Requirements and a Meta Model for Exchanging Additive Manufacturing Capacities

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Abstract. In an environment shaped by digital transformation and globalization, manufacturers face increasing market dynamics, cost pressure, and more sophisticated customer requirements. As this demands flexibility and adaptability, enterprises rely on new solutions for collaboration. A marketplace for production capacities supports companies in reducing order risks and improving responsiveness to changing market conditions. We seek to define requirements for a marketplace that is capable of matching products with production processes. With an initial focus on additive manufacturing, we aim to build a blueprint for similar application scenarios in other industrial contexts. Therefore, we employ a qualitative research based on expert interviews. Our results suggest that a marketplace for production capacities must address various requirements, which can be grouped under the categories of technologies, machines, and products. We further build a conceptual meta model that sets the groundwork for the matching and thus facilitates the implementation of the marketplace in practice.

Keywords: Additive Manufacturing, Market Engineering, Sharing Economy, Sharing Capacities, Two-sided Markets

1   Introduction

In a globalized and digitalized business environment, manufacturers face various challenges that question established strategies and business models. At the center of their business activities, the area of production is influenced by many of the current megatrends, including *Industry 4.0* or *Internet of Things*. They do not only alter production concepts. Enterprises also face more sophisticated customer requirements, increasing competitive pressure, and higher market dynamics. The ability of manufacturers to respond to these changes is mainly determined by their production capacities. On the one hand, the number of orders can exceed available capacities, yielding delays or the non-fulfillment of orders with negative consequences on sales and profits. On the other hand, underutilization imposes the risk of fixed costs that cannot be fully covered. Overcoming the tradeoff between availability and production capacity related costs is frequently perceived as a key factor for the competitiveness of

manufacturers [1]. Furthermore, specialization has led to the emergence of supply networks, in which enterprises focus on their core competencies to contribute to and jointly build a complex product or service [2]. This comes with a division of tasks, activities, and responsibilities, which yields direct and indirect interdependencies between market participants and the emergence of single points of failure [3].

To cope with these challenges, enterprises rely on solutions that enable them to adapt to dynamic market conditions by offering or sourcing production capacities to other market participants. This does not only provide enterprises with the opportunity to align capacities with demands, but also fosters collaboration, communication, and the coordination of distributed actors.

Nowadays, complex material flows are supported and controlled by integrated information systems [1]. Most Industry 4.0 scenarios require a seamless integration of processes and information flows based on advanced information and communication technology. Thereby, production planning systems provide enterprises with an integrated database that contains information about available capacities, current delivery times, and future demand [4]. While these systems offer various functionalities for the company-specific management of production capacities, they hardly support transactions between multiple participants that collaborate in a supply network [1].

Against this backdrop, this study[1] seeks to conceptualize a marketplace for production capacities that operationalizes data from multiple manufacturers and yield improvements in various dimensions, such as performance, quality, and costs. Implemented as a central platform, the solution connects to enterprise software of different supply chain participants and allows for superior communication and collaboration. Based on the principles of the *Sharing Economy*, the proposed marketplace matches products with production processes as well as supply and demand. Similar solutions, such as Uber for transportation and Airbnb for housing, have proven effective in various contexts and application scenarios [5, 6]. Due to the complexity of the underlying research problem, we initially focus on the production technology of additive manufacturing. Additive manufacturing is more flexible and subject to less constraints. Hence, it provides the optimal starting point for this research endeavor. It allows us to build a proof of concept and to establish a conceptual foundation for similar solutions that address the requirements of other industries. Our research is guided by the following research questions (RQ):

1. What are the requirements for a marketplace that enables manufacturers to exchange production capacities in the field of additive manufacturing?
2. How can we design a meta model that matches products to production processes and thus facilitate the practical of implementation of a marketplace for production capacities?

To answer these RQ, we structure this study as follows: we present related work on platforms and collaborations in supply networks in the subsequent section. We describe the applied research design in Section 3 and present the results of our interview study in Section 4. Subsequently, we integrate our findings and build a meta model for the matching of products and production processes in Section 5. Ultimately, Section 6 concludes this study with a summary of findings, limitations, and future research potentials.

