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Development of a Life Cycle Model for Deep Tech Startups

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Abstract

Startups with a technological focus usually pursue the overarching goal of scaling and establishing themselves as a corporate with a product portfolio as quickly as possible. Deep tech startups in particular identify market niches in which no established players are present and aim to disrupt existing or create new markets with deep technology innovations. In this context, deep tech startups face the challenge of not only developing their organization, but also developing their technology and building a market in parallel. Here, a collaboration with a corporate could be helpful, but, yet often fails due to the insufficient knowledge about life cycle stages and associated goals. To date the goals of deep tech startups in their specific life cycle stages are not precisely formulated in literature. Consequently, the aim of this paper is to develop a life cycle stage model for deep tech startups that enables the explication and pursuit of tangible goals for the individual stages. In the context of a literature review, existing approaches for the description of life cycles of startups as well as goals in the development of organizations are examined. Deficits are then discussed and suitable life cycle stages as well as goal dimensions for the development of a deep tech startup are derived. The life cycle model is based on five distinct development dimensions of startups, and, thereby, enables the derivation of generic goals.

Keywords

Startup; Life Cycle; Life Cycle Stages; Goals; Deep Tech Startup; Scaling; Growth

1. Introduction

Startups usually pursue the overarching goal of scaling and establishing themselves as a corporate[1] with a product portfolio as quickly as possible [1]. Deep technology startups (deep tech startups) in particular, aim to disrupt existing or create entirely new markets with capital and resource intensive deep technology

[1] Startups either focus on establishing as a corporate or accept being bought and integrated by a corporate. In either case, they attain corporate status.

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innovations [2–4]. Thereby, they face the challenge of not only developing their organization as well as a novel technology, but also a new market in parallel [1,5,6].

In contrast to established corporates, deep tech startups often attach little to no importance to strategic planning and the associated formation of adequate strategic objectives [7,8]. Empirical studies show that if at all, the strategic dimension is generally only very weakly developed in startups [9]. Instead, the focus of deep tech startups usually lies on operational activities [7]. The reasons for this are in most cases the highly dynamic and volatile business environment, limited financial and temporal resources, as well as a lack of knowledge regarding appropriate planning methods [7,10]. Even though the effort associated with strategic planning is everything but beneficial to the agility and flexibility of a deep tech startup, a lack of foresight in particular is one of the most frequent reasons for the failure of young companies [11]. Accordingly, deep tech startups also need a certain degree of goal orientation and steering of their organizational activities in order not to waste the scarce resources available [12].

An appropriate approach to address this supposed paradox and to provide deep tech startups a practical orientation along their growth path on the way to becoming an established corporate is the startup life cycle concept. The startup life cycle represents a listing and structuring of regularities, patterns, typical problems, and behaviors that newly founded companies usually face, divided into different stages. From these commonalities, generic objectives can be derived, which virtually all startups have to consider and achieve in certain stages. These generic objectives can thus be used as a guideline on the way towards becoming an established corporate. [13–16]

Accordingly, the present work aims to develop a detailed life cycle model for deep tech startups, which is intended to support them in their growth process. Based on this objective, the following research questions are derived:

1. How is the life cycle of deep tech startups composed and which stages as well as development fields can be distinguished?
2. What are relevant characteristics and generic development goals within these stages?

As the introduction shows, the design of a life cycle model for deep-tech startups has a high practical relevance. Hence, in order to answer the research questions raised in this paper, the research process of applied sciences according to ULRICH is adopted [17]. Basically, ULRICH's methodology consists of seven sequential process steps, of which steps 1 to 5 are covered in this paper [17]. Step 6 (Testing) and Step 7 (Verification in industrial practice) are not within the scope of this work and are subject to ongoing research activities.

In order to achieve the formulated objective and following the research process, this paper is divided into five sections. Section 1 elaborates the practical problem, which is observed in past and current bilateral industry and research projects. Section 2 deals with underlying theories of fundamental sciences. Thereafter, section 3 serves to identify and review the deficits of existing approaches in literature. Building upon this, a structure for the deep tech startup life cycle model is presented in section 4. Finally, a conclusion and an outlook are given in section 5.

2. Theoretical Background

From a scientific point of view and following the research process of applied science by ULRICH [17], the development of a life cycle model for deep tech startups requires first a discussion of underlying theories

and fundamental sciences. Therefore, this section presents fundamentals regarding startups, deep technology startups and organizational life cycles.

