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CREATING VALUE IN ADDITIVE MANUFACTURING – MODELING OF ECOSYSTEM DETERMINANTS

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Research Paper

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Abstract

Despite the increasing managerial awareness for ecosystems to organize complex value propositions, little is known about how different roles can establish their business models (BM) in ecosystems. AM drives innovations in the product design and manufacturing fields predominantly across companies, indicating the eco-systemic organization of value creation without orchestrating and dominant keystone actors yet. This paper explores ecosystem determinants by analyzing the dynamic additive manufacturing (AM) paradigm. We conduct an empirical study with companies from the AM domain to visualize their value activities and define generic roles in the interdependent value creation process, adopting the e³-value methodology. By exploring these ecosystem determinants, our results aid practitioners in positioning their BMs in the AM domain and generate descriptive insights for the orchestrator BM design in a dynamic domain without orchestrating keystones.

Keywords: Additive Manufacturing, Ecosystem, Orchestrator, Business Model Design, e3-value.

1 Introduction

Scholars and practitioners intensively debate the ecosystem construct (Adner, 2017; Jacobides et al., 2018). Ecosystems can create various benefits, such as the ability to leverage the value between collaborating companies. By this, the value-added is organized so that the output increases disproportionately compared to input (Cao and Thomas, 2021; Autio, 2021). Hence, ecosystems represent an appropriate form to organize the complex value-co creation across companies' borders, of which there are already many different types identified in current research (Hein et al., 2019; Suominen et al., 2019). Ecosystem research mostly goes back to the findings of Iansiti and Levien (2004), who conceptualized the formation of ecosystems around keystone companies. Keystones may offer a dominant technology to orchestrate heterogeneous companies for joint value creation, but they are also empowered to regulate the access points to the ecosystem and the value distribution between the ecosystem participants (Iansiti and Levien, 2004; Jacobides et al., 2018). Against this background, it is interesting to study ecosystems in markets that lack such keystone companies empirically.

We conduct an empirical study of the current state of the business-to-business (B2B) additive manufacturing (AM) domain to understand better how potential orchestrators can emerge in the process of business model (BM) design. AM is an emerging and fast-developing paradigm determined by a significant yearly growth (Wohlers et al., 2021). In the industrial application of 3D printing, AM covers production processes that automatically deposit material layer-by-layer to create physical objects based on digital product models (Gebhardt and Hötter, 2016). Extant research classifies the impact of AM on the industrial sector differently since it varies between complementing and disrupting traditional manufacturing systems and processes (Rong et al., 2018; Hämäläinen and Ojala, 2015). Whether it is a disruptive or complementing technology, collaborative services between multiple actors are an important part of added-value by AM (Bouncken et al., 2019). From the manufacturing perspective, the integration of AM in manufacturing processes also leads to the entry of new players into the domain, impacting the traditional supply chains between manufacturers, distributors, and customers (Rong et al., 2020). In line with these observations, initial studies observe the ecosystem emergence in the AM domain (Rong et al., 2018; Bouncken et al., 2019; Kwak et al., 2018; Xu et al., 2018; da Silva, 2013). In contrast, to repeatedly studied ecosystems (Saarikko, 2016; Hannah and Eisenhardt, 2018), the co-created outcome in the AM ecosystem remains physical, although the input is partially digital. Whilst ecosystems based on software, services or digital products seems to be a well-researched field, ecosystems with physical outcome need a distinct look in some terms (Autio and Thomas, 2016; Nischak and Hanelt, 2019; Sandberg et al., 2020). Physical products differ from software on the basis of various properties. Examples of differences are the need for interface standardization or the possibility of generating indirect network effects, as is the case with digital products as reprogramming at the device level is not possible (Jacobides et al., 2018; Sandberg et al., 2020).

Against this background, we propose the following research question: *Which determinants shape the ecosystem in AM, and how can they contribute to design business models in a generic AM ecosystem?* To answer this question, we collect empirical data through interviews with AM domain experts, combining coding techniques for qualitative data with the e3-value methodology to develop a generic AM ecosystem. Applying the ecosystem analysis lens, our study identifies the (1) *AM-specific value-adding activities*, (2) *the relevant roles involved in the value creation*, (3) *the value proposition of the individual actors,* and conceptualizes (4) *a generic AM ecosystem with its specific scenario paths*. The purpose of our study is threefold. First, our systematic analysis and conceptual modeling support BM design and innovation in the AM domain. Second, we generate descriptive insights on the orchestrator BM design in AM and ecosystems without the keystone influence. Third, we learn about the orchestrators' options during the BM establishment, enabled by the conceptual modeling of generic ecosystems and their determinants, which scholars can use to develop methodologies and approaches to support decision-makers in assessing eco-systemic value creation, repositioning own value proposition, and entering a domain.

2 Related Work and Background

2.1 Value proposition in Ecosystems

BMs are a much-discussed topic within various research fields, described by numerous frameworks (Foss and Saebi, 2017). A comprehensive overview on the topic of BMs give Al-Debei et al. (2008), Zott et al. (2011), or Burkhart et al. (2011). Reduced to their essentials, BMs define in a rather conceptual way how a company generates value, provides it to the customer satisfying his needs, and captures value by getting paid (Teece, 2010). Most BM frameworks rate the value proposition together with the profit formula as a core element of a BM (Al-Debei et al., 2008; Osterwalder and Pigneur, 2011). A value proposition can be defined as the creation of value for the customer by offering solutions to meet customers' needs, solving a fundamental problem (Osterwalder and Pigneur, 2011; Al-Debei and Avison, 2010; Johnson et al., 2008).