2 Foundations and Related Work

The concept of *Collaboration in Supply Networks* describes networking manufacturers, which has gained tremendous importance in recent years [7]. More sophisticated customer needs, considerable product development costs, and market dynamics yield an increasing pressure on supply networks and require them to realize continuous performance improvements [8]. Effective collaboration can leverage economies of scale, specialization, and integration [9–11]. The ongoing trend of the *Sharing Economy* has already led to a reorganization of a variety of established business activities [12]. Innovative technologies and business models incorporate the principles of this emerging paradigm and change industries by reducing transactions costs and providing easier ways to interact with customers. Thereby, products are increasingly augmented with services, which can be offered and sold based on various business models.

Electronic Commerce (e-commerce) is frequently described as a subclass of *Electronic Business (e-business)*. E-business does not only cover the buying and selling of products and services, but also includes internet-based activities, such as customer service or electronic transactions [13]. E-commerce belongs to the e-business paradigm and describes the generation of revenues by initiating, negotiating, or processing business transactions via networks [14]. In 2015, e-commerce revenues amounted to 1,55 trillion US dollars and are currently expected to increase to 3,4 trillion US dollars in 2019 [15–17].

Collaborative Business (c-business) augments e-business or e-commerce with the concept of collaboration. It provides a holistic view on processes and inter-organizational cooperation. The concept uses the notion of end-to-end processes to integrate all participants of a supply network that collaborate and interact via the Internet, EDI, e-portals, or e-marketplaces. Represented by delivery deadlines or demand forecasts, collaborations can yield benefits in various dimension through the exchange of information [18].

Electronic Platforms in e-business can be divided into three types: the concept of *e-procurement* focuses exclusively on electronic purchasing, while *e-shops* pertain to sales activities. Furthermore, *e-marketplaces* provide platforms for the exchange of products and services. Products or services should be offered or requested without charge, but in an organized manner [14]. As of now, there is no marketplace that connects with established enterprise software and allows enterprises to exchange production capacities in order to address demand or supply fluctuations.

Building an e-commerce platform for exchanging additive manufacturing capacities requires profound knowledge about corresponding production processes, configurations, and influence factors. In general, manufacturing defines an industrial or artisanal production process and describes the way in which something is made. The production of components is specified in geometric and material terms [19]. *Additive Manufacturing*, commonly known as 3D printing, is one way of manufacturing. However, additive manufacturing summarizes a variety of manufacturing processes with the aim of producing physical objects on the basis of digital models that are converted into layer models by so-called *slicing*. Additive manufacturing processes add material in layers to obtain a desired object [20–23]. In the past, several techniques have been introduced that differ in regard to the way in which layers are created and connected. Because manufacturing works process oriented and depends upon the used material and machines, the dimensions machines, processes and materials are characterized by significant interdependencies [24].

3 Research Methodology

We employ a qualitative research design based on expert interviews to determine requirements for a marketplace that exchanges additive manufacturing capacities. The chosen design is a result of the limited knowledge on marketplaces for capacity sharing. Hence, we rely on an explorative research approach that integrates the perceptions and opinions of multiple stakeholders with extensive knowledge and experience in the domain of interest. The following section summarizes our research method and elaborates on the selection of interview partners, the design of the semi-structured questionnaires, and the procedures performed for data collection and analysis.

3.1 Selection of Interview Partners

Out of all interview partners four groups of companies and associated experts are defined and interviewed: (1) *potential buyers* of additive manufacturing capacities, (2) *potential sellers* of additive manufacturing capacities, (3) *producers of machines* for additive manufacturing and (4) *platform providers*. The interviewees are required to have knowledge about essential IT and management concepts as well as about the additive manufacturing technology. To select the experts, we first interview various employees of the nine companies to ensure they possess the necessary knowhow.

We interview potential buyers and sellers that already use additive manufacturing, intend to use it in the future, or are interested in buying additive manufacturing capacities. We integrate producers of additive manufacturing machines to evaluate aspects that are relevant for the underlying production processes and platform providers to shed light on requirements that must be addressed when implementing the proposed marketplace in practice.