2.1 Startups

Given the great interest that the topic of startups has been experiencing for quite a while, numerous definitions can be found in literature. In part, they differ in focus and scope. For example, the BUNDESVERBAND DEUTSCHER START-UPS E.V. (Federal Association of German Startups) defines startups as companies that are less than 10 years old, have (highly) innovative products, services, business models or technologies, and are aiming for significant growth [18]. Both, HAHN and SCHNEDLER confirm these characteristics and extend the definition by the extraordinary capital and resource requirements of startups, which are driven by their high growth and innovation ambitions [19,20]. RIES and KÜHNAPFEL also emphasize the dynamic and highly volatile market environment in which startups typically operate [12,21]. In contrast to an established corporate, a startup is, according to FRICK & MEUSBURGER, a temporary organization with limited resources in search of a functioning and scalable business model. Due to their organizational characteristics, startups are considered the epitome of exploration [22]. Accordingly, they usually have flat hierarchies, informal organizational and communication structures, a high degree of agility and flexibility in decision-making and a strong willingness to experiment and take risks [23–25]. The founders team plays a key role, whose experience, personality, motivation, and expertise have a decisive influence on the newly founded company [13,26]. At the same time, startups are more likely to fail than established corporations, given the attributes outlined above [7,27].

2.2 Deep Technology Startups

Deep technology startups share the above-mentioned startup characteristics and have in addition a particularly strong technological focus. While "deep technology" initially describes this strong technological focus, the term has not been sufficiently researched and defined from a terminological perspective to date. According to SIEGEL and KRISHNAN, deep tech is often used as a collective term for future- and technology-oriented research [3]. However, there is a lack of clarity about what specifically characterizes deep tech and how it differs from other technological classifications [3]. In principle, technologies can be distinguished by a variety of characteristics. For example, a differentiation can be made on the basis of functions, areas of application or technological life cycle phases [28]. Deep tech innovations refer to breakthrough scientific and technological discoveries that demonstrate significant advances over existing technologies and aim to solve the most important societal and environmental challenges of the 21st century [2–4]. Due to their technological novelty and sophistication, deep tech innovations are unique, difficult to imitate, and substitute [2,4]. At the same time, they require a considerable amount of funding, are characterized by a long time to market and depend on a number of specific skills, expertise and infrastructure [29–31]. Successful deep tech innovations have the power to fundamentally change existing industries and to create new markets [3,30]. Within the understanding of the present work, deep technology originates from a high-tech or medium-high-tech industry according to the OECD´s classification for manufactured goods [32] and can be found in the fields of artificial intelligence, Internet of Things, sensor technology, drones, robotics, and biotechnology. Innovations in these fields are leading to solutions in sectors including healthcare, agriculture, energy use and storage, manufacturing, consumer goods and mobility [3,16,33]. There are two key characteristic features that distinguish deep tech from other technological classifications: First, deep tech innovations are always subject to a comparably high risk of technological feasibility, since innovations in the respective context are completely new and have not yet been tested [6]. Second, deep tech startups usually face an extraordinarily high market risk due to their high degree of novelty. The technology is so different that the

market may not yet be ready to accept it, which means that commercialization cannot always be guaranteed [2–4,6]. Additionally, due to missing development partners, deep tech startups rely on the establishment of a production and need to handle complex functions and material processing know-how [34].

Given the characteristics outlined above, deep tech startups are defined in the context of this paper, as:

Startups with a key physical offering to be manufactured that is based on deep technology, originate in a high-tech or medium-high-tech industry and are driven by the founding team's self-developed knowledge edge in a deep technology.

2.3 Organizational Life Cycles

Even though companies often differ from one another in many aspects at first glance due to the wide range of possible organizational dimensions and configurations, from an organizational point of view they share certain parallels over the course of their existence [35–37]. A suitable approach to capture these parallels as well as the associated attributes, is the organizational life cycle concept [38,39]. Based on the life cycle of organisms from biology, this concept is regularly used to explain the gradual organizational change of companies in the course of time [40]. Although differently accentuated life cycle models can be found in literature, a general distinction between the four ideal-typical stages of Start-up, Growth, Maturity and Saturation has prevailed [25]: Companies in the *Start-up Stage* can be characterized by a small organizational size, flat hierarchies, informal organizational and communication structures, spatial centralization, and a strong willingness to experiment and take risks, which is exemplified and encouraged by the founding team. In combination, these attributes lead to the free flourishing of explorative activities, which results in a high level of innovativeness [23–25]. With the transition to the *Growth Stage*, there is not only a rise in sales figures, but also an increase in complexity due to the associated growth of the company and the starting spatial distribution of employees. This is counteracted by the introduction of first structures and processes as well as an increasing formalization of decision-making. The company's innovative power is diminished by the increasing emphasis on exploitative activities [23–25,41]. By the time a company enters the *Maturity Stage*, usually when it reaches its sales and profit peak, the structures that promote innovation give way to a high degree of formalization, standardization, processualization and bureaucratization. Additional hierarchical levels are introduced, and the focus is placed on efficiency and optimization programs, making explorative activities increasingly difficult, steadily decreasing the innovative power [23–25,37]. Once a company reaches the end of its life cycle, it enters the *Saturation Stage*, which is characterized by complex control mechanisms, low flexibility, strictly hierarchical structures, and a low willingness to take risks. At this point, it becomes clear whether the company will shrink and gradually decline, or reorganization and realignment succeed. The innovativeness of the company is at its all-time low. [23,24,37]

