

A novel method for identifying and characterising stakeholders in the development of DfAM methodologies based on lead user theory

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Abstract

The increasing industrialisation of additive manufacturing (AM) has highlighted the need to address the strategic and organisational aspects of design for additive manufacturing (DfAM). These aspects affect various stages of product development and are embedded in broader development methodologies. Consequently, identifying and characterising suitable stakeholders for developing and validating related artefacts is a complex task. Existing research has not yet systematically investigated the needs and behaviours of larger populations to identify industrial users who are well suited to co-developing and validating such artefacts together with academic institutions. Instead, it often relies on individual case studies, which limits the generalisability of the findings. This paper presents a theory-guided method for characterising and identifying users who have a strong need for strategic and organisational DfAM and demonstrate an advanced level of engagement with it. Based on data from 15 semi-structured interviews with industrial DfAM experts, this study codes and operationalises two characteristics derived from lead user theory: high expected benefit, reflecting a pronounced need for strategic-organisational DfAM artefacts, and ahead of trend, indicating the trend leadership in the strategic-organisational implementation of AM in industrial practice. The proposed method provides a systematic basis for selecting stakeholders for the development and validation of strategic-organisational DfAM artefacts, thereby reducing reliance on narrowly defined case studies and supporting more transferable methodological research in DfAM. Findings indicate that trend leadership in strategic-organisational DfAM is reflected in self-developed methods for systematically assessing DfAM potential, including identifying products suitable for AM as well as employing AM for series production. Conversely, organisational fragmentation of individual DfAM expertise across development processes signals a strong need for strategic-organisational interventions. The proposed method to assess these characteristics can be applied independently, combined with lead-user workshops, or used to support and validate empirically derived samples in strategic-organisational DfAM research.

1. Introduction

Design for additive manufacturing (DfAM) is a field of knowledge concerned with the interrelationships between additive manufacturing (AM) processes and the design methods, knowledge, tools, and development methodologies applied in this context [1]. The field of DfAM can be conceptually differentiated into two principal streams based on the artefacts proposed: *operational* DfAM and *strategic-organisational* DfAM. *Operational* DfAM studies develop and evaluate design methods intended to support practitioners in the product design process for additive manufacturing by orchestrating technology-specific opportunities and restrictions [2]. Research in operational DfAM exhibits a primary focus on design objectives for the additively manufactured product itself (e.g. material savings, functional integration or optimisation of load distribution [3]), with the aim of improving its efficiency, functionality or performance [4]. The artefacts proposed in operational DfAM are intended to demonstrate or support how such design objectives can be fulfilled. These include abstract knowledge-based, often verbally formulated design principles [5] and heuristics [6] that support the designer's thinking, technology-dependent design rules [7] as well as increasingly advanced computational

methods, such as topology optimisation, lattice generation, and artificial intelligence aided design applications [8]. In this context, studies in operational DfAM typically interpret ‘design’ as a verb, in the sense of the actual design activity, which may be regarded as DfAM in its strictest sense [9]. However, operational DfAM also includes methods to support other downstream or upstream activities within the development process, such as methods for selecting components suitable for additive manufacturing [10]. In contrast, *strategic-organisational* DfAM comprises studies that display an explicit relationship to the product development process itself. Research in strategic-organisational DfAM typically interprets ‘design’ in a higher-level, procedural, and development-methodological sense. Artefacts in this stream contextualise, adapt or extend industrially established development processes like the VDI 2221 [11] or generic models like the process proposed in Pahl/Beitz [12] by introducing AM-specific considerations, phases or structural elements (e.g. [13, 14]). It is also not unusual for work in this stream to propose approaches to entirely new product development processes that are enabled by AM (e.g. [15]). Furthermore, studies in the field of strategic-organisational DfAM focus on integrating the technological characteristics of AM with specific development methodologies, such as iterative-incremental (agile) development [16]. The growing interest in examining the impact of AM on business models of companies, value- and supply chains also highlights the close link between strategic-organisational DfAM and industrial product development [17].