We use multiple criteria, such as market position, experience in the field of additive manufacturing and e-commerce platforms, and industry and company size for case selection. This leads to a final sample of nine companies with one expert each. It

consists of three companies from each of the two groups of potential buyers (buyer A, buyer B, buyer C) and sellers (seller A, seller B, seller C), two manufacturers (manufacturer A, manufacturer B), and one platform operator (platform operator A). There is only one platform operator existing on the market, which can serve as a basis and orientation for our research project. Users of the platform are the key actors on the platform and therefore reflect the most important group for the development of requirements. For this reason, three experts are interviewed there. Machine manufacturers all have similar structures and do not differ as much as the companies using the platform. For this reason, fewer experts are surveyed than in the category of users.

3.2   Questionnaire Design

The interviews are conducted by phone and are based on group-specific semi-structured questionnaires. The questionnaires contain basic information for the interviewees as well as guidelines and questions.

In order to ensure high quality and rigorousness, we operationalize the criteria proposed by [25]. Not included are the criteria *scaling*, *standardization*, and *fairness*, as they are primarily relevant for psychological analysis.

The following section describes the structure of the questionnaires. They are designed in a semi-structured manner, as the interviewees have a basic knowledge of the topics of interest. The interviews are conducted flexibly on the basis of open questions and provide the opportunity to include emerging concepts and ideas [26, 27]. In addition, the questionnaire contains different question types. Besides essential, factual, or direct questions, which address the key topic of this study, so-called *throw-away questions*, introductory, and structuring questions are used to guide the interview progress [28].

Each of the four questionnaires is introduced with a short preamble explaining the goals and scope of this study. In addition to a verbal explanation of the research, we provide information about the recording procedures, anonymity agreements, and data privacy and ask for the interviewees' approval. This is followed by two questions about their educational and work background. Thereby, we ask them to provide general information about their company and their function and responsibilities within it. This allows us to draw conclusions about the quality of their answers and to consider them in subsequent phases of this research.

The second section contains two general questions that introduce the topic and prepare the interviewees for more complex questions. Hence, we ask the interviewees about potential benefits of exchanging additive manufacturing capacities on the one hand, and about possible challenges on the other hand. These questions only serve the flow of discussion and the answers are used to justify this research but are not presented in more detail.

The subsequent part of the questionnaire varies with the expert group. Section three of the questionnaire for manufacturers and platform operators covers the portfolio of additive manufacturing technologies and machines. Questions about selected additive manufacturing methods, models, and production machines as well as about their

characteristics are to be answered. In contrast, the third part for platform users includes questions about the buying and selling of capacities. Questions in this section analyze the external and/or internal additive manufacturing capacities used so far as well as their reasons for using a platform in this context.

The fourth section of the questionnaires for manufacturers and platform operators requests information about their machines, such as target groups and industries, applications, and covered product categories. Platform users are further asked about required processes and for characteristics that can be used to distinguish processes and machines.

The fifth part of the questionnaire for platform operators contains questions about the matching of products and additive manufacturing processes. The experts are asked for necessary/unnecessary attributes that must be considered when designing a matching mechanism. The questionnaire for manufacturers does not have a fifth section. Platform users are asked to provide information about the characteristics of additively manufactured products, including their material or size and other aspects.

3.3 Data Collection and Analysis

In order to achieve high-quality results, we describe the employed procedures for data collection and analysis subsequently [29]. Prior to the actual data collection, a pilot study was conducted with two independent researchers. The test confirmed that the questionnaire is understandable, well-structured, and of reasonable length and complexity [28]. As a result, we did not implement any significant changes to the design of the questionnaire.

Despite the various advantages of personal interviews as pointed out by [28], long distances required us to conduct the interviews via phone. The full conversations were documented based on audio recordings.

For data analysis, we followed the process explained in [30]. First, the available audio recordings were transcribed. The transcripts were written literally, the sentence structure was adapted, and filling words were deleted. Finally, we anonymized the transcripts.