Life cycle models exist not only with respect to companies in general, but also with regard to startups in particular. Similar to the corporate life cycle, the startup life cycle represents a list and structuring of regularities, patterns, typical problems and behaviors that newly founded companies usually face in different stages. From these commonalities, generic objectives can be derived, which virtually all startups must consider and achieve in certain stages. These generic objectives can thus be used as a guideline on the way towards becoming an established company [13–16]. The most common startup life cycle models are introduced and discussed within the following literature review.

3. Literature Review

In present literature, various approaches can be identified with regard to organizational life cycle models. Some of which differ considerably in the number and delimitation of the stages listed. It quickly becomes clear that the transitions between the stages are always blurred and therefore not quite distinct [1,42]. In addition, their specific course and length are subject to a large number of factors. For example, the market environment, the industry or the technology, on which the company's offering is based, can be mentioned as possible influencing factors [43]. The latter is particularly evident regarding deep tech startups. In contrast to conventional startups, technology and product development play a central role in technology-oriented startups, especially in the early stages of life [35,44]. In the following, nine approaches are presented, that have been identified in the course of a literature screening and distinguished from other concepts due to their particular relevance for this paper. To systematically evaluate the identified approaches and to demonstrate the research deficits in a comprehensible way, an assessment is made along the object and target area of this work. The object area relates to the subjects of this paper, whereas the target area of the review results from the research questions to be solved. As given in Figure 1, a distinction is made between approaches from the field of *Organizational Life Cycle Models*, *Startup Life Cycle Models* and *Startup Financing Models*.

3.1 Review of Existing Approaches

Organizational Life Cycle Models

In his paper on the topic of evolution and revolution as organizations grow, GREINER provides one of the most popular organizational life cycle models in literature to date [45]. It is divided in five consecutive stages (*Creativity*, *Direction*, *Delegation*, *Coordination*, and *Collaboration*) and outlines company characteristics of each stage along five development fields (management focus, organization structure, top management style, control system and management reward emphasis). Even though GREINER mentions aspects of high-growth industries, the model as a whole is relatively generic [45]. GUGGENMOOS on the other hand, presents a five-stage life cycle model specifically designed for growth-oriented technology companies [46]. Along the four dimensions of formal, business, technological and financing requirements, he lists ideal-typical characteristics and goals for companies within the respective stages. Furthermore, GUGGENMOOS contrasts the elaborated phases with common startup financing stages [46]. GRIMM combines market and technology life cycles in order to derive a life cycle model for high tech companies that is subdivided into three main and eleven substages. In doing so, he refrains from further detailing the stages and directs his focus on the company's product [47].

Startup Life Cycle Models

Based on data collected from 105 companies, KANZANJIAN develops a stage-contingent model of design and growth for technology-based startups. The model consists of four consecutive stages and argues that the rate of growth of a technology-based startup depends, at least in part, on the consistency or fit between its stage of growth and certain structural features of its organization [48].TECH introduces a life cycle model designed for growth-oriented high tech startups, which also consists of four stages. He distinguishes between *Seed*, *Startup*, *Growth*, and *Later* stage and specifies typical targets to be achieved along the three dimensions organization, product and market [16]. Like the other two authors, PASSARO ET AL. also present a four-stage startup life cycle model. Following a multiple case study approach, the model is divided into the stages of *Ideation*, *Intention*, *Start-up* and *Expansion* and outlines key activities and factors, required capabilities and resources as well as milestones. In contrast to the other approaches, however, PASSARO ET AL. do not particularly emphasize technology-oriented startups [49].

Startup Financing Models

SCHULTZ develops a more granular model for financing technology-oriented startups in Germany [35]. He divides the model into the three superordinate stages *Early*, *Growth* and *Maturity* and in six common financing stages, which range from *Seed* to *Initial Public Offering (IPO)*. He mentions characteristic activities, typical success factors and dominant problems along the different stages [35]. WILSON outlines a very similar model for financing young innovative firms [50]. Unlike SCHULTZ, however, the author distinguishes between four superordinate and seven sub-stages. Nevertheless, the activities listed by WILSON within the respective stages correspond to those mentioned by SCHULTZ to a large extent [50]. The same applies to HAHN, who distinguishes the three development stages *Early*, *Expansion* and *Later* and puts them in relation to the five financing stages *(Pre-) Seed*, *Start-up*, *(Emerging-) Growth*, *Bridge* and *Exit*. Like the other authors, HAHN lists tasks, goals and other characteristics of startups in the individual phases [19].