From the perspective of the artefacts emerging from the two DfAM publication streams, it becomes clear that the characterisation and identification of the principal stakeholders involve a considerably higher degree of complexity in strategic-organisational DfAM. Strategic-organisational DfAM touches upon various aspects of industrial product development that are not directly related to DfAM understood as a design activity in the strict sense but may nevertheless be of decisive importance for the methodological artefacts to be developed or validated. These aspects encompass not only role-, position-, and organisation-specific sociodemographic characteristics, but also more difficult to capture perception- and behaviour-related aspects of this stakeholder group regarding overarching development methodology.

With this present work, we address a lack in strategic-organisational DfAM research regarding the reliable identification of relevant stakeholders for the proposed methodological artefacts, insofar as these stakeholders are only rarely characterised with respect to their suitability for development or validation of the respective artefacts. We therefore regard the population of industrial stakeholders for strategic-organisational DfAM as ‘poorly-mapped’ (cf. [18]), in which sampling is inappropriate without clarity regarding the characteristics to be identified. It is important to resolve this through a systematic approach, as attempts to circumvent this problem would lead to an excessive reliance on specific case studies for the development and validation of such artefacts, resulting in findings that can only be generalised to a limited extent – a trend that is already evident in the DfAM literature [19].

This paper presents a theory-driven method for characterising and identifying industrial stakeholders for strategic-organisational DfAM artefacts. The method consolidates data derived from 15 semi-structured interviews with industrial DfAM experts and is intended to capture the needs and behaviours of this

stakeholder group. For this purpose, the study adopts the concept of lead users proposed in von Hippel's lead user theory [20]. With the development of this method, this paper provides insights into empirically grounded needs and innovative solution approaches of industrial stakeholders in the context of strategic-organisational DfAM. Three fields of application for the presented method are discussed, ranging from its use as a stand-alone method in the form of an empirical survey, to its combined application in the conduct of lead user workshops [21], and finally to the validation of empirically drawn samples for studies in strategic-organisational DfAM based on participant characteristics.

2. Contextualising lead user theory for DfAM as a research approach

Lead users are characterised by needs that are ahead of those of the rest of the market [20] (see Fig. 1). Owing to the particularly strong manifestation of these needs, they are in a position to benefit to an exceptional degree from the satisfaction of those needs through adequate products, and at the same time they are motivated to experiment with their own solution approaches, to attempt to resolve these needs before such products exist. These needs may be addressed by physical products, or by intangible products such as software, services or, as later shown by Schmidt [22], even methods. What makes lead users interesting for product development is the simultaneous presence of two specific characteristics arising from their particular need situation, namely 'high expected benefit' (HEB) and 'ahead of trend' (AOT) [23]. These two theoretical dimensions describe a particular need situation and the associated desire for solutions (HEB), while the independently driven experimentation with and development of solution approaches motivated by the HEB characteristic can lead to the emergence of trend leadership (AOT). Lead users can therefore be regarded as particularly valuable stakeholders for certain developments, which they can also decisively support through their innovative capacity.

The lead user approach is therefore a particularly suitable theoretical basis for identifying and characterising industrial stakeholders who can contribute to the development and validation of strategic-organisational DfAM. The use of AM for rapid prototyping purposes can now largely be regarded as established in industrial practice and no longer constitutes a strongly differentiating characteristic among industrial AM users [24]. By contrast, the application of AM for the production of complex series products (direct manufacturing [25]) remains a comparatively young field of application, one that is associated with considerations on product development that have played only a subordinate role in the context of rapid prototyping [26]. These considerations include the use of specific development methodologies, such as those proposed in academic research on strategic-organisational DfAM. Unlike rapid prototyping, direct manufacturing can therefore still be understood as a field of innovation, where innovators are confronted with novel challenges [27, 28]. These challenges require dedicated development-methodological interventions as well as the experimental exploration of new solution approaches, which may in turn lead the innovators involved to develop and exhibit characteristics similar to *ahead of trend* (AOT) and *high expected benefit* (HEB). Precisely these industrial users are of particular interest for the development and validation of artefacts in strategic-organisational DfAM, as they not only exhibit a concrete need for such artefacts but may also be regarded as particularly advanced owing to their self-motivated drive for innovation.