The transcripts were then analyzed in order to derive requirements for the matching of products and production processes. For this purpose, the process of content analysis according to [30] was initiated by coding the data. Codes allowed us to break down relevant information to keywords. The coding process was performed by using the MAXQDA Version 18.0.8 software. We initially used the frequencies with which certain words were mentioned in order to determine suitable codes. We sorted the resulting words, consolidated synonyms, and classified sub-codes in subsequent steps. We then formed summarizing categories to group codes with similar meanings. In the next iteration, we controlled whether and to what extent all relevant questions of the guideline were covered by the codes and categories. The results of the categorization provided the basis to derive requirements for matching and sharing additive manufacturing capacities.

4 Requirements for Capacity Exchange

Subsequently, we introduce the requirements for a marketplace for capacity sharing and thereby answer RQ1. In summary, data analysis yielded a total of 371 coded text passages that are relevant for this research and thus suitable for requirements engineering. The passages are grouped into three categories *(1) characteristics of additive manufacturing technologies and machines* (192 occurrences), *(2) characteristics of products to be additively manufactured* (149 occurrences), and *(3) matching products and additive manufacturing technologies* (30 occurrences).

The analysis is carried out by means of a category-based evaluation along the main topics summarized of these three categories [30]. We define requirements for the process of developing the matching and thus exchanging additive manufacturing capacities via an e-commerce platform.

Recent studies identified more than 200 machine types for additive manufacturing on the market [24]. As a basis for expert evaluation and discussion we performed in-depth analysis of literature and actual technical documentation available, which cannot be mapped-out in further detail within the limitations of this paper. However, the findings served as the necessary conceptual foundation of clustering the multitude of additive manufacturing technologies, machine types and suitable characteristics.

Although all manufacturing processes are based on the manufacturing steps already explained, they differ e.g. in terms of how the respective layers are manufactured and bonded and which material is processed.

First of all, it is necessary to examine which additive manufacturing processes can be used for which groups of material.

Requirement 1: Additive manufacturing processes for plastic materials must be evaluated for exchanging manufacturing capacities in a first step, as these are most frequently used in practice.

The first code in category *(1) characteristics of additive manufacturing technologies and machines* contains selected manufacturing technologies represented by subcodes. These were derived on the basis of word frequencies. According to the experts, additive manufacturing processes for plastics are most frequently used in an industrial context. The companies surveyed named the technologies Stereolithography (SLA), Binder Jetting/3D Printing (BJ/3DP), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Multi Jet Fusion/High Speed Sintering (MJF/HSS), Multi Jet Modeling/PolyJet (MJM/PJ) and Digital Light Processing (DLP). Experts have described these as standard technologies. The material group *plastics* represents the largest group of materials for additive manufacturing and is therefore the first category to be considered [24, 31]. Furthermore, the subcode *plastics* in category *(2) characteristics of products to be additively manufactured* implies that buyers A, B and C mainly manufacture plastic products. The focus on the material group *plastics* could thus be decided.

Requirement 2: Additive manufacturing processes for metal materials must be included in a second step due to a high relevance in industrial production.

Following the manufacturing processes for plastics, experts attribute high importance to Selective Laser Melting (SLM) as manufacturing technology for

processing metals. Among the interviewees, manufacturer B described the advantages of the SLM process in particular detail: "On the one hand, there is a large variety of materials that can be processed. You can process almost all types of metallics that can be pulverized. On the other hand, the devices are relatively flexible in their settings for different parameters. […] Speed is another aspect. We have some of the fastest devices on the market […] and also have a high build-up rate. This is a very high value, which of course also leaves some potential to be exploited. […] A great advantage is knowing that the speed can be further increased and the quality can be maintained at the same time." This was assigned according to the material group *metals* by means of codes and should be included in further research work due to its relevance. A second requirement arises in relation to the choice of additive manufacturing processes for a matching.

Requirement 3: The characteristic *material* must be considered separately due to various dependencies and specifications.

