**Appendix F: Identification of constructs**

As discussed in the manuscript, the design of an ecosystem following the ecosystem pie model consists of gathering information on seven constructs, i.e. the *Ecosystem’s value proposition*, the *Actors* involved, and, per each actor, the *Resources* needed, the required *Activities*, the *Value Addition* to be put in place, the *Value Capture* (or benefits/opportunities) generated, and *Risks* (or challenges) to be faced. With the exception of the *Ecosystem’s value proposition*, which is obviously the adoption of AM medical products, we elaborate on the other six constructs below. The results have then been used to develop Table 5 in the main body of the text.

***Actors***

As discussed, under this construct, we identified the different entities required to participate in the ecosystem to accomplish the *ecosystem’s value proposition*. In addition to the obvious *actors* (*AM manufacturers*, *hospitals and medical practitioners*, and *patients*), the results of this study enabled us to identify three other *actors*, i.e. (i) *governmental bodies*, (ii) *certification entities*, and (iii) *higher education institutes*. These *actors* were identified as crucial to overcoming the identified challenges: *governmental bodies* are needed to allocate funding to overcome challenges like “*High Production Costs*” (C2), “*High Investment Costs*” (C3), “*High* *Material* *Costs*” (C4), etc., while *certification entities* are required to commit to the development of new and AM-suitable standards and certification processes to overcome the challenge “*Standardization and Certification*” (C7). Finally, *higher education institutes* have been identified as crucial *actors* due to their role in overcoming the challenges related to specialized workforce (C9 and C10).

***Resources***

*Resources* relate to the *actors’* assets (both tangible and intangible assets) required to support the accomplishment of the *ecosystem’s value proposition*. Starting from the higher level, the *resources* required by the *governmental bodies* are the funding required to overcome the above-mentioned challenges, while *certification entities* need to leverage their regulation power, i.e. their capabilities to develop and set new standards. For *higher education institutes*, the *resources* needed are all those connected to creating and enhancing AM-related skills and knowledge, and therefore their knowledge on AM, their training facilities and equipment, and their staff (e.g. professors, researchers, technicians, …). For *AM manufacturers*, then, the *resources* required are the knowledge and experience on AM, the staffs, and the AM machines. These, indeed, are needed not only for producing AM parts, but also for supporting the boost of AM through the mitigation of the challenges identified. As an example, the countermeasure identified to mitigate the challenge “*Quality*” (C13) consisted of *AM manufacturers*’ time and resources to find the optimal production process parameters. Finally, another *resource* of *AM manufacturers* required to support the adoption of AM medical products is their supply chain, which is crucial for distributing the AM medical products. Next, the *resources* of *hospitals and medical practitioners* consist of the equipment to provide medical services, the knowledge and experience in providing medical services and the staff (surgeons, nurses, …). Finally, no particular resources are needed from *patients* excepts money to pay for medical care.

***Activities***

As described above, these are the *activities* put in place by the different *actors* to use the *resources* just described to generate *value* by accomplishing the *ecosystem’s value proposition*. This includes all the *activities* required to boost and further extend the use of AM in the medical sector. Therefore, as described above, *governmental bodies* are required to provide funding opportunities to overcome some of the identified challenges (e.g. “*High Production Costs*” (C2), “*High Investment Costs*” (C3), “*High* *Material* *Costs*” (C4), etc.). Moreover, governmental bodies can also support *higher education institutions* in their activities (cf. below), providing more resources for developing new AM-centered courses and/or hiring new staff knowledgeable in AM. Then, as previously discussed, *certification entities* are required to develop new standards for AM, thus supporting AM adoption since they can mitigate the challenge “*Standardization and Certification*” (C7). Dealing then with *higher education institutions*, their *activities* deal with the development of the knowledge and skills required to overcome the challenges related to, e.g., specialized workforce (C9 and C10), filling the gap between theory and practice. Among these, practitioners have suggested developing new study programs/courses dedicated to AM, to establish internship with companies and to support the development of skilled employees through lifelong learning programs. For these last two *activities*, the cooperation of *AM manufacturers* is important. In addition to supporting internship and lifelong learning programs, *AM manufacturers* are required to commit in terms of time and resources to find the optimal production process parameters to mitigate the challenge “*Quality*” (C13). Moreover, as suggested by practitioners in their countermeasures, they also have to focus their *activities* on developing new AM solution/processes. To facilitate this, they can get access to the funding provided by *governmental bodies* and they can be supported by *higher education institutions* if they do not have the required knowledge in-house. Moreover, among the countermeasures identified for mitigating the challenges related to specialized workforces (C9 and C10), it was also suggested that *AM manufacturers* can provide intra- and inter-organizational trainings to share the knowledge. Next, *hospitals and medical practitioners* are required to support the lifelong learning of their staffs on AM products in order to appreciate the opportunities of AM products, how to handle such products, etc. In this way, by enhancing their knowledge on AM, it is expected that the personnel would prefer AM products. Furthermore, hospitals must also improve their IT systems to mitigate the challenge related to IP issues and data breaches. Finally, the *patients’* *activities* consist of creating demand for medical services.