To date, however, there has been no systematic approach for capturing the characteristics of these stakeholders in a measurable way, to assess both their actual needs and their innovative capacity. This paper addresses this gap by defining the lead user characteristics HEB and AOT for the context of strategic-organisational DfAM based on empirical data and translating them into a methodological approach that enables the operationalisation of these theoretical dimensions for the identification and characterisation of relevant stakeholders.

3. Methodology

This study contextualises von Hippel's (1986) lead user theory [20] as the theoretical foundation for a method to identify and characterise suitable DfAM stakeholders for strategic-organisational DfAM artefacts. The identification of such stakeholders can be facilitated through a questionnaire, with items defined in a theory-driven manner based on the two central lead user characteristics [23] *high expected benefit* (HEB) and *ahead of trend* (AOT). The basic idea underlying the method is based on contextualising the two characteristics of particularly innovative need holders described in lead user theory [20], in this case regarding a DfAM-specific development methodology for industrial DfAM. The aim is to identify practitioners who, on the one hand, can be regarded as need holders with respect to methodological interventions in the field of DfAM who would be expected to generate value from such interventions (i.e. there is *high expected benefit* (HEB)). On the other hand, these practitioners distinguish themselves from mainstream users of additive manufacturing in the product development context through their practices, proprietary approaches, and handling of additive manufacturing technologies in product development, thereby exhibiting a form of trend leadership (i.e. they are *ahead of trend* (AOT)). To achieve this, the two characteristics AOT and HEB must be rendered measurable, thereby enabling an assessment of the degree to which these characteristics are exhibited by individuals, in the following also referred to as exhibiting a certain degree of '*lead-userness*' for strategic-organisational DfAM.

3.1 Empirical data basis

This study draws on interview transcripts that were collected in 2024 as part of a previous study [27]. It therefore constitutes a qualitative secondary analysis [29]. Parts of the interview material, the interview guide (see Table 1 in the Appendix), and a primary analysis based on a subset of 11 of the total 15 interviews and addressing a different research question were already published in [27]. The present study includes all 15 interview transcripts and pursues a different research question, a different analytical perspective, and a different epistemic purpose. Nevertheless, in line with good scientific practice, the following sections provide transparency regarding the context in which the data were generated and the new unit of evaluation (i.e. the dataset).

Table 1

Semi-structured interview guide from the 2024 study on industrial product development for additive manufacturing (reproduced from [27] with permission of the authors).

No.	Question
1	In your experience and assessment, what are the decisive reasons for manufacturing a component additively instead of conventionally?
2	When and how is the decision made for/against the use of additive manufacturing technologies for the production of a part under development?
3	In your experience, are the specific AM machines selected according to the components to be manufactured or vice versa, and why is this the case?
4	Please describe how a typical design process for a component that is to be additively manufactured looks in your work.
5	Which steps precede (i.e. before the design process begins) or follow (after the design has been finalised and before the final product is manufactured) the actual design process?
6	What do you use additive manufacturing for in your work?
7	What are current challenges in the development of components for AM in your company?
8	To what extent do the additively manufactured components you work with represent new developments (i.e. new concept, design and detailing) or refinements of existing ones (i.e. adaptations or variants)?
9	To what extent do you make use of the possibilities to design the manufacturing process advantageously according to the component design? (e.g. by adapting process parameters or exposure strategies)
10	Please describe to what extent and at what stages in the design process individual geometric features up to prototypes of the component to be developed are additively manufactured to support the development process.

3.1.1 Context of data generation

The interview transcripts used in the present study stem from a series of interviews with a total of 15 experts on DfAM from industry, conducted in July and August 2024. The purpose of the interviews at that time was to understand how industrial product development is currently taking place for products intended for additive manufacturing. The original research question, which was addressed in [27], was: What challenges should a development framework for additive manufacturing address to support efficient product development? The material analysed for answering this question is also suitable for the present study because the semi-structured interview guide was designed within a broad product development context (see Table 1 in the Appendix). It covered higher-level processes and structural elements derived from ISO/ASTM 52910 [30], as well as strategic decisions related to DfAM, operational DfAM activities, individual behaviours, and organisational aspects. At the same time, the format allowed for an open interview setting. This made it possible to collect nuanced individual accounts from advanced users of AM technologies in industrial practice across different companies, positions, and job

titles (see Chap. 3.1.2). The job titles of four participants even explicitly included the term ‘additive manufacturing’ (highlighted in Fig. 2 and Fig. 3). The material is therefore well suited to an analysis based on the criteria HEB and AOT, which are drawn from lead user theory [20].