A total of 45 text passages were coded with the code *material* in category *(1) characteristics of additive manufacturing technologies and machines*. Material is considered by interviewees to be one of the most important parameters of additive manufacturing technologies and machines, which is why it is considered separately. According to manufacturer B, parameter settings, such as device temperatures, depend on the specific material within one group (e.g. metal or plastic). Different material variants or different manufacturers of similar materials do not have to be differentiated at first. Almost all experts emphasize the relevance of quality factors in connection with materials, especially plastics. Material properties include impact resistance, stability, food safety, density and roughness. Furthermore, according to platform operator A, the intended use of the products depends on the selected material: "The difficulty is that it is unclear what certain products are intended to be used for, how durable they have to be, and whether one has to stick to certain specifications, which again depends on the machine or material." In terms of the code *quality*, strength, elongation at break, food safety, heat resistance or biodegradability in this work can be defined as material properties and not as product properties. *Density* was mentioned by manufacturer B and platform operator A as one property of products. This is also regarded as material property.

Requirement 4: The property *material* should be used to link devices to sales offers and purchase requests.

Platform operator A suggests an intense relationship between devices and materials ("processing"). Hence, we must account for them when matching, selling, and exchanging additive manufacturing capacities. The choice of additive manufacturing machines is largely determined by the choice of one or more materials. The property *material* must therefore be related to the purchase order as well as devices. One or more materials can be selected for exactly one purchase request. In return, exactly one sales offer with one or more materials can be offered in the area of sales of additive production capacities, since not all materials to be processed for devices necessarily have to be offered by vendors. Again, one or more materials can be processed by one or more devices. This also results in the following requirement.

Requirement 5: For selling production capacities, it is relevant to specify the materials available in the company.

In the interview with manufacturer B especially, we found that it is important to account for the availability of materials in the company that sells production capacities. This confirms to requirement 4.

Requirement 6: The attribute *quality* is considered in the context of the two characteristics material and layer thickness, since these depend significantly on the material, manufacturing technology, and intended use.

Experts consider quality as an important criterion, but it is dependent on the material, intended use, and technology. Sellers A and B as well as manufacturer B use the term *quality* in relation to materials and manufacturing methods. This has to be considered in the selection of the characteristics in further research work. Manufacturer B concludes correspondingly with regard to an achievable quality in additive manufacturing processes: "There are no welding seams [in additive manufacturing], so that the parts [...] have a higher performance. This makes it more resilient than if it had a welding seam". Buyers A and B use the term *quality* to describe the outer appearance of the product, e.g. its geometry or surface finish. Manufacturer A mentions it in connection with the strength of the product. Seller B also places quality in connection with the intended use of a product. Furthermore, the factor *quality* must be defined differently for different purposes. A prototype, for example, has different quality requirements (high, medium, low) compared to a functional component. Figure 1 illustrates these dependencies.
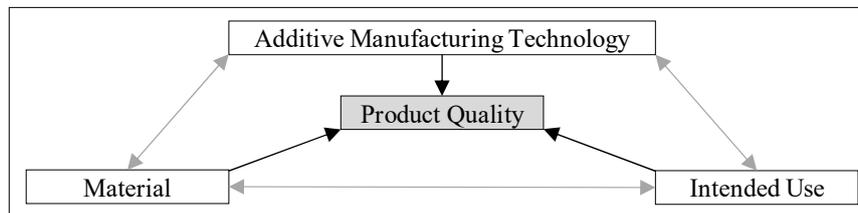

Figure 1. Factors Influencing Product Quality [32]

Within the scope of quality, sellers A, B and C consider it necessary to be aware of the purpose of a product or its category within the meaning of the subcode *product categories*. Often it is not possible to identify which products they manufacture. In this case, a request from the customer is necessary in order to be able to decide which production process is suitable for the respective application of the product in order to achieve the highest possible quality.