***Value addition***

As already described, the *value addition* construct represents the products/services/financial supports/support of other kinds provided by the actor to accomplish the ecosystem’s value proposition, and it is the direct outcome of the *activities* put in place. Therefore, if the activity of *governmental bodies* is to provide funding opportunities, it is obvious that funding for research/innovation projects is the corresponding *value addition*. Moreover, since *governmental bodies* are also suggested to support *higher education institutions* in developing new AM-centered courses and/or hiring new staffs skilled in AM, funding dedicated to *higher education institutions* is another *value addition*. Similarly, *certification entities’* *value addition* corresponds to the creation of new AM standards. Another *value addition* of *higher education institutions*, in addition to creating internship, courses and lifelong learning programs, is the generation of more AM market-oriented graduates, who possess all the required knowledge and skills to be introduced immediately and successfully into the work market. Moving then to *AM manufacturers*, their main *value addition* corresponds to the development of databases for optimal production process parameters to improve quality and of new AM machines/solutions to mitigate challenges like “*High Production Costs*” (C2), “*High Investment Costs*” (C3), or “*High* *Material* *Costs*” (C4). As a result, they enable the production of AM products that cost less and are higher in quality. Finally, as *value addition*, *hospitals and medical practitioners* can now rely on AM-informed staff, leading to a higher demand for AM products. Moreover, hospitals have also improved IT systems, which increases the trust of *patients*. All these elements will result in higher surgeries with AM products for *patients*, who brings money inflow.

***Value capture***

This construct corresponds to the benefits achievable by each *actor* for committing to the ecosystem. The *value capture* (or benefits) of each actor is clearly linked to the opportunities arising from the use of AM, and it can thus be derived from the results previously presented. For the sake of clarity and better understanding, we start with the *patients* to describe the *value capture*. The main benefit for the *patients* is to have access to highly customized medical products (“*Customization*” (O6)), with clear benefits in terms of improved *patients’* wellbeing. This is also rated by the Delphi study participants as the most relevant opportunity. Other benefits for *patients* are related to a more responsive and resilient supply chain (cf. “*Hedged Sourcing Strategy (Demand Risks)*” (O1), “*Resilient Supply Chain*” (O3), “*Responsiveness (On-Demand Production)*” (O7), and “*Responsiveness (Geographical Convenience)*” (O8)), ensuring adequate and timely healthcare, regardless any potential disruptions. Minor benefits for *patients* deal with the environmental benefits of AM (“*Environmental Sustainability*” (O4)) and its shareability capabilities (“*Shareability*” (O13)), with the reduced environmental footprint of the supply chain leading to better quality of air and the possibility of sharing products design online that allows patients to access customized healthcare regardless of their geographical location. For *hospitals and medical practitioners*, in addition to higher customer (*patients*) satisfaction deriving from the *patients’* benefits associated with “*Customization*” (O6), “*Hedged Sourcing Strategy (Demand Risks)*” (O1, “*Resilient Supply Chain*” (O3), “*Responsiveness (On-Demand Production)*” (O7), and “*Responsiveness (Geographical Convenience)*” (O8), *hospitals and medical practitioners* also experience benefits related to a simpler supply chain (“Simpler Supply Chain” (O11)) and to the reduced inventory needed (“*MTO Production*” (O10)). Indeed, a simpler supply chain leads to more consistent quality, lower operation costs and greater responsiveness (Hoole, 2005), while reduced inventory levels result from a make-to-order strategy and ensures a continuos high quality of AM products and obviously reduces costs. These benefits (“Simpler Supply Chain” (O11) and “*MTO Production*” (O10)) are also shared by *AM manufacturers*, whom in addition can also benefit from the capabilities of AM to reduce waste (“Waste Reduction” (O9)) and consolidate parts (“*Part Consolidation*” (O12)), although these benefits are not deemed so relevant by the Delphi study participants, especially the “*Part Consolidation*” (O12) due to the nature of medical products. Moving now to *higher education institutions*, the benefits achievable would be to have more support (i.e. funding) for financing AM-related research activities and developing new study programs/courses dedicated to AM and/or hiring new staffs skilled in AM. Furthermore, these are also expected to have a closer connection with companies (e.g. by establishing internship), hence closing the gap between theory and practice and increasing student satisfaction. Finally, *certification entities* and *governmental bodies* will also benefit from participating in such ecosystem. More in details, the former will benefit from a higher satisfaction on the AM standards and from the certification-related income arising from a higher use of AM. The latter, then, will benefit in two main ways. First, through a better welfare and wellbeing of the population due to improved healthcare (e.g. customization of medical products (O6)) and environment (e.g. reduced pollution (O4), reduced wastes (O9), …). Then, through a wider adoption of AM that will result in the establishment of new companies and organizations working on AM, hence leading to increased tax incomes. Specifically, these can preliminarily be evaluated considering the possible future AM adoption scenarios where the AM market development is hypothesized based on Delphi study participants’ opinions.