3.1.2 Unit of evaluation and demographics

The dataset (i.e. the unit of evaluation according to Mayring & Fenzl [31]) of the present study comprises four additional interview transcripts compared with the primary analysis published in [27]. In the primary analysis, two roles were excluded from the sample because, from the more technology-oriented perspective that was appropriate for the earlier research objective, they showed less direct connection to AM technology: a trainer (education & training) and a project manager (project management). Following the same rationale, the transcript of one interviewee from executive management (executive management & leadership) was also not analysed. The fourth transcript not included in the primary analysis was from a design engineer who worked in the same company as another participant already included. This was done to avoid a methodological overrepresentation of a specific organisational context. For the present study, however, it is analytically valuable to include roles that are more distant from the technology, as the needs and behaviours of DfAM stakeholders are to be analysed in the context of strategic-organisational DfAM. Although the limited multiple representation of individual organisational contexts constitutes a limitation of the empirical dataset, the authors consider the degree acceptable. Overall, three participants each are affiliated with the same company, resulting in 15 participants from 12 companies being included in the analysis. The sociodemographic characteristics of the interview participants are presented in Figs. 2 to 5. Figure 2 shows the participants’ areas of work. Figure 3 presents their experience with AM, differentiated by job title. Figure 4 shows the five industry sectors to which the 12 companies and their 15 participants can be assigned. Finally, Fig. 5 presents company size.

3.2 Theory-driven qualitative content analysis

Within the scope of this study, interview transcripts are subjected to qualitative content analysis in accordance with Mayring & Fenzl [31]. The following units of analysis were applied:

Unit of evaluation (i.e. the dataset):

- The dataset is represented by the entirety of all 15 transcripts
- The order of analysis was sequential (effectively random, as it depended on scheduling with the interviewed experts)
- The analysis was conducted on a case-by-case basis (i.e. one interview transcript in full, followed by the next)

Coding unit (i.e. the minimum text segment allowed for coding):

- The coding unit constitutes a semantic unit (single sentence, an entire paragraph, or several sentences expressing one idea, even if interrupted by parenthetical insertions)
- Individual words do not constitute valid coding units

Context unit (i.e. the largest text segment allowed for coding)

- The context unit is an entire interview response

To ensure compliance with Mayring & Fenzl's quality criteria [31], two independent coders each coded the entire dataset twice, thereby supporting the assessment of intracoder agreement. During the coding process, the codings of both coders were compared and discussed in regular project meetings held once a week over a period of four weeks. Following completion of the analysis, the full set of results was reviewed, discussed, and the codes were consolidated to ensure intercoder agreement.

Within the theory-driven qualitative content analysis, an additional metric was constructed to describe the ratio of coding frequencies between the two overarching categories AOT and HEB that were derived from lead user theory [20]. As several subcodes may be assigned to each of these main categories, this metric aggregates the coded text passages at the level of the theoretical core dimensions which they represent. The ratio of AOT to HEB is not interpreted as an independent reliability measure in the strict sense, but rather as a supplementary indicator of the similarity in interpretative emphasis across multiple coders (in this case two coders according to Mayring & Fenzl's criteria for inter coder reliability [31]). If the ratios are of a similar magnitude across coders, this suggests that the interviews were perceived and interpreted in a comparable manner regarding the two central theoretical dimensions trend leadership (AOT) and expected benefit or need (HEB). One advantage of this ratio-based approach is that it can partially mitigate differences in individual coding preferences. Some coders, for instance, may tend to mark longer text passages as a single coding instance, whereas others may segment the same substantive content into several smaller units. As the metric is not based on the absolute frequencies of a single category, but rather on the ratio between two conceptually related main categories (AOT & HEB), such coder-dependent differences in segmentation intensity are partially levelled out. From a methodological perspective, this approach appears justifiable, as the analysis of code frequencies or category densities is also widely accepted in qualitative content analysis as a supplementary means of condensing and interpreting results [31].