As companies increasingly create value in cooperation with other companies (Linde et al., 2021; Moore, 1993; Teece, 2010), they balance internal value creation and the integration of external resources. To describe such strategies, Moore used biological concepts of coexistence to coin the concept of business ecosystems. Accordingly, an ecosystem is an alignment structure to organize a set of multilateral companies that work together on a shared value proposition (Moore, 1993; Adner, 2017). Following Adner's (2017) conceptualization of the "ecosystems-as-structure" perspective, eco-systemic value creation is intra-organizational, and the value proposition requires the interaction of multiple firms and their alignment to realize a focal value proposition (Adner, 2017). Therefore, ecosystems are characterized by value creation complementarities and interdependencies between providing companies' activities (Adner, 2017; Kapoor, 2018). In this context, ecosystem participants create value without a formal contractual base, relying on a shared vision to support the ecosystem development without the formal coordination of bilateral contracts, which usually apply to traditional supply chains (Adner, 2017; Dattée et al., 2018). However, if the value actors and their activities are orchestrated adequately, ecosystems may generate leverage effects that foster the realization of disproportionately gains for the specified value proposition (Adner, 2017; Cao and Thomas, 2021; Autio, 2021). In order to analyze the joint value proposition in an assumed AM ecosystem, Adner's "ecosystems-as-structure" perspective can be linked to the previously described BM frameworks due to the similarity of their conceptual elements. The starting point of the ecosystem-as-structure perspective is the value proposition, which is achieved through complementary value activities (e.g., discrete actions to create the value proposition) by interdependent actors (e.g., entities that undertake the activities) (Adner, 2017). Similarly, BMs should be conceptualized by value activities performed by actors to produce output by adding value to the input. Otherwise, the separation of BMs from processes and activities leads to poor business decision-making and inadequate business requirements (Gordijn et al., 2000). Drawing on the conceptual similarities, we apply the theoretical BM lens to study AM ecosystems. We do this by applying the e3-value modeling approach which is designed to show interdependencies and value exchanges within an ecosystem of different actors (Gordijn and Akkermans, 2003). Figure 1 illustrates the applied research framework, which arranges the relevant concepts.

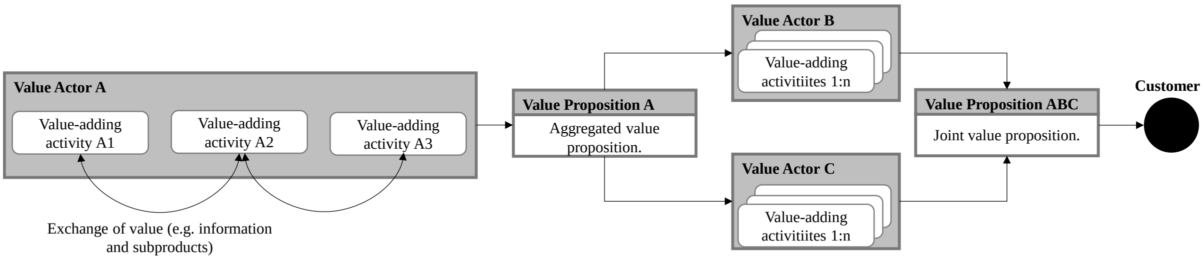

Figure 1. Shared value proposition of value-adding activities by multilateral actors.

Drawing on the conceptualization of ecosystems (Adner and Kapoor, 2010; Jacobides et al., 2018; Adner, 2017), prior research mainly presumes platform companies orchestrate an ecosystem. As our literature review preceding the empirical study reveals, this does not seem to be the case with AM, although the research literature also indicates that the organization of value creation in AM is eco-systemic. Therefore, the next section documents the current state of research on BMs and the eco-systemic value creation in the AM domain.

2.2 Additive Manufacturing Ecosystem

We define AM as the transformation of a digital product model into a physical object through the automated assembly of individual volume elements (layers) in an industrial domain (Gebhardt and Hötter, 2016). AM can be seen as a concept of different layer-by-layer manufacturing technologies in which processing techniques differ based on materials or various applications. Based on the layer-by-layer manufacturing, AM enables the production of nearly any kind of part (Gebhardt and Hötter, 2016; Weller et al., 2015). Since AM processes are based on digital product models, no construction plans are required to start AM manufacturing (Gebhardt and Hötter, 2016; Lasi et al., 2014). Despite the technological differences, however, the general AM process can be divided into five phases, focusing either on digital artifacts or physical ones (see figure 2) as detailed below.

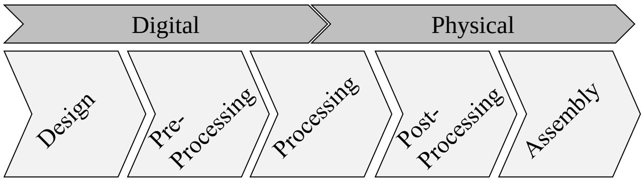

Figure 2. Additive Manufacturing process (Hiller et al., 2016; Caviezel et al., 2017).

The objective of the **design phase** is to generate a digital product model, which is usually a computer-aided design (CAD) file (Piller et al., 2015). Traditionally this is the task of a designer who converts the requirements and ideas of a product with CAD software (Gibson et al., 2015). In the case of already existing parts, it is possible to generate a digital product model by reverse engineering such as scanning the original part (Petrick and Simpson, 2013). The de-facto industry-standard file format is STL as the interface between the design and pre-processing phase. In the **pre-processing** phase, usually different kinds of product models of to be printed parts get packed into one manufacturing space (packaging or nesting). The whole nested manufacturing space is then digitally sliced into layers, that are manufactured in the following processing phase (Mechanical Engineering Industry Association, 2014; Hiller et al., 2016). The **processing phase** includes the physical generation of the part(s) in the manufacturing space of the AM system. Speed, material, possible part size, and quality are dependent on the chosen AM technology and material. The output of the processing phase is a semifinished product (Mechanical Engineering Industry Association, 2014; Hiller et al., 2016) whose desired features are finished in the **post-processing** phase. Most of the time, conventional manufacturing approaches and machines are used for pst-processing. Examples are heat treatment, surface finishing, or the drilling of threats (Mechanical Engineering Industry Association, 2014; Hiller et al., 2016). If the AM part is part of an assembly group, there is a final assembly phase. If not, the finished part is directly used.