In relation to quality it is also necessary to investigate methods for post-processing, such as finishing, painting or assembly, which is represented by another code. In addition to platform operator A, the three groups of sellers named this characteristic. Seller B defines the removal or washing off of support structures in the FDM process as a standard process. Seller A, on the other hand, sees *CNC post-processing* as a necessary standard for increasing surface quality, which they could still not achieve. Seller C emphasizes that the material group *metals* in particular requires post-processing: "There are processes that are very new and more focused on the metal

sector. This requires intensive mechanical post-processing, which we cannot do in-house, and therefore we have also made a certain selection there."

Requirement 7: Besides material group and material, multi-color, multi-material, and build volume dimensions/product size are relevant characteristics for matching additive manufacturing technologies and products.

As part of the code *multi-color* and *multi-material* in category *(1) characteristics of additive manufacturing technologies and machines*, the technology MJM/PJ offers the possibility of processing several colors during a production process, even if this is only in limited demand according to seller A. For seller B, the BJ/3DP method also enables multi-color. This confirms the statement that only a small number of procedures offer this functionality. Furthermore, a special feature in the area of plastics according to sellers A and C is the flexible material variety when using the MJM/PJ process. A distinction can be made between soft pressure and fixed pressure. According to the experts surveyed, most devices, with the exception of additional materials for support structures, have no functionality that supports processing more than one material. Platform operator A confirms the request for multi-material on the market. Seller A, on the other hand, experiences a rather low demand for multi-material.

In category *(2) characteristics of products to be additively manufactured* multi-color products are not relevant for buyers A, B and C. However, if this option is offered for a similar price, it would be an interesting option for the experts and thus, according to buyer C, a unique selling point of the products. The color is important for buyer B, as products are then painted, and the color of the base must therefore be accounted for. Similarly, buyer A emphasizes the importance offers that allow him to produce a desired color. This confirms the relevance of this criterion for future research.

Dimensions of the build volume serve as an important differentiator between various machines analyzed in category *(1) characteristics of additive manufacturing technologies and machines*. The space dimensions of the machines of all surveyed experts are smaller than one meter in height, width, and depth. The devices of manufacturer A, seller A, B and C can manufacture components of at least 5 mm in size. Sellers A defined typical sizes between 30 mm and 350 mm. These dimensions can be used as an average. A general statement on additive manufacturing technologies with predominantly larger or smaller dimensions cannot be formulated.

The experts agree that the size of the products for additive manufacturing is relevant for the selection process and can vary strongly. All experts of the group of buyers predominantly manufacture smaller products with approx. 5 mm to 200 mm in height, width and depth. Dimensions between 5 mm and 800 mm were mentioned. Platform operator A emphasized the fact that a product model which did not originally fit into the installation space can be made suitable by rotation or other slicing. In addition, a product that is too large could be manufactured in several parts and then be assembled.

Requirement 8: Production costs and time are one criterion for selecting additive production devices in comparison to conventional production processes and constitute an important requirement for the platform.

Another relevant code of category (1) *characteristics of additive manufacturing technologies and machines* is costs. Buyer B emphasized that by introducing the e-commerce platform, consideration would be given to the purchase of additive

manufacturing devices. In addition, according to buyers B and C, the current production costs are one criterion for selecting additive production devices in comparison to conventional production processes. A distinction is also made between additive manufacturing processes with regard to acquisition costs as well as manufacturing and material costs. Manufacturer A describes the FDM process as the most cost-effective. Cost and price mechanisms on the developed platform are not considered in this work as a first analysis, but according to the interviewees they are an important factor, which will be included in further research.

Manufacturers A and B distinguish between machines according to their speed / production time, e.g. influenced by the size of the print head or the number and strength of the lasers in the SLM process. Buyer C considers speed to be an important factor in the purchase of additive manufacturing capacities. The relevance of the delivery time was emphasized according to buyer B: "For us only the delivery time of products is relevant. Of course, it depends on the priority of the order. [Normally we need our products] within two weeks." This was also emphasized in the sense of the code *production time*. Likewise, buyer C attaches importance to a certain speed. No distinction was made for buyer C between production and delivery time. Since production speed is dependent on the used technology, material, and quality in the sense of layer thicknesses and therefore require comprehensive analyses for comparability, separate research should be carried out in this respect.