3.2 Derivation of Deficits

Based on the examination of the identified approaches, the following research deficits are derived, after which the focus of the present work is sharpened accordingly.

First, current research lacks a consideration of deep tech specifics in general. While there are several approaches in literature that take the peculiarities of tech and high-tech startups as well as of established companies in the respective field into account, none can be identified that specifically focuses on deep tech. Consequently, the analyzed concepts fall short in terms of the stage structure as well as the consideration of recent developments and do therefore not cover the entire life cycle of deep tech startups. Second, existing approaches lack a distinct structure and a division into discrete dimensions of consideration that include the different potential development fields of a deep tech startup. This bears the risk that certain individual development goals are neglected, creating an incomplete overall picture. Third, existing life cycle models are not sufficiently detailed to provide guidance to deep tech startups at any point and at any stage of their development. This especially the case for goals that are neither action-oriented nor formulated in a life cycle phase-specific way. Although GUGGENMOOS, SCHULTZ and HAHN present models that contain a breakdown into more granular subphases, they are still not specific enough to serve as a stringent and consistent orientation for deep tech startups along their entire life cycle. The presented deficits indicate the need for the development of a dedicated deep tech startup life cycle model in the subsequent section. Figure 1 summarizes the examined approaches found in literature through an evaluation along the object and target area of this work, and furthermore highlights the derived deficits:

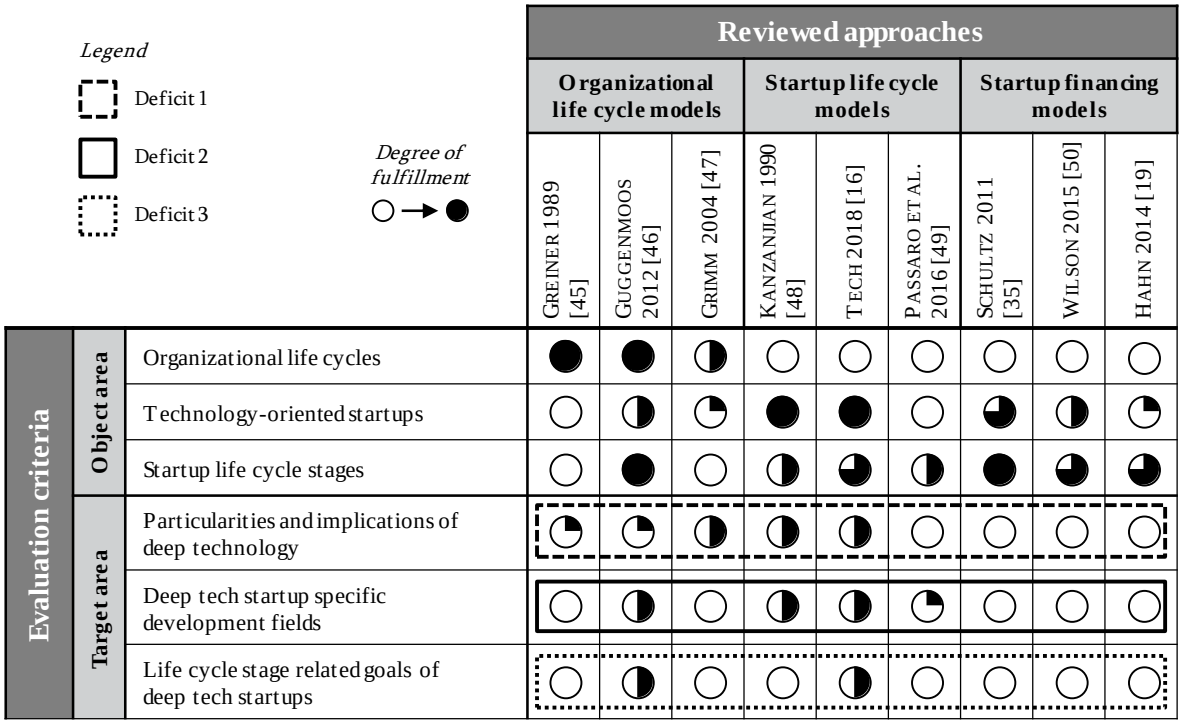

Figure 1: Evaluation of reviewed approaches

4. Results

In the following section, the conception of a life cycle model for deep tech startups is elaborated. Initially, appropriate development fields are derived. Subsequently, an overarching stage structure is described, which is then detailed into further sub-stages. Within each stage, generic development goals are identified along the defined development fields.

4.1 Development of a Life Cycle Model for Deep Tech Startups

Subsequently, the life cycle model for deep tech startups is introduced. In a first step, relevant development fields are derived in order to structure the manifold development activities of deep tech startups. Hereafter, an overarching four-stage model structure is elaborated. Finally, this structure is further detailed through the subdivision into eleven sub-stages.