Merging ecosystem value creation and AM technology leads to **AM Ecosystems** that are characterized by creating value through AM application. In order to cover the current state of research in this context, we systematically examined the literature on AM through BM and ecosystem lenses. Our main purpose was to synthesize existing publications that highlight ecosystem or BM aspects in AM. Following the approach of Levy and Ellis (2006). We performed a comparable search within the ACM Digital Library, AIS eLibrary, and SpringerLink. ACM and AIS eLibrary were chosen to capture the ecosystem-oriented research in Information Systems and related disciplines. Additionally, we opted to include SpringerLink for the knowledge synthesis on ecosystems and AM. According to a preliminary screening of potential databases, it turned out that SpringerLink offered research from a broad context of the AM in various domains. However, additional filters are applied during the search to ensure comparability and quality of literature identified (i. e. excluding monographs on SpringerLink). The received hits were checked for relevance to our research topic in two steps by each research team member independently. The analysis of titles and abstracts during the first step of the review left in sum 113 publications. During the second step, we checked the publications for the following topics: (1) AM ecosystem or AM platform, (2) Elements of roles or stakeholders, and (3) use-case-specific BMs. After discussing the relevance of each publication to support the researcher team's knowledge base, the selection included 44 publications. In a subsequent step, we performed a backward search, adding two more relevant papers to the body of literature. Due to the length restrictions, the details of the search process, the final literature selection, and the concept-centric visualization of the literature body were externalized and can be assessed under the following URL: https://bit.ly/3qNlPXR

The reviewed literature reveals that the AM domain's structured and overarching BM analysis has not been done yet compared to other domains such as IIoT (Endres et al., 2019). Based on our sample, we observe the diversity of BM. For instance, we discovered the presence of multiple transaction platforms in the AM domain (Freichel et al., 2021). This can be explained by the fact that the AM industry profits from a digital format standardization for virtual 3D models so that various digital platforms with the possibility of uploading the model for further production already shape value co-creation in the AM domain (Kwak et al., 2018).

However, most articles describe a prototypic implementation of transactional platform BMs, revealing a firm-centric view instead of an ecosystem view. The introduced platforms (Rayna et al., 2015; Kwak et al., 2018) indicate a fragmented market. One can assume that these platforms neither manage positive network effects attracting a critical mass of platform users, nor they establish a sufficient differentiation from other platforms. As a result, platform leadership is not achieved (Stummer et al., 2018; Gawer and Cusumano, 2008; Leong et al., 2019). Therefore, one can conclude that the AM market lacks leading keystone firms that orchestrate the AM domain. In the absence of keystones, the uncertainty for potential ecosystem participants to launch an ecosystem increases. As stated before, the formation of ecosystems remains under-researched in this critical setting (Dattée et al., 2018). In addition to the transaction platforms and marketplaces, the production of AM systems involves focal machine tool companies that align various complementary component suppliers (Rong et al., 2018). However, the examined literature does not present detailed results on the value proposition created by the actors inside their ecosystem, so domain-specific use-cases as snippets of ecosystems are presented as BM. Consequently, with single exceptions in personal 3D printing (Piller et al., 2015), prior research does not provide a holistic picture of AM BMs that determine a generic AM ecosystem. In every domain, successful companies create value for their customers, helping them to solve fundamental problems through their offerings.

However, it is challenging to implement and execute the value proposition, aligning it with an appropriate value capture mechanism (Johnson et al., 2008; Teece, 2010). Usually, various roles work together along the value creation process, creating dependencies and ultimately forming an ecosystem (Adner, 2017; Christensen and Rosenbloom, 1995). Therefore, we sense a clear benefit in identifying the key roles and their value propositions in the AM domain, particularly since AM is characterized as an extremely dynamic domain (d'Aveni, 2015). Furthermore, AM draws on certain flexibility in corporate relationships not secured by individual contractual dyadic relationships to create value (Adner, 2017; Rong et al., 2018). This indicates that the value creation in AM can be conceptualized as a generic ecosystem. Current research notes that the output of different ecosystem types is commonly characterized by super modular complementarities (Jacobides et al., 2018). Consequently, in contrast to traditional supply chains, we classify AM components as super modular from both a production and a consumption perspective. Regarding the production perspective, increasing demand for AM components in the manufacturing process of goods positively impacts the investment in further maturity and enhancement of AM technologies (e.g., through research). It ultimately increases component quality and reduction of prices (i.e., supermodular production). Regarding the consumption perspective, growing AM adoption increases the variety of AM designs and the range of products manufactured with AM, from which the demand side of AM components can benefit (i.e., supermodular consumption). Considering the effect of supermodularity (Jacobides et al., 2018), we recognize the presence of network effects and the resulting lock-in (Gawer, 2021). This is caused by the need among AM component customers to invest in adjusting the engineering of physical components towards specific technology in order to gain added value through AM. For instance, to transform a conventionally designed (or conceptualized) part into an AM part, several redesign steps usually have to be done (e.g., remove material not needed for part stability to save manufacturing cost, check joined parts for functions to integrate etc.). Even for copying most conventionally manufactured spare parts, one has to rework at least some constructional sections (e.g., wall thickness, etc.). In conclusion, we see indications of eco-systemic value co-creation in AM, although none of the defined ecosystem types are known from IS research (Valkokari, 2015; Suominen et al., 2019; Guggenberger et al., 2020) entirely fits the value creation structures in AM.

3 Research Design

This research paper is located in the field of design-oriented information systems. We follow the iterative four-step design-oriented IS research approach proposed by Österle et al. (2011). The analysis phase is taken into account in chapter 1 and chapter 2, whereby this paper represents the diffusion phase.

Design: The design phase aims to design an artifact based on established research methods (Österle et al., 2011). We relied on empirical data collected through semi-structured interviews with experts from different companies in the AM domain. This methodology suits to understand complex phenomena from the interviewees' point of view and allows both open questions as well as comparison across interviews through a common guideline (Myers, 2013). We identified relevant companies alongside the AM value process based on the membership lists of the German Mechanical Engineering Industry Association and the Crunchbase database (see the list under the following URL: https://bit.ly/3qNlPXR). To answer the research question, we intended to generate insights into how value-creation is structured and organized collaboratively in AM. Accordingly, we asked the interviewees for their specific value creation process. Subsequently, we openly discussed possible stakeholders (i.e., suppliers, customers, and other partners) involved in each value creation phase. In order to cover a sufficient variety of perspectives, we iteratively identified stakeholders alongside the discussed value creation processes and contacted additional experts of upcoming fields (snowball process).

