy in virtual worlds. In turn, the growing virtual economy is recognized by other users and lead to further endeavors to create own businesses in the environment. While the user thus can be the actual creator of a virtual good, the integration of the user in the creation process, is examined in [51]. In this study, user co-creation is the user's willingness to contribute to product development by sharing game experience in forums or cooperate with others, not by explicitly designing virtual objects themselves for the game environment. From the authors' perspective, the role of users shift from "passive consumers to active collaborators" ([51], p. 247).

4 Discussion and Implications

In this section, the findings from the literature review are synthesized and discussed, resulting in a preliminary model of product development processes and intermediate 3D models illustrated in Figure 2. Three major findings can be derived from the discussion of the results: the holistic integration of 3D models in the product development process in the form of virtual assets, the gaining importance of the non-functional attributes of 3D models, and the increasing user involvement in the creation process.

4.1 Virtual Assets

First, literature suggests that 3D models are prevalent in the entire value chain of manufacturer and retail firms and virtual world and game developers. In the manufacturer and retail firm domain, concepts have been developed that allow for an entirely virtual product development process, from sketching to testing, evaluation and fabrication [6, 17, 21, 30]. Especially VR and AR based applications are utilized in the prototyping and fabrication phase to enhance the interaction with and the spatial perception of the product in development. The sketches and models from the prototyping and fabrication phase are thereby stored and exchanged based on digital platforms [26]. Hence, while the virtual sketches are the basis for the creation of virtual products (Figure 2, M2), both virtual sketches and products can be considered as *virtual assets* [52] that can be used and adapted in different phases of the product development process (Figure 2, M1, M3). Although no publication in the virtual world and game domain explicitly focusses on the prototyping process for virtual goods, the study on user created designs in virtual worlds provides insight in the creation process from a prosumer perspective [46]: As for manufacturers, virtual sketches and models are designed that can be considered as a virtual asset and adopted in subsequent steps of the prototyping and virtual production process (Figure 2, V1, V3). But essentially, the virtual sketches are the basis for the creation of virtual objects that in turn can become virtual goods when they are integrated in the dedicated virtual environment (Figure 2, V2, V4). By using VR and AR environments, manufacturers implicitly shift their product development to virtual environments, where the core competences of virtual worlds and game developers are essential: interactivity, usability, and user engagement [12]. Hence, a collaboration with virtual world and game developers or an adoption of product development methods from virtual world and game developers may foster the advantages that result from the application of the VR and AR in the manufacturers' product development processes. Vice versa, virtual worlds and game developers may adopt product development methods from manufacturers, as already examined in [45].