4.1.1 Derivation of deep tech startup development fields

The analysis of existing life cycle models in section 3 implies that the evolution of companies takes place along different cross-stage development fields [16,46,48]. During a company's existence, the focus and accentuation on these development fields changes noticeably due to constant need for reconfiguration and renewal caused by changing parameters, problems and goals within the respective life cycle stages [6,51,52]. Accordingly, at the beginning of a startup, different organizational development fields are in the spotlight than in later stages, which at the same time requires deviating competencies [52]. Simultaneously, such categorization helps to structure the diverse activities of companies over time. However, the literature review revealed that there is no uniform delimitation in current approaches that comprehensively captures these development fields. This applies both to companies in general but also to deep tech startups in particular. Consequently, adequate development fields must be defined.

TECH distinguishes between three dimensions organization, product and market in which development activities of high tech startups take place [16]. In addition to the development fields mentioned by TECH, O'CONNOR & RICE emphasize the aspect of business model development in their work on new market creation for breakthrough innovations [53]. So do DENOO ET AL. in their paper on business model adaptation in emerging industries [6]. SCHWEIGER identifies a range of key competency deficits (such as market and customer orientation, marketing and sales, organization and personnel management, financing, accounting and controlling, as well as the establishment of information and communication structures) of young technology-oriented companies which need to be addressed through specific measures that match the four development fields mentioned above [52]. Considering the deep tech characteristics outlined in section 2.2, technology development also inevitably plays a central role for deep tech startups [35]. While aware that there may be numerous more deep tech startup development dimensions, these five represent key development fields to evolve as a deep tech startup from an initial idea to an established company and therefore serve as an overarching structure in the context of this work:

- **Technology development:** Activities in the field of technology development aim to develop new technologies or improve existing ones and thus serve to build up promising technological potential [54].
- **Product development:** Activities assigned to the area of product development relate to the development of new or the improvement of existing products based on the deep technology [54–56].
- **Market development:** Market development activities aim to shape the market environment and actively influence future market developments in favor of the company [57–59].
- **Business model development:** Activities are assigned to the dimension of business model development if they are targeted at basic principles according to which a company creates, conveys, or captures value [60–62].
- **Organizational development:** Activities in the area of organizational development refer to the development or renewal of structures and processes in order to improve the company's innovation performance [63]. Startups in particular need skills to master the organizational change processes induced by rapid growth [52].

The evolution of deep tech startups is found to take place along these five development fields. Thus, development goals of deep tech startups are assigned to these five fields in the following. The focus on the respective area is closely related to the life cycle stage of the startup.

4.1.2 Derivation of superordinate deep tech startup development stages

As shown in the previous section, different publications in literature address the particularities of tech and high-tech startups [16,46,48]. Due to the high degree of congruence with the author's observations in practice, the following superordinate deep tech startup development stages are based on the previously introduced four-phase approach for high tech startups developed by TECH [16]. Incorporating the other life cycle models evaluated in section 3 as well as the deep tech characteristics presented in section 2.2, the stages outlined by TECH are transferred to deep tech startups and overarching generic objectives for each stage are derived. In this context, it is especially important to reemphasize that in contrast to conventional startups, technology and product development play a central role in technology-oriented startups, particularly in the early stages of their existence [35,44]. Although the same stages are passed through as by other startup companies, there is a compression and deviating focus within the stages due to the high research and development (R&D) requirements [30]. Figure 2 illustrates the four stages together with the overarching generic deep tech startup goals.

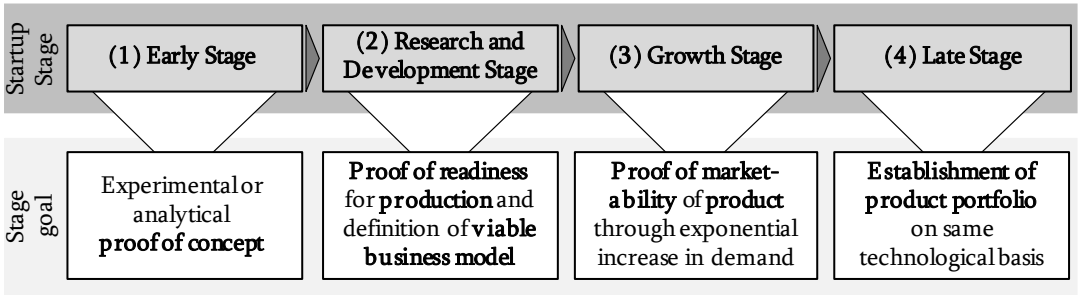

Figure 2: Life cycle stages of deep tech startups [16,46,49]

Early Stage: The *Early Stage* serves to develop an initial rough concept and to validate the potential of the deep technology. The general marketability as well as the technical and economic feasibility of the idea must be evaluated in close cooperation with experts, and a sound analytical or experimental proof of concept has to be provided to justify the further pursuit of the idea. [16,46,48,49]