Considering the known risks of qualitative research based on interviews, we have taken some measures to increase the validity of the interpreted information. To mitigate the "descriptive validity" we attended each interview with at least two researchers to correct each other in case of misunderstandings and ask more follow-up questions iteratively. During the interviews, we visualized the information shared by the experts. In addition, the experts could intervene directly in case of misunderstandings, as the interactive board was shared during the interviews, which took place online. Besides, the online format of the interviews enabled us to record the discussed value activities except for two interviews where we were not granted permission. In total, we conducted 15 interviews with experienced domain experts between June and November 2021 (see a complete list of the interviewees under the following URL: https://bit.ly/3qNlPXR). As no new value creation steps and stakeholder types were uncovered during the last five interviews, we assumed theoretical saturation (Myers, 2013).

Our codebook included the descriptions of specific value activities. Since these activities represent individual steps of the value creation process, they enable the decomposition of value propositions of the analyzed AM companies. Adopting the logic of axial coding, we were able to cluster individual value activities into groups in a further step of the content analysis. As the groups consist of related activities, this aggregation helped us to define the value proposition and derive the generic roles in the AM domain. These derived roles indicate partial overlaps in the value offering. This illustrates how different AM companies operate in value networks and compete with each other simultaneously. Since each interview reflected a value network, the sum of the interviews forms the data basis for modeling a generic AM ecosystem. To model the AM ecosystem, we apply the e3-value approach (Gordijn and Akkermans, 2003). This approach helps to combine the roles involved in the value creation for the end customer, including the illustration of value linkages among the defined value modules (Gordijn and Akkermans, 2003). Since e3-value helps to model multi-actor networks, it was also used to conceptualize value creation in ecosystems in other domains (Böhm et al., 2010; Riasanow et al., 2017; Gleiss et al., 2021). In our study, e3-value enables us to identify value-adding activities that are critical for joint value creation to satisfy end customers' AM demand.

Evaluation: We achieved a two-part evaluation of our artifact. At first, interim evaluations were done by modeling the individual enterprise ecosystem based on the expert interviews and sending those generic ecosystem fragments back to the corresponding experts, questioning whether their value-adding activities and interdependencies with other ecosystem roles corresponds to the reality or if adjustments must be made. The second part of the evaluation was done with the developed artifact. We presented the generic AM ecosystem (see section 4) in three additional interviews with two AM experts and researchers in the field of ecosystems BMs. By presenting the whole AM ecosystem, the experts had the chance to make adjustments, reducing the researcher bias and increasing the overall external validity of the results achieved. The interviews to discuss the artifact were guided by the questions on the usefulness of the generic ecosystem from a managerial perspective to expand a partner network, identify value-added niches in the offering and adjust a strategic positioning in an ecosystem (Weiller and Neely, 2013). Hence, we primarily discussed the potentials and limitations of the artifact. Additionally, we examined the theoretical added value of the artifact (see section 5) and the rigor of the artifact creation with the interviewed scientists.

4 Findings

In order to interpret the empirical findings in the next step, the main empirical artifacts of each interview need to get homogenized. Therefore, the interpreted data is partitioned into three hierarchically related concepts. These concepts form a specific ecosystem for the AM application context of the interviewed company. The first-order concept is represented by value-adding activities that different actors provide in an AM ecosystem. We conceptualize value-adding activities as the smallest elements of a firms' definable offering, proposing value to the ecosystem (e.g., design an AM product or finish a semi-finished AM part (section 4.1)). The second-order concept of the findings are AM-specific roles, which combine one or more complementary value-adding activities, setting the boundaries for a value proposition (see section 4.2). These roles have a higher abstraction degree than BMs or single firms.

4.1 Value Adding Activities

The synthesis of the value processes of each interviewed firm led to the definition of 15 abstract value-adding activities. Each value-adding activity is characterized by its type of creating value and its specific output. The identified value-adding activities are summed up in table 1.

Value-adding Activity	Description	Stated by Expert
AM Engineering	AM Engineering Activity includes specific AM knowledge to conceptualize an AM product/part (e.g., selecting feasible product functions or appropriate AM technology). Results are requirements for the AM product.	# 1-6, 9, 11-14
AM Design	AM Design Activity creates value by geometrically designing an AM part and specifying further properties based on its requirements. The result is a digital product model (e.g., CAD model).	# 1, 2 ,4-6, 11-14
AM Production	AM Production Activity provides the layer-by-layer production of the AM part based on the digital product model and a specific AM technology. This value proposition also contains necessary pre-processing activities, e.g., packing/nesting of a building job. The result is a physical AM part (semi-finished).	# 1-7, 9-15
Post-Processing	The Post-Processing Activity focuses on refining of semi-finished AM parts into final AM parts based on different technologies (e.g., surface finishing, removing of support structures).	# 1-5, 9, 11
Assembly	The Assembly Activity ensures the assembly of AM parts into components. The result is a final product that contains AM parts	# 4-6
Sales	Sales Activity facilitates new orders as well as order management.	# 2, 6, 7, 8
AM Consulting	AM Consulting Activity includes various consulting services that use AM-specific knowledge (e.g., market, technology, material, design, …) alongside the AM process.	# 2, 3, 7, 10-12
AM-specific Software Solution	AM-specific Software Solution Activity sums up the development of heterogenous AM-specific software solutions (e.g., CAD-, simulation-, pricing-tools, etc.).	# 1-5, 8, 9, 11-14
AM Production System	AM Production System Activity includes manufacturing and/or provision of AM production units (hardware) for the AM Production. Besides AM systems (coll. 3D printers), this term also comprises machinery for AM-specific post-processing.	# 1-4, 6, 7, 9 ,11, 12, 15
Service	Service Activity contains the maintenance of AM production systems.	# 7, 10
Standardization & Certification	Standardization & Certification Activities address regulator conditions. Standardization of processes, (manufacturing) technologies, and products deliver value to all market participants by raising transparency and reducing transactional costs. Additionally, the certification of operators in terms of education is valuable in order to acquire knowledge.	# 2, 3, 10
Material Supply	Material Supply Activity ensures the provision of primary materials for the AM production systems (e.g., metal powder).	# 1-4, 6, 7, 9, 11, 15
Material Distribution	Material Distribution Activity channels and controls the materials supply between raw material suppliers and material demanders (e.g., printer manufacturers, print service providers, producing end customers).	# 15
Material Refining	Material Refining Activity enables the individualization and the improvement of materials to reach a desired level of quality in the demanded AM part.	# 15
Material Recycling	Material Recycling Activity enables the recycling of unused or waste material alongside the AM process.	# 3