Requirement 9: There is increasing potential in the application area of additive manufacturing for small series as well as series production. Therefore, the attribute quantity must be included in this analysis.

In a first step, the subcodes *prototypes*, *customized production*, *spare parts*, *small serie*s and *series production* are used to determine the purpose for which additively manufactured products are used. According to the experts, the products are mainly used as prototypes, individual production and spare parts. According to buyers A and C, platform operator A and seller C, there is increasing potential in the area of application of small series and series production. Manufacturer B has evolved from its original focus on prototype types to a manufacturer of additive production equipment for the production of functional components. Buyer B only focuses on individual production, which is in the focus of the company's business model. Both manufacturer A and seller A build spare parts or individual products for their own requirements for additive production machines. Small series and series production are often related to quantities. For example, platform operator A applies small series for quantities of 10 to 100 parts, while buyer A suggests that using additive manufacturing is beneficial even when producing series containing more than 100,000 parts.

Requirement 10: The platform should support application scenarios in different industries.

The subcode *industries* suggests that additive manufacturing is used across industries. The interviewees agree that the automotive industry especially benefits from the use of additive manufacturing. Buyers A, manufacturer B and platform operator A also name the medical, dental, and aviation industries as leading users of additive manufacturing.

5   Meta-Model

Based on the identified requirements, we can define a meta model that supports exchanging production capacities over an e-commerce marketplace. Thereby, *Sales Offers* reflect additive production machines or technologies and *Purchase Enquiries* reflect products. In order to ensure the structured and consistent storage of data and the efficient use of the database, this section introduces a conceptual data model shown and thereby answers RQ2.
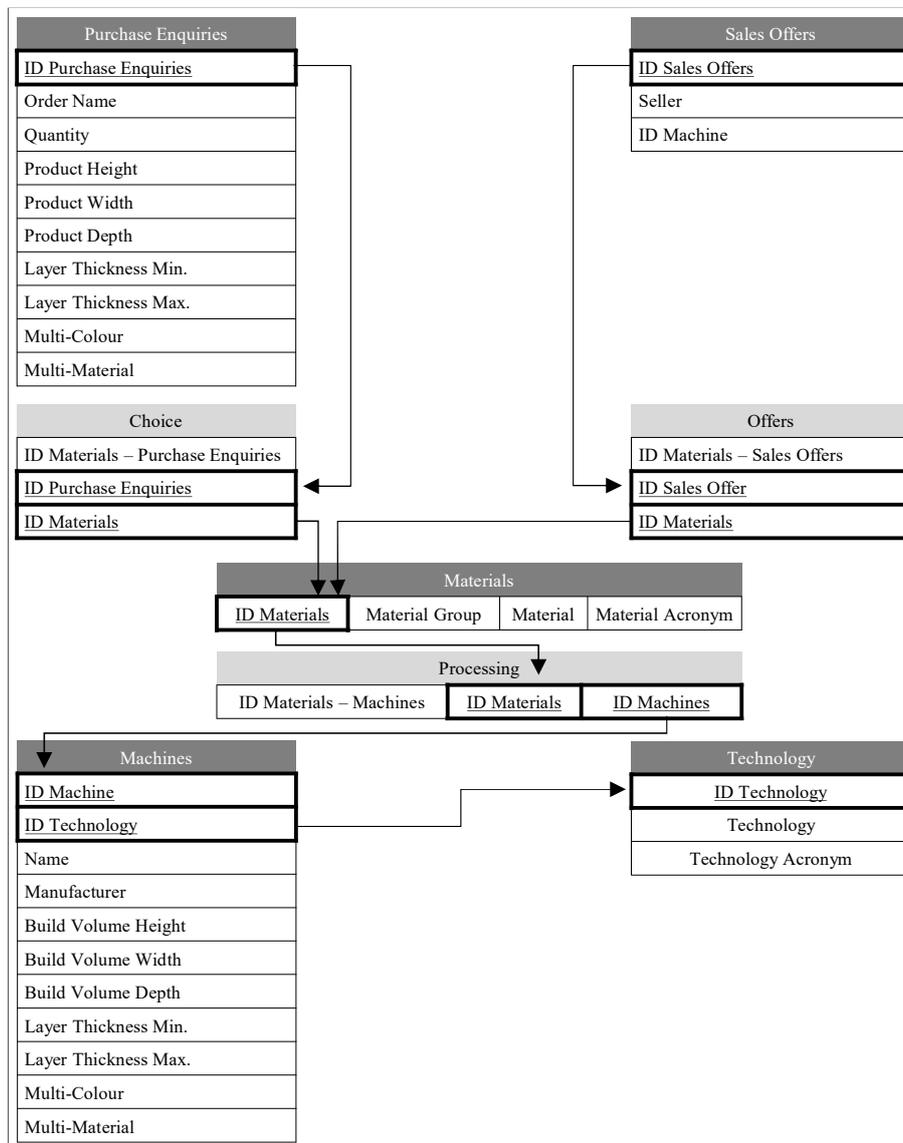