Research and Development Stage: In the *Research and Development Stage*, the analytical or experimental proof of concept is to be transferred into a first product, which is ready for series production through systematic technology and product development in close coordination with relevant stakeholders. At the same time, a viable business model has to be identified together with pilot customers in order to prove not only the technical but also the economic feasibility of the technology in practice. [16,46,49]

Growth Stage: The *Growth Stage* is characterized by the market entry of the company with the previously developed product. An exponential increase in demand is to be generated through various measures, thus confirming the actual marketability of the innovative product in practice. [16,46,49]

Late Stage: In final instance, the meanwhile proven technology must be integrated into further products by the deep tech startup in order to start a diversification of the product portfolio. The overarching goal is to successfully establish these additional products on the market, continue to achieve high growth rates and, in best case, establish a new market or a new market segment. [16,46,49]

A transition to the next life cycle stage can only take place once the respective overarching stage goal has been achieved. Until then, the deep tech startup is guided by the target of its current life cycle stage [13–16,49]. The goal of the current stage functions as temporal strategic objective to which the startup aligns its actions [13]. The proof of broad marketability of the deep technology among a product portfolio in the *Late Stage* marks the transition from startup to corporate.

4.1.3 Derivation of deep tech startup development sub-stages

As the literature review in section 3 revealed, existing approaches not only lack a consideration of deep tech peculiarities in general, but also a sufficient level of detail and granularity. Accordingly, the four stages presented above are subsequently further subdivided into eleven sub-stages. Considering the exceptionally high capital requirements of deep tech startups mentioned in section 2.2 as well as the associated investment necessity until the deep technology is ready for the market (in some cases even beyond that), the financing stages of startups are used as a frame of reference for further specification. The financing stages are mirror images of the development stages of startups and describe temporal checkpoints and operational milestones which must be achieved in order to receive further financial resources and which are used as a guide by external investors when evaluating startups [19,46]. Considering the deep tech characteristics discussed in section 2.2, these milestones are transferred to deep tech startups along the five development fields introduced in the previous section and henceforth understood as generic goals. In this context, the focus is

consciously placed on the development fields and associated goals, which are the main focus of deep tech startups in the corresponding stages. Progress is, of course, also made in the other development fields, but is without equal relevance for the achievement of the overarching life cycle stage goal and the reaching of the next life cycle stage. Figure 3 illustrates the explanations and interrelations and connects them to one another (see Appendix).

(1) ***Early Stage:*** As described in section 4.1.2, the focus in the *Early Stage* is put on technology development. At the same time, selected activities are required in the area of organizational development to obtain financing [16,46,48]:

Pre-Seed: The *Pre-Seed Stage* represents the first life cycle stage of a deep tech startup. It serves to identify and analyze a far-reaching social or ecological problem and to discover ideas on how this problem can be addressed with the help of deep technology [30,64,65]. Based on this, a core team is to be formed, initial fundamental research is to be carried out and an understanding of the principles and potential of deep technology is to be developed. The findings are to be compiled in a rough concept and discussed with experts from the relevant field [19,66].

Seed: Subsequently in the *Seed Stage*, the general market viability in terms of market development as well as the technical and economic feasibility in terms of technology and business model development of the idea must be presented in a comprehensible manner. This has to be verified, and confirmed through exchange with potential stakeholders as well as through targeted market research [35,46,66]. Furthermore, the developed rough concept has to be transformed into a business plan, on the basis of which the potential of the idea can be assessed by external parties and capital for the upcoming cost-intensive research and development activities can be raised from investors [19,67].

Start-up: In the *Start-up Stage*, technology development has to be advanced to the point where an analytical or experimental proof of concept of critical basic functionalities of the deep technology can be provided [66,68]. This proof of feasibility represents the overarching target of the Early Stage and marks the transition to the next development stage of the company. If the feasibility can be proven, the foundation of the deep tech startup as well as the establishment of appropriate structures that support the extensive R&D activities of the company in the upcoming *Research and Development Stage* must be carried out [46].

(2) ***Research and Development Stage:*** In the *Research and Development Stage*, the focus continues to be on technology development, while product development is initiated and actively promoted. At the same time, the market and eventually also the business model development is increasingly pushed in order to raise funding from investors [16,46]:

First Stage: Whereas conventional startups in the *First Stage* (see also *Series A*) already launch a product ready for series production, deep tech startups continue to focus on technology and product development [30,68]. In order to convert the technology from theory into a practical product, it is necessary to integrate it into a first prototype with the previously evaluated basic functionalities and to test its functionality in the laboratory as well as under real conditions[16,66]. Moreover, a target market has to be identified and the requirements of the various stakeholders need to be recorded in order to ensure a product-market fit later on and to form a value proposition [16].