Table 1. Value Propositions inside the AM Ecosystem based on expert interviews.

4.2 Additive Manufacturing Specific Roles

In the next step, we assign the value-added activities to build value propositions, enabling us to derive abstract roles. Accordingly, generic roles might have multiple and overlapping value-adding activities. The authors derived the roles in multiple workshop sessions.

AM Designer & Producer: This role unites AM Engineering, AM Design, AM Production, and Prost-Processing with an optional Assembly of AM parts. Therefore, it creates added value by creating virtual and manufacturing physical AM parts. Typically, AM service providers represent this role because there is a need to analyze (and often re-engineer) the digital product model ahead of physical production. This is caused by a lack of design know-how for specific AM technologies of most B2B customers.

AM Value Creator: The objective of AM Value Creator is to leverage the AM potential of a product. In many cases, AM technology cannot compete against conventional production technologies in terms of costs per part. It is crucial to create added value to the customer by integrating additional value into a part (e.g., bionic lightweight structures or individualization) or gaining additional value from the process (e.g., decentralized production of spare parts). Therefore, this role unites the engineering, consulting, sales, and design value-adding activities.

AM Refinement: The AM Refinement role unites activities of post-processing and assembly of AM parts into components or products. Highly specialized companies with post-processing technologies represent this role in order to charge their production capacities. Conventional manufacturing providers and AM service providers can both offer their post-processing capacities to their competitors.

AM IT Solution Provider: This broadly defined role incorporates the value-adding activity of AM-specific IT solutions. Therefore, IT solutions, provided to different roles and enhancing value-adding activities, vary significantly and range from classical stand-alone software to web-based services or system-integrated software. Examples are configurations for the sales and engineering department or CAD/CAM software for AM Designer & Producer. Also included in this role is the providence of the software needed for the AM systems.

AM System Provider: The AM System Provider combines sales, AM production system, and service activities. Thereby this role provides adequate AM production systems and corresponding services for the AM Designer & Producer role.

Sales Platform Provider: The Sales Platform Provider combines Sales and AM specific IT Solutions digitizing and automating the placement of orders to allocate demand of AM parts with existing manufacturing capacities. This is an intermediary role that is based on a network of different AM production service providers, receiving part designs or possible production orders from AM customers through the platform.

AM Consultant: This role (note that AM Consulting is also part of other roles) provides AM-specific knowledge to various AM-specific roles. For instance, an independent production technology scout that covers AM amongst other technologies is represented by this role.

AM Researcher: This role differs from the before-mentioned AM Consultant by adding value through Standardization & Certification. AM domains like aerospace or the medical domain are crucial to certified products and processes. Furthermore, this role addresses aspects of education and qualification by imparting knowledge to employees.

AM Material Supplier: This role provides the basic materials for AM production (e.g., polyamide or metal powder, filament etc.). The value-adding activity AM Consulting is used to provide special material qualification for AM technologies to AM production, which usually requires an in-depth analysis of the specific AM use case.

Material Recycler: In some cases, unused AM Material (e.g., thermally stressed polyamide powder) is utilized within other manufacturing processes (e.g., die casting) or recycled by the role of Material Purchasers.

Figure 3 illustrates the generic AM roles defined above in an overlapping notation according to their covered value-adding activities and with their unique value proposition. These identified roles are based on empirically observed value propositions of AM-related companies. It should be noted that taking a role does not exclude from other roles. For instance, an AM Systems Provider could also distribute qualified material as a Material Supplier, or an AM Designer & Producer could spin off its AM design knowledge as AM Value Creator.