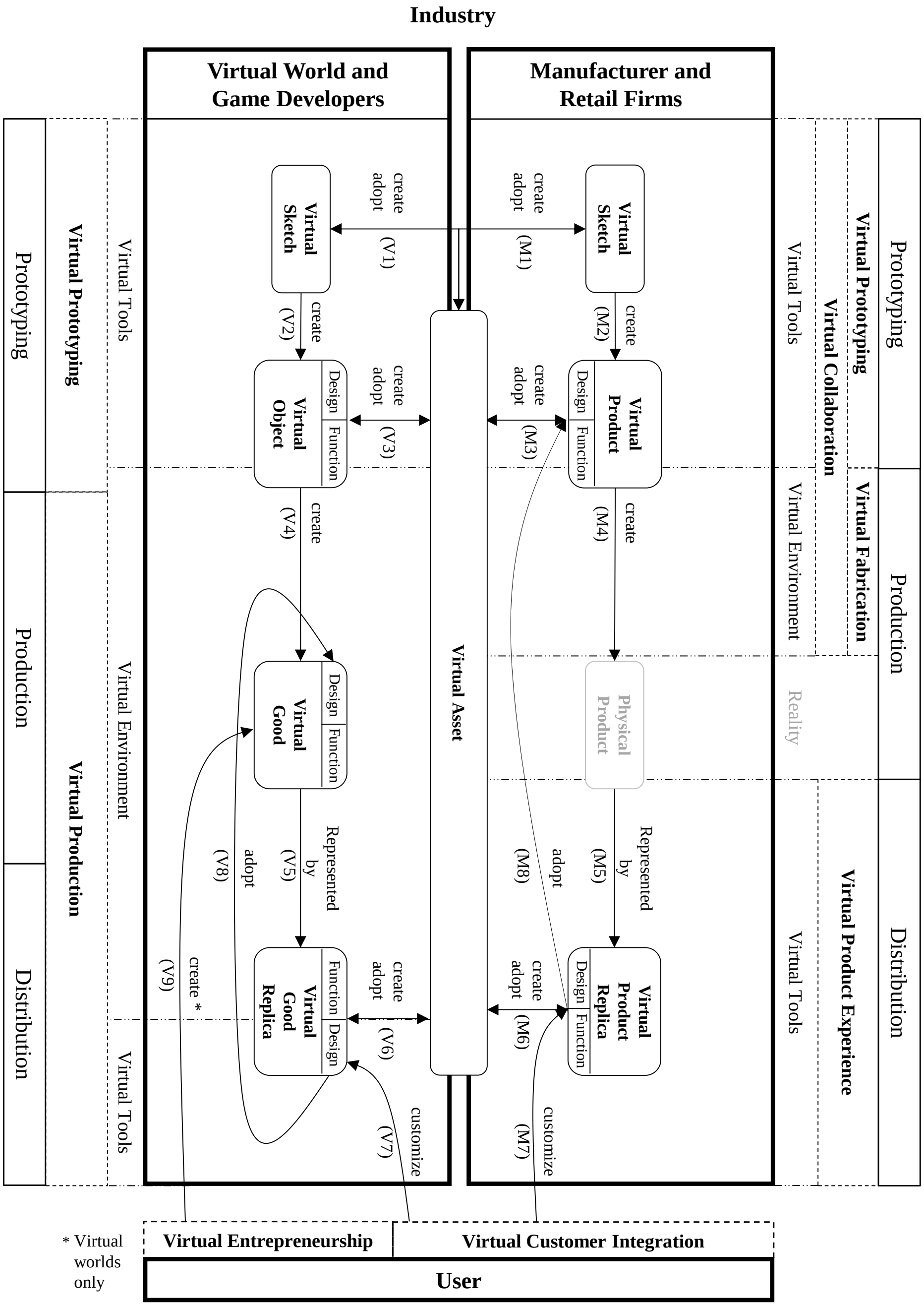

Figure 2. Product development processes and intermediate 3D models (own figure).

4.2 Non-Functional Attributes

Second, both virtual products and virtual goods consist of non-functional (design) and functional (function) attributes that determine the production of the good, either in form of a physical process (Figure 2, M4) or an integration of the good in a specific virtual environment (Figure 2, V4). In both domains, the appearance, thus the non-functional attributes of the 3D model, is of increasing relevance. While virtual world and game developers concentrated on functional attribute for virtual goods to provide the player with a competitive advantage, gaining advantages by paying money is not welcomed by the majorities of players [8]. Hence, most virtual world and game developers today generate revenues by selling non-functional goods to address consumption mechanisms inherent to physical goods, for example social distinction and hedonic motivation [48]. While manufacturing and retail firms draw on established methods to foster the consumption of their products, their need for non-functional attributes occurs due to the complexity of their virtual products. Since virtual products include complex components and material attributes to allow the simulation, testing or virtual fabrication of the physical product, virtual products are mostly not of use for virtual environments or virtual product experiences. The 3D models must be down-sampled by neglecting specific components of the model or displaying them in a simplified way with adjusted functionalities (e.g., as in [53]). Hence, the non-functional attributes of the product need to be completely redesigned. Given that most manufacturers and retails offer a multitude of products, this process is considered as time and resource consuming. Since these 3D models are replicas of virtual products with considerably different characteristics, they are described in this study as *virtual product replica* [52] (Figure 2, M5). These virtual product replicas can be adopted as virtual assets for manufacturing and retail firms since they can be used throughout the entire product development process if needed (Figure 2, M6). Due to the expertise of manufacturers and retail firms regarding the consumption of consumer products, methods may be transferred from manufacturing and retailer domain to the virtual world and game developer domain to foster virtual good purchase. Vice versa, virtual world and game developers draw on methods to specifically prepare 3D models for the usage in virtual environment that might be transferred to the manufacturer and retail firm domain. In both domains, technical artists or design studios may be required to create non-functional attributes and goods which offers a business opportunity for companies focusing on the creation of even such.