Second Stage: In the *Second Stage* (see also *Series B*), the functional prototype must be transformed into a Minimum Viable Product (MVP) that barely fulfills the requirements of the various stakeholders and thus matches its intended value proposition [66]. Through the involvement and close collaboration with pilot customers, the practicality of the product must be demonstrated while identifying a viable business model that ensures commercialization [16,30].

Third Stage: Comparable to the *Start-up Stage* of conventional startups, the *Third Stage* (see also *Series C*) of deep tech startups requires the MVP to be advanced to series maturity through targeted product development by incorporating pilot customers. At the same time, operational activities must be prepared [30,46]. This includes the development of scalable processes and organizational structures as well as the recruiting of qualified employees in the newly formed departments [69]. Furthermore, initial marketing and sales concepts must be developed and partially implemented, as well as a pilot production plant needs to be set up to ensure that the new product is available in the required quality and quantity [30,46].

(3) ***Growth Stage:*** In the *Growth Stage*, the organizational, product as well as the market development are actively promoted to extensively mobilize financial resources [16,46]:

Fourth Stage: In the *Fourth Stage* (see also *Series D*), deep tech startups must start the production of the market-ready product, implement, or intensify the previously developed marketing and sales concepts, and launch the production-ready product in the market [30,70]. Typically, the *Fourth Stage* also serves as bridge financing to prepare the company for an IPO [42]. This also applies to deep tech startups, which need to raise additional capital on the stock exchange for the upcoming expansion of the company [30]. Accordingly, the company must be professionalized, and transparency must be created regarding internal processes, systems and figures [71].

IPO: Only with the capital raised through an *IPO*, the deep tech startup is able to unfold its full potential, realize an exponential rise in sales and meet its extraordinarily high growth ambitions. Comparable to the *Second Stage* of conventional startups, the *IPO* is followed by the penetration of defined core markets through intensifying sales and marketing activities [30]. This goes hand in hand with the expansion of production and logistics capacities in order to meet rising demand [35,42].

Emerging Growth: Comparable to the *Third Stage* of conventional startups, the *Emerging Growth Stage* of deep tech startups focuses on improving and expanding existing activities and systems and transferring the range of products and services to adjacent markets. By increasing the production quantities, economies of scale are to be sought and the initially high unit costs of the novel product are to be successively reduced. [19,35,72]

(4) ***Late Stage:*** In the *Late Stage*, the focus of the deep tech startup lies on product and organizational development as well as exponential growth [16,46]:

Conquering: Similar to the goals to be achieved by ordinary startups in the *Fourth Stage*, the main goal of deep tech startups in the *Conquering Stage* is to become the market leader in their respective segment. In addition, new markets are to be developed and a diversification of the product portfolio is to be forced. The financial surplus generated is to be fully invested in the further growth of the company and economies of scope are to be sought through the introduction of new products. [19,35]

Capturing: The *Capturing Stage* represents the last stage in the development of a deep tech startup before its transition to a corporate. It is therefore to a certain extent comparable to the *IPO Stage* of conventional startups in terms of goals. Accordingly, the goal for deep tech startups is to shape and seize the newly established market, become the dominant player, and eventually realize economies of density. [73]

As Figure 3 (see Appendix) illustrates, the capital requirement of deep tech startups increases as they progress through their life cycle. According to the explanations in section 2.2, it exceeds that of conventional startup companies considerably even in the early stages of the life cycle. The opposite is the case with the entrepreneurial risk, which decreases with each stage [19]. Only when the respective life cycle stage goals have been achieved, a transition to the next stage of the life cycle can take place. Until then, the company is guided by the targets of its current life cycle stage. Accordingly, the outlined model allows to position deep

tech startups in the life cycle according to their current stage of development. On the other hand, generic goals can be derived at the action level for achieving the next life cycle stage. However, the generic goals must be supplemented by individual goals specific to the organization, technology, product, market, and business model.

5. Conclusion and Future Research

The present work shows that deep tech startups differ from conventional startups in various aspects. Particularly noteworthy is the fact that technology and product development are of major interest for deep tech startups, especially in the early stages of their existence. Although other startup companies proceed in the same life cycle, for deep tech startups there is a compression and deviating focus within the stages due to the associated high R&D requirements. Taking this characteristic into account, four superordinate and eleven sub-life cycle stages were introduced in the presented life cycle model for deep tech startups. The focus and accentuation on the derived development fields changes noticeably due to constant need for reconfiguration and renewal caused by changing parameters, problems, and goals within the respective life cycle stages. The life cycle model that emerged from this paper represents an initial point of reference and serves as an orientation for the systematic and life cycle-oriented explication of deep tech startup development goals. By providing a holistic, and practice-oriented approach, the developed model therefore provides deep tech startups with the necessary guidance on their way towards becoming an established corporate. The present work contributes to making the fragmented subject area of deep tech startups more transparent and concise. Thereby, the work provides a basis on which further research activities can be built on.