At the highest level of coding, the two categories AOT and HEB, conceptually derived from lead user theory, were applied deductively. During a pilot phase, both categories were specified based on concrete challenges, behaviours, thoughts, and similar aspects described in the first three transcripts, and were formulated as subcodes, which were then incorporated into the initial coding guideline. The initial guideline was discussed and consolidated by both coders before the entire dataset was coded. During the analysis, both coders applied the initial guideline and extended it through the inductive development of additional codes, which were discussed regularly and reviewed to avoid over-differentiation.

3.3 Formulation of questionnaire items based on lead user characteristics

After completion of the content analysis, the specific characteristics of theoretical lead-users for strategic-organisational DfAM are available in coded form. For application in the method, these characteristics must be rendered measurable. This requires their conversion into a question format. In determining the appropriate question format, it is necessary to distinguish whether an item is supposed to capture clearly differentiable facts, for example whether a company uses AM solely for prototyping or also for series production, or whether the respective lead user characteristic depends on the respondent's perception. Perceptions are more appropriately captured by asking respondents to indicate their degree of agreement with a given statement [32]. This is suitable for measuring the extent of needs (to resolve specific challenges) that are reflected in the theoretical dimension HEB. For the development of the corresponding items, the codes categorised under HEB are therefore converted into statements to be rated on an odd-numbered (five-point) Likert scale. The rationale for using an odd-numbered scale is the assumption that participants showing a strong expression of the HEB characteristic are likely to distance themselves voluntarily from the offered neutral midpoint of the scale. For items intended to render the theoretical dimension AOT measurable, semi-open question formats are used. First, a closed question (yes/no) is asked to determine whether the respondent performs an activity or uses a specific artefact associated with pronounced trend leadership. If the respondent answers affirmatively, they are then asked to provide an open description of the respective activity or artefact. This open component is particularly important because the free-text response is decisive for the subsequent assessment of how innovative (i.e. *ahead of trend*) the stakeholder is. In this way, it is also possible to control for the risk that the presence of an AOT characteristic is distorted by implicit desirable response behaviour [33]. Such distortion could arise if the person being characterised recognises trend leadership as the latent construct underlying the items and, as a self-perceived DfAM expert, feels compelled to present themselves as especially innovative.

4. Results

4.1 Lead user characteristics in industrial DfAM

This chapter first presents the results of the qualitative content analysis. These results represent the lead user characteristics in coded form (see Table 2). Based on these codes, the items (i.e. questions and statements) presented in Chap. 4.2 for measuring the AOT and HEB characteristics are developed. For the scope of this study, the minimum number of codes whose cumulative coding frequency (sum of both coders i_1 & i_2) accounts for 80% of the total number of codings within the unit of evaluation (i.e. the complete dataset) was used to formulate the corresponding items (Table 2). This measure is, in the broadest sense, guided by the 'vital few, trivial many' interpretation of the Pareto principle [34] and is intended to provide proportionality between the effort required and the analytical benefit when these

items are transferred into a questionnaire. Table 3 in the Appendix presents the remaining codes generated, which account for the remaining 20% of the coded segments.

Table 2

Consolidated codes with coding frequencies n for the two coders i_1 and i_2 . Relative (rel.) and cumulative proportions of the number of codings measured against the total number of coded text segments (unit of evaluation) are presented.