***Risk***

As described above, here falls the challenges that might hinder or limit the accomplishment of the *ecosystem’s value proposition*. As for *value capture*, these can be derived from the results previously presented in terms of identified challenges. As for *value capture*, for the sake of clarity and better understanding, we start from the *patients* to describe the *risk*. The risk that *patients* can encounter mainly deal with two main challenges, i.e. the high costs of AM medical products and “*IP issues*” (C5), with the former leading to the risk of higher costs for their healthcare if these are not covered by the public system and the latter leading to risks of personal data theft (although these risks are low considering the relevance attributed to C5 by the Delphi study participants). Moreover, *patients* are also affected by the challenge “*Quality*” (C13): if AM medical parts are of low quality, these cannot be used, hence leading to the risk for the *patients* to be deprived of the possibility of having customized AM medical products. Similarly, this risk might occur also due to another challenge, i.e. “*Material Limitation*” (C8), since the suitable material is not available in AM and hence the medical product needs to be produced in CM or with another material that would, however, reduce the healthcare level. Similarly, these challenge risk to affect also *hospitals and medical practitioners.* Indeed, the presence of such challenges might lead to reduced levels of healthcare, with negative consequences for patients’ satisfaction. Moreover, challenges such as “*Dependency on Supplier*” (C1) and “*Production Limitation*” (C11) represent a further risk for *hospitals and medical practitioners*: to overcome the slow and uncertain supply caused by these two challenges, to ensure a high responsiveness of the supply chain, they need to increase their inventory levels. The same can be said for *AM manufacturers*. Moreover, these are expected to encounter risks arising from other challenges, if not mitigated, i.e. “*High Production Costs*” (C2), “*High Investment Costs*” (C3), “*High Material Costs*” (C4), “*Social Sustainability*” (C6), “*Standardization and Certification*” (C7), “*Material Limitation*” (C8), “*Specialized Workforce (Design Phase)*” (C9), “*Specialized Workforce (Production Phase)*” (C10), “*Need for post-process operations*” (C12), and “*Quality*” (C13). Specifically, due to the challenges related to high costs (i.e. C2, C3, and C4), reduced types of raw materials (C11), additional production times and costs (C12) and low quality (C13), *AM manufacturers* risk to experience low demand for AM medical products due to higher costs and/or lower responsiveness and/or lower quality compared to CM counterparts. Moreover, current standards also risk to reduce the demand of AM medical products since these are either unfavorable for AM or too complicated, hence favoring CM counterparts. Furthermore, the low availability of specialized workforces (C9 and C10) also represents a risk for *AM manufacturers* since this might lead to an inability to produce the part and/or higher cost to produce the part since more attempts are required and/or inability to optimize the customization level of the part. Finally, if a manufacturer switches from CM to AM to produce medical products, it might experience employees’ reticence since they might resist to this strategic choice because they might perceive AM as a ‘job killer’. This, however, is hardly likely to occur due to the low relevance attributed by the Delphi study participants to this challenge (actually the lowest relevance among all). Dealing then with *higher education institutions* and *certification entities*, the identified challenges are not expected to lead to any significant *risks*. These *actors* are, instead, expected to overcome/mitigate some of the challenges, and the only *risk* is that they fail to do so. Finally, the *governmental bodies* might suffer from the challenges related to the high costs (i.e. C2, C3, and C4) if the healthcare system is public.