The life cycle model developed in this paper represents a first attempt to map the specifics of deep tech startup development. Although the model developed insists on existing startup life cycle stages, it requires a practical validation within a next research step. The validation of the superordinate deep tech startup development stages can be carried out both in the context of an interview study and by retrograde analysis of financing rounds of known deep tech startups. As the presented work is part of a doctoral thesis at the Fraunhofer IPT in Aachen, the deep tech development sub-stages as well as the associated goals will be the subject of further research in the future. Further, the life cycle model for deep tech startups shall be integrated in the research field of collaboration between corporates and startups, enabling a goal-oriented collaboration approach.

Appendix

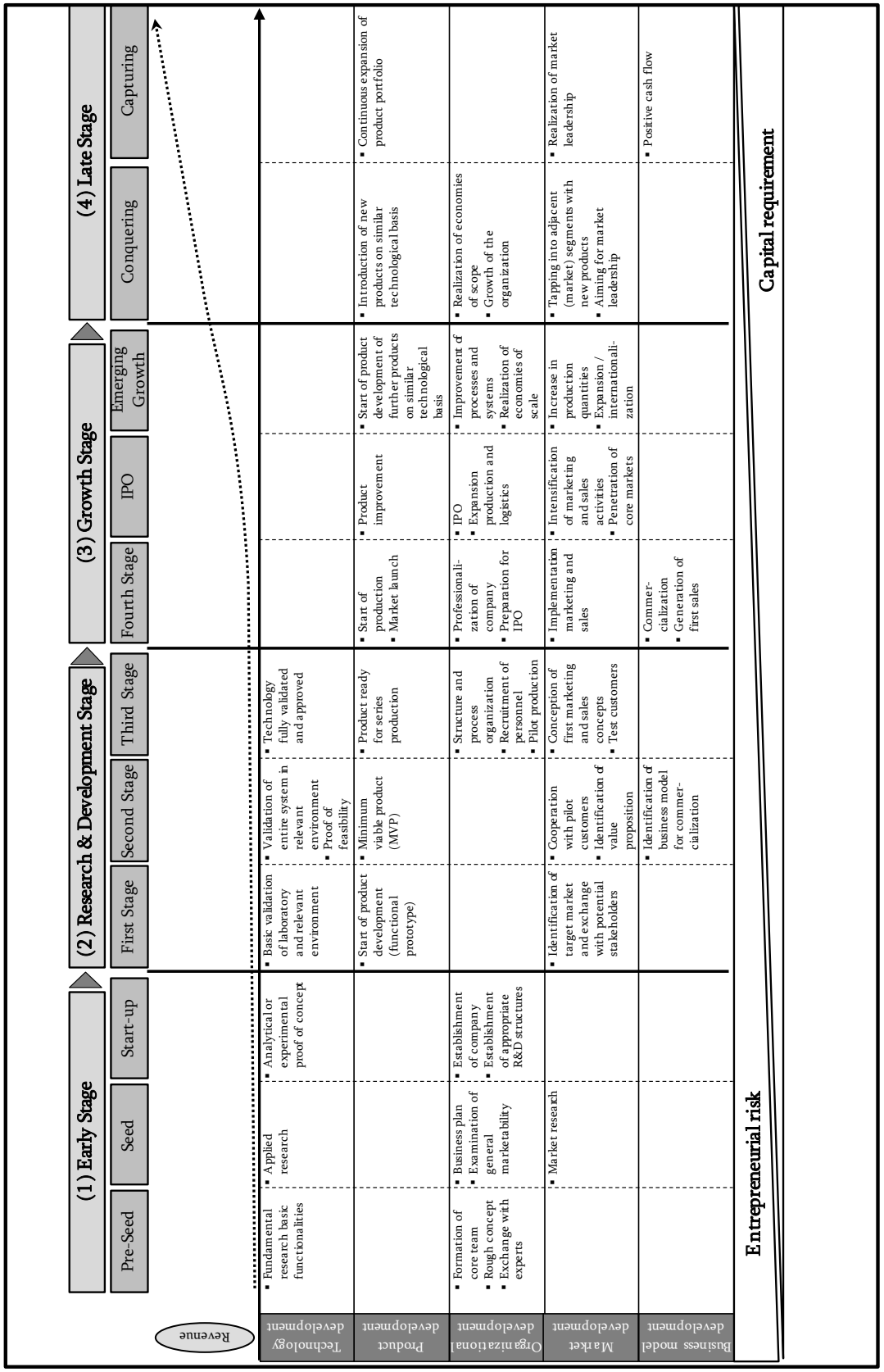

Figure 3: Life cycle model for deep tech startups

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