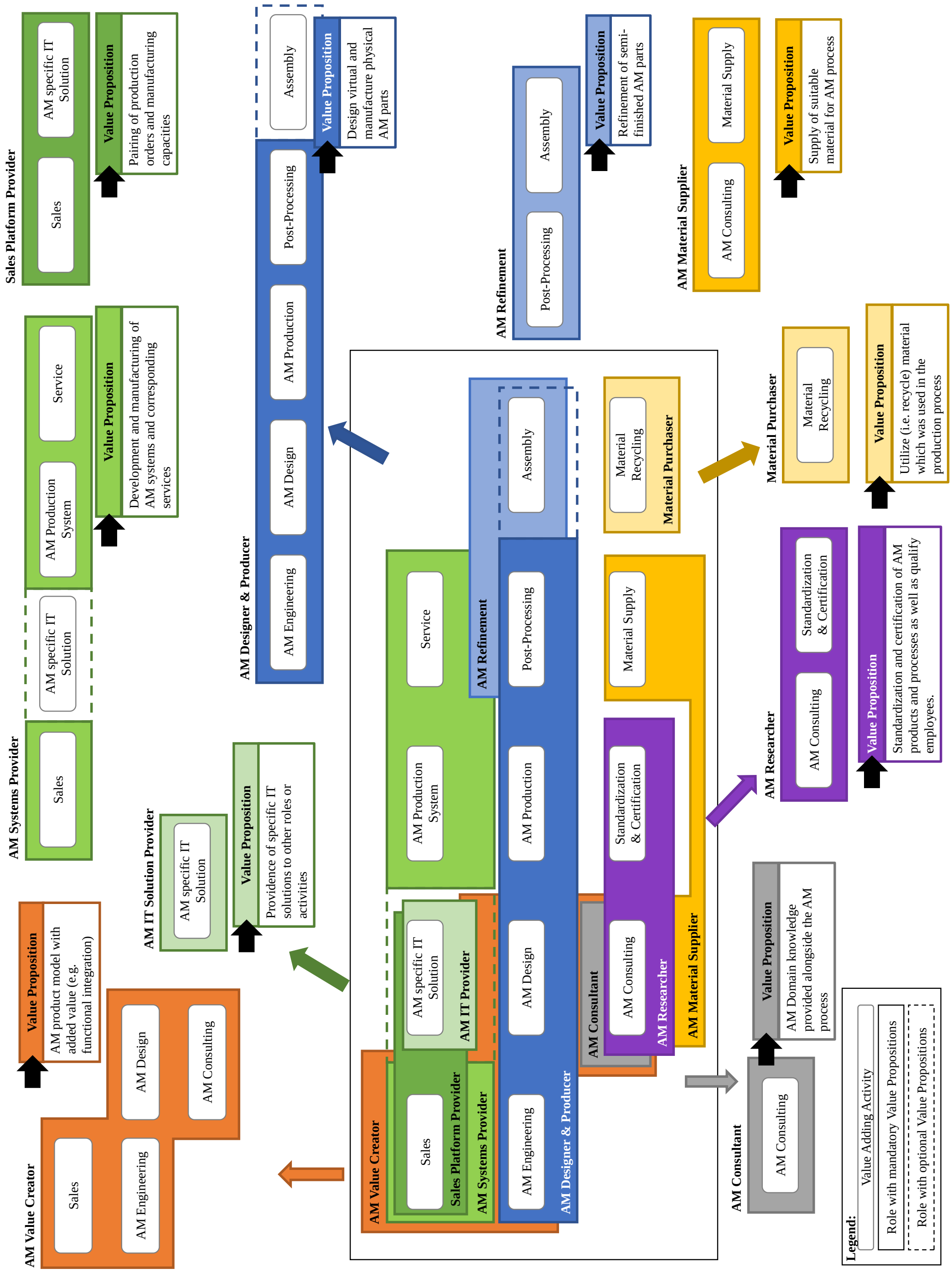

Figure 3. Identified AM-specific Roles.

4.3 Generic Additive Manufacturing Ecosystem

Finally, we utilized the logic of the e3-value method to model a generic AM ecosystem. Due to the multiplicity of the roles in terms of the combination of activities, we have chosen the granularity level of the activities. Nevertheless, the overlap of several roles in some value-adding activities hampers the modeling of countervalue flows (i.e., monetary countervalue) in the value exchange (Gordijn and Akkermans, 2003). If alongside the value flow consecutive activities are provided by one ecosystem actor, typically there is no money flow as in the case of an external actor. Hence, the overlaps prevent the chaining of intra-organizational value exchange between value-adding activities in the original e3-value methodology. In order to model financial return flows, we adopted the extension of e3-value for handling real options (Kundisch and John, 2012), which contains additional notation elements for modeling optional, but not necessarily occurring flows.