Figure 2. Meta-model for matching products and additive manufacturing technologies

Figure 2 summarizes the resulting model for matching machines with products in a structured collection of tables that are connected through relations. The characteristics of the *Purchase Enquiries* and *Sales Offers* were derived from the developed requirements. The choice of additive manufacturing *Machines* is mainly determined by the choice of *Materials*. These have therefore been added as a separate table and are directly related to *Machines, Purchase Enquiries* and *Sales Offers,* each connected via junction tables (*Processing*, *Choice*, *Offers*). *Materials* can be selected for a *Purchase Enquiry*. In return, a *Sales Offer* with one or more *Materials* can be offered in the area of capacity sales, because not all materials that are processed for devices necessarily have to be offered by vendors. Material properties have to be accounted for in future studies. Again, *Materials* can be processed by *Machines*. The *Machines* have the analyzed attributes and are assigned to *Technologies*.

6   Conclusion

A marketplace for production capacities can significantly contribute to the competitiveness of manufacturers and reduce risks in interwoven supply networks. It supports companies in accomplishing their strategies and business goals, such as a reduction of order risks caused by equipment failure or adaptability in case of changing market demands. Furthermore, they can benefit from synergies, economies of scale, and economies of scope.

This study set out to build the conceptual foundation for a marketplace solution for buyers and sellers of production capacities from the domain of additive manufacturing. Therefore, we sought to develop a catalog of requirements for a workable platform solution (RQ1) as well as to build a meta model that allows the matching of products and production processes in practice (RQ2). To answer RQ1, we conducted a qualitative study based on expert interviews. We questioned experts from nine companies that provided valuable insights from the perspectives of market participants, platform operators, and machine producers. As a result, we derived 10 requirements that can be grouped under the categories of *characteristics of additive manufacturing technologies and machines*, *characteristics of products to be additively manufactured*, as well as *matching products and additive manufacturing technologies*. A marketplace for production capacities must address these requirements to be adopted and to facilitate the expected benefits. To answer RQ2, we integrated our findings and built a meta model that supports the matching of products and production processes. It consists of 8 components and provides a conceptual foundation for the implementation of a matching algorithm in practice. By addressing a white spot in the current IS literature, this study represents a suitable starting point for future research endeavors that aim to examine requirements for exchanging production capacities in other scenarios and industry contexts.

This research is not without limitations. First, it is exploratory by nature and builds upon the perceptions and conclusions of the researcher. Other researchers may have derived different implications and requirements. Second, with only nine participants, our data sample is yet too small to derive a definite set of requirements for exchanging

production capacities. Larger studies with more participants are necessary to provide definite evidence on the validity and reliability of our findings. Third, the resulting meta model is of preliminary nature and only provides an initial conceptualization of the marketplace. In future studies, we seek to implement, evaluate, and refine its properties. Future research opportunities lie primarily in transferring our findings to other industries and business scenarios. While its relevance is constantly growing, additive manufacturing only accounts for a small portion of industrial production capacities. As a consequence, future research must incorporate larger industries to realize the full potential of production capacity sharing.

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