4.3 User Integration

Third, the role of the user changed from a passive customer to an active participator, also driven by the previously described need for non-functional attributes and goods. Both manufacturing and retail firms and virtual world and game developers use virtual tools to integrate the user in their product development processes (e.g., [38, 46]). As manufacturing and retail firms, virtual world and game developers provide replicas of the virtual goods used in the environments to allow the user a customization of the good. Since these replicas do not include all attributes of the virtual goods in the environment, i.e., functionality or textures and materials, these goods are defined as *virtual good replica* in this study which can be adopted by virtual world and game developers as virtual assets and used throughout the product development process (Figure 2, V5, V6). The virtual good replicas empower the user to customize non-functional characteristics of the object for both virtual worlds and games. In game environments, the game provider is thereby taking mostly the part of the “producer”. The production process is conducted by adapting user created, non-functional content and transferring the attributes to the in-game item (Figure 2, V7, V8). An example for this process is the steam workshop environment which allows users to take part in challenges with the purpose to create non-functional designs (skins) for weapons [54]. The challenge winning skins are afterwards adapted by the game developer for the virtual good. In some virtual worlds, however, the user can act as the creator of the entire virtual good, thus define both functional and non-functional characteristics [46] (Figure 2, V9). Hence, the user can either create both functional and non-functional attributes of a good inside the dedicated virtual environment or create non-functional attributes of the good outside the virtual environment by using a virtual tool. Manufacturers and retail firms on the other hand use 3D models to provide users with a virtual product experience and allow them to customize the product they intend to buy (Figure 2, M7, M8). For the virtual product experience, the virtual product replica should correspond with the characteristics known from the virtual world and game developer domain, i.e., user friendliness, user friendly and an enjoyment [12]. Differences between both domains occur due to the specific environments the goods are produced and used in: While virtual goods are produced and used in the virtual environment, manufacturers are required to produce the good physically. Hence, the 3D models are information carrier and recorder that contain necessary manufacturing information. Due to the current developments in additive manufacturing [31], users might be enabled to create entire products and relying on manufacturing firms solely as contractors for the production process. But to date, users can not create and produce entire physical products in cooperation with manufacturers as it is possible in virtual world environments.

5 Limitations and Future Research

The limitations of the study stem from the methodological approach and the analysis of the results. First, conference proceedings were not included in the literature search and selection process. The inclusion of high-quality conference proceeding may not only strengthen the results of the study but provide a better understanding of current research. While the methodological approach does not require the inclusion of conference proceedings, an extension of the study with conference proceedings might be considered in future research. Second, the analysis and interpretation of the results were conducted by a single author. Although the findings were discussed with other researchers, the results remain subjective. Third, since no research was identified that considers the in-house processes of virtual world and game developers, the findings regarding the creation process rely on publications that describe the creation from a user perspective. However, since the results stem from virtual worlds that allow the users to use the scripting environment of the virtual world for the creation of the goods, the processes provide an understanding of how the in-house development process of the corresponding development team might be established.

Due to the sparse research on the creation process of virtual goods, future research may focus on the analysis of these processes based on case studies or expert interviews. Especially the mechanisms and approaches to integrate the user as a customizer or creator of virtual goods constitute an interesting research avenue because the degree of integration may influence the business model of virtual world and game developers. The user as an independent creator and producer of virtual goods in the environment, also in games, may bear a user-based business model that focus revenue share rather than a one-sided producer-dominated market. For research on manufacturers and retail firms, product development processes may be reconsidered. Virtual product replicas meant for virtual product experience and virtual customer integration seem to have more similarities with the 3D models used in the prototyping stage than the rather complex virtual product. Thus, research may focus on the characteristics 3D models considered for prototyping and if they can serve as objects for user integration and virtual product experience. In addition, less research analyzes the interdependencies and knowledge exchange between the manufacturer and retail firm and the virtual world and game developer domain which may lead to the transfer of theory and methods. In the same vein, virtual assets at the intersection of manufacturer and retail firms and virtual world and game developers are not considered in the identified literature. Although public markets exist which offer virtual assets (e.g., [55], [56]), these platforms are largely unexplored. Lastly, the derived product development process model in Figure 2 is the first model that considers both domains, the dependencies of the corresponding virtual objects and intermediate 3D models. However, the preliminary model needs to be validated and extended by practical empiricism and case studies with companies from both domains.

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