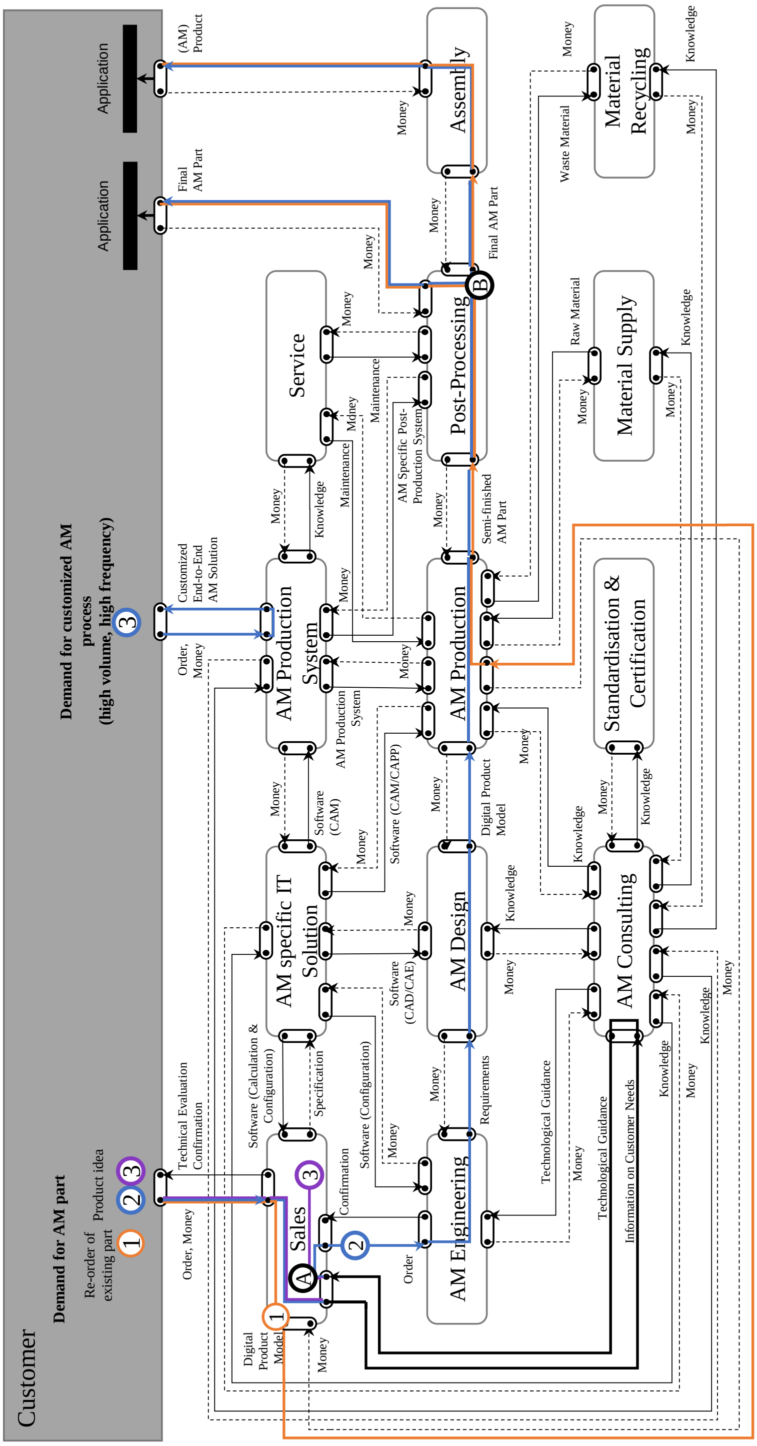

Figure 4. Generic AM Ecosystem, based on the derived value-adding activities.

From a theoretical perspective, the generic AM ecosystem calls upon the generic ecosystem schema proposed by Adner and Kapoor (2010), and the ecosystem-as-structure view (Adner, 2017), which intend to demarcate interdependencies of joint value creation, highlighting activities required to materialize a value proposition. In addition to value-adding activities and the related value exchange, there are three significant value flows modeled. Firstly, the reordering of an existing AM part initiates an order in Sales that is directed to the AM Production activity since there is no engineering and design necessary (#1 in figure 4). Secondly, a product idea initiates an order in sales, leading to further coordination (#2 and #3 in figure 4). Based on various criteria (e.g., application field, lot size, product quality), design principles and AM technologies have to be individually chosen. In this step, early AM Consulting can deliver technological guidance (A in figure 4). Usually, AM Engineering and AM Design are passed through to create a Digital Product Model (#2 in figure 4). An alternative path could be chosen to develop a complete AM production system (i.e., production line) to produce AM parts in high quantity internally. This path leads to a separated order for an AM production system (#3 in figure 4). Finally, there is an option downstream between an AM part with and without assembly (B in figure 4). Accordingly, we propose the following generic AM ecosystem, as shown in figure 4.

This generic ecosystem indicates four major conclusions according to value flows to create an AM part:

- **Sales activity is crucial** in order to coordinate different value flows. Therefore, profound AM knowledge is needed (e.g., compare AM to other production technologies). In addition to the splitting of optional value flows, the overlapping of different roles (c.f., figure 3) in Sales activity and first contact to customers highlight the significance of the Sales activity.
- The **AM Value Creator** and **AM Designer & Producer** combination cover the **complete value flow of an AM part** (c.f., figure 2). It could be stated that companies that take both roles can provide AM technological excellence to their customers and add value by leveraging AM potential in terms of design. It has to be noted that this applies while ordering AM parts from AM service providers is more economical than operating an AM Production System (e.g., production line).
- **AM Specific IT Solution, AM Production System, and AM Consulting** are the value-adding activities **enabling AM value creation**. This can be seen in figure 4, as these activities contain the most value ports and offer relations to the main value-adding activities alongside the value flow of an AM part. Accordingly, the roles AM Value Creator, the AM IT Solution Provider, and the AM Production System Provider can be considered as pivotal in the joint AM value creation, which includes both physical (i.e., physical component) and digital value flows (i.e., associated software to design and produce it). Interestingly, the critical roles predominantly focus on design and production, as value creation focuses on qualitative components.
- **Digital platforms** are in the foreground to solve the organizational question of one's own production capacity utilization since they cover the Sales activity and crucial coordination activities. This is the reason why we deliberately titled the corresponding role **Sales Platform Provider** (and not AM platform). This last point marks a major distinction between AM platforms in B2B and B2C. Whilst there are various AM platforms for AM design and production in the consumer space, we could not identify B2B platforms providing other services than sales coordination to professionals.

5 Discussion

Conducting interviews with the different company types from the AM domain, we were able to derive determinants (i.e., value-adding activities and roles) for developing a generic AM ecosystem. Based on the proposed ecosystem determinants, we develop implications for BM creation in an ecosystem organization without a keystone presence. Our study provides conceptual guidance on edge between BMs and ecosystem creation by supporting a potential orchestrator BM and fostering the establishment of currently lacking leadership roles in AM. Recent analyst reports, such as the one published by Boston Consulting Group, even attested a missing business ecosystem in AM (Heising et al., 2020).

According to Adner (2017) we can identify ecosystem value creation in AM. Nevertheless, the industry experts interviewed also did not see any company in a ubiquitous technological leader role, according to Gawer and Cusumano (2014). Considering the heterogeneity of applications for AM technology described in the literature (i.e., hearing aids or aerospace), the orchestrating role may be occupied by firms that already possess or acquire (e.g., mergers and acquisitions) capabilities to embrace the critical value-adding activities and transferred to new application domains. Following this logic, partnering with companies that dominate critical activities in specific application domains can be considered as the **instantiation of the tipping strategy** from the platform strategy. Tipping is a strategy to establish a platform where none existed before (Gawer and Cusumano, 2008). Similarly, alignment of critical value activities could foster leveraging existing resources in industries without the overall domination of AM production and disrupting new application domains. Therefore, the proposed generic ecosystem and its roles build a blueprint for firms that pursue the strategy to orchestrate the evolvement of the AM technology due to their leadership role (Adner, 2017) in specific application domains and support the creation of sub ecosystems for distinctive AM applications. This evolution is similar to that described by (Isckia et al., 2020), except that sub ecosystems emerge identified using different AM applications with determinants similar to those in the generic ecosystem.

Our second implication aims to provide insights on the emergence of leadership strategies with orchestration power in the AM domain. We can see that certain activities and the corresponding roles in the AM domain demonstrate **a shift toward a multi-sided structure**. Hence, traditional pipeline models are not optimal to contribute to the AM domain's value creation in a competitive way. This is particularly interesting because existing platforms do not offer orchestrator roles in the AM domain. Accordingly, orchestrator BMs can be consistently expanded and pursued by different roles that already have such activities that combine many value streams in their BM. These are, for example, **AM-specific IT Solutions**, **AM Production Systems**, and **AM Production**.

Additionally, extant research suggests that BM design aiming to orchestrate an ecosystem requires careful positioning in the ecosystem (Weiller and Neely, 2013). Considering this, our findings illustrate overlaps in BMs of the firms already present in the domain. These overlaps can be explained by the AM-specific knowledge intensity needed to create added value. According to our data set, this can be particularly observed for the first time demand for AM parts. In this case, customers favor a single source AM solution, which is why a clear intra-organizational division of activities is still lacking (e.g., missing AM-specific knowledge for AM Design activity). New market entrants with innovative services can primarily address those identified value-adding activities that (1) either have a lot of overlap and thus promise to scale or (2) are more likely to be addressed by a few roles to create specific niche offerings. On the one hand, this finding helps with entry into the AM domain by **identifying peripheral value-added niches**.

On the other hand, our findings also help in the BM design of the orchestrators. Ecosystem alignment to balance the shared value is a critical task in orchestrator BMs (Iansiti and Levien, 2004; Morgan et al., 2013). The combination of the knowledge of the application domain diversity, the existing overlaps in the value proposition of different roles, as well as the heterogeneity of roles and their interdependencies, support the BM design of a potential ecosystem leader who is eager to cope with these challenges and align them in future. Stakeholder identification and analyses are an essential part of the requirements engineering (RE) process (Glinz and Wieringa, 2007; Zowghi and Coulin, 2005). Accordingly, the demarcation of different roles and their value-adding activities supports the establishment of orchestrator BMs by **supporting the development of partnership networks**, the **resourcing strategy** to engage the partners, and the **key channel development activities** that a potential AM orchestrator has to cope with (Osterwalder and Pigneur, 2011).

Due to these interdependencies, however, it should be noted that a classic prioritization of roles, as practiced in traditional RE, is not feasible. It is possible to distinguish between those roles that perform an activity included in the value creation of the end customer (e.g., AM Production) and those that only perform complementary activities (e.g., Material Recycling). Since these activities also contribute to the final value proposition, a classic prioritization is not appropriate to serve an entire ecosystem as an orchestrating leader. Therefore, our study adds descriptive insights on the positioning in an ecosystem setting (Ivarsson and Svahn, 2020; van Dyck et al., 2021) as a necessary strategy to execute a BM in the dynamic and, therefore, the competitive domain of AM, providing practical guidance for manufacturing and software companies. Utilizing the generic ecosystem, these entrants can focus their own value proposition on the value-adding activities traversed by signal paths and the associated roles.

Given the lack of software support that can fully support a cross-company AM process, our third implication relates to the methodology utilized. We argue that to establish leadership in any domain, it is not enough to offer silo software solutions for bridging two roles, but a **data continuity along the entire value chain** from the creation of demand to its satisfaction must be established. The analysis of the literature and the interviews on the AM domain reveal a multitude of different already existing and soon-to-be-released digital platforms for the digitalization of the ordering process of AM parts. However, these platforms are not (yet) able to completely map the value creation process along the signal paths (c.f., Figure 4). Thus, AM value creation is characterized by data discontinuities, even though an AM end product is entirely digital at the beginning. For this reason, conceptual modeling of a generic ecosystem can help software companies understand the existing interdependencies of individual BMs. In turn, this can help to develop a platform to enable the data pervasiveness alongside the value stream and foster domain-specific leadership of AM platform providers.

Lastly, the proposed generic ecosystem extends the ecosystem perspective and its specific business models (Piller et al., 2015) in the industrial use of AM. Furthermore, we provide empirical evidence on the heterogeneous BMs in the AM domain, complementing the AM-specific BM knowledge (Savolainen and Collan, 2020), which mainly stems from the scientific literature.

6 Conclusion and Outlook

From the perspective of research, our artifacts comprise 10 AM-specific roles and their value-adding activities to create a generic ecosystem of the AM domain. These empirical findings add to the body of knowledge, as stated in the paragraph before. Additionally, we encourage other researchers to conduct follow-up research on the impact of AM, especially on domains with distinct features. Further in-depth analysis of our data could lead to the formation of design principles for orchestrator BMs in the future, based on Giessmann and Legner (2013). Our artifacts combined with the e3-value approach are of value for companies inside the AM domain or can support entering it. The evaluation experts stated that based on the generic AM ecosystem companies entering the market (e.g., through merger & acquisitions), they could align, which activity they want to offer, and which role they want to enter, which would open up further research. Besides, future research can use our results to develop structured approaches for leadership or orchestrator BM design. Already established BM frameworks based on key partners or key activities can be enhanced by our presented roles and value activities.

Our research is based on a literature review, expert interviews, and evaluation interviews. Although we claim the usefulness of our results for the ecosystem orientation of BMs in the AM domain due to the richness of perspectives captured through interviews, we analyzed only one industry, which is why the generalizability of our findings regarding the orchestrator BM blueprint is limited considering other domains. Also, the AM market is very versatile, with new players establishing new technologies and BMs, so the derived roles and activities can become outdated quickly. Therefore, a comparison with further ecosystems arising from new technologies without keystones would strengthen the generalization of the results. This could also increase the cross-domain universality of the defined roles. Future research could also consider interdependencies within the roles and value activities from two perspectives. From the engineering perspective, proposed artifacts may help to identify the disruptive potential of AM. If that should be the case, research and practice should be able to predict whether AM can revolutionize the industry in the near future or not. From the ecosystem perspective, understanding different ecosystem subtypes could be improved. Replications of our study can help validate its usefulness in ecosystem positioning. Besides, the visualized generic ecosystem and further analysis of the interview data can reveal technological, economic, and cognitive interdependencies present in ecosystems (Thomas and Autio 2020). Lastly, aligning our collected data with databases such as Crunchbase could extend the derived list of roles and activities, improving the AM-specific results.

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