Code	Char.	$n(i_1)$	$n(i_2)$	n	rel.	cumulative
Systematic identification of DfAM potential	AOT	36	37	73	15%	15%
Organisational fragmentation of DfAM expertise	HEB	29	22	51	10%	25%
Use of AM for series production	AOT	35	9	44	9%	34%
Loss of DfAM potential due to conventional mindsets	HEB	18	19	37	7%	41%
Development of proprietary methods for securing and disseminating DfAM knowledge	AOT	17	15	32	6%	48%
Sobering experience following the hype around AM	HEB	15	16	31	6%	54%
Strategic technology development for AM	AOT	16	14	30	6%	60%
DfAM expertise is tied to individual people	HEB	23	/	23	5%	64%
Use of iterative and incremental component output	AOT	10	8	18	4%	68%
Use of AM across different application stages	AOT	/	18	18	4%	72%
Integration of DfAM into overarching development methodologies	AOT	11	3	14	3%	74%
Conventional manufacturing as a fallback option	AOT	11	/	11	2%	77%
Lack of early involvement of AM expertise	HEB	11	/	11	2%	79%
Customer-driven demand for AM	AOT	4	6	10	2%	81%

Table 3

Consolidated codes with coding frequencies n for the two coders i_1 and i_2 . Cumulative proportions are continued from Table 2.

Code	Char.	$n(i_1)$	$n(i_2)$	n	rel.	cumulative
Retrospective conversion of existing products into AM variants	AOT	9	/	9	2%	83%
Use of time-to-market advantages	AOT	/	9	9	2%	85%
Late commitment to AM or conventional manufacturing	AOT	/	8	8	2%	86%
Use of in-house DfAM guidelines and processes	AOT	/	7	7	1%	88%
AM as an option rather than a necessity	AOT	6	/	6	1%	89%
Iterative component optimisation	AOT	/	6	6	1%	90%
Loss of DfAM potential due to time pressure	HEB	1	3	4	1%	91%
Use of more suitable processes for the product portfolio	HEB	/	4	4	1%	92%
Lack of a specific methodology for AM component development	HEB	/	4	4	1%	92%
Reduced exploitation of AM potential due to verification requirements	HEB	/	4	4	1%	93%
Reduced exploitation of AM potential due to uncertainty	HEB	/	4	4	1%	94%
Integration of AM into a conventional production environment	AOT	3	/	3	1%	95%
Questioning the practicality of DfAM methods	AOT	3	/	3	1%	95%
Dependence on external supplier know-how on the most suitable AM process	HEB	/	3	3	1%	96%
Physical validation rather than analytical verification for proof of compliance	AOT	/	3	3	1%	96%
Advances in the verification of AM processes and materials	AOT	/	3	3	1%	97%
Product variety as a driver of AM adoption	AOT	2	/	2	< 1%	97%
Perceived labour intensity of pre- and post-processing	HEB	/	2	2	< 1%	98%

Code	Char.	$n(i_1)$	$n(i_2)$	n	rel.	cumulative
Cross-functional collaboration in DfAM	AOT	/	2	2	< 1%	98%
Reduced usable DfAM potential due to inconsistent component properties	HEB	/	2	2	< 1%	99%
Management-driven AM adoption without prior potential analysis	HEB	/	1	1	< 1%	99%
Flat hierarchies enabling rapid incremental output	AOT	/	1	1	< 1%	99%
Risk reduction for additively manufactured components	AOT	/	1	1	< 1%	99%
Higher costs due to low machine utilisation	HEB	/	1	1	< 1%	99%
Development of automation for identifying AM potential	AOT	/	1	1	< 1%	100%
Recognition of AM potential only at the end of development	HEB	/	1	1	< 1%	100%
Reduction of DfAM process time	HEB	/	1	1	< 1%	100%

Table 4 shows the total number of coded segments in the interview material for both coders, as well as the resulting AOT-to-HEB ratio, which is 1.68 (i_1) and 1.74 (i_2) respectively.

Table 4
Ratio of the number of coded text segments for AOT and HEB for both coders.

Coder	$n(AOT)$	$n(HEB)$	AOT [%]	HEB [%]	$\frac{AOT}{HEB}$
i_1	163	97	62,7	37,3	1,68
i_2	151	87	63,4	36,6	1,74

4.2 Items for HEB and AOT

In this chapter, the items (i.e. questions and statements) that may be used to measure the extent of the AOT (Table 5) and HEB characteristics (Table 6) among stakeholders considered particularly suitable for strategic-organisational DfAM artefacts, are presented.

Table 5
Formulated survey items to assess AOT characteristics.

Item	Question	Value	Follow-up
AOT1	Do you have a defined approach for identifying components or products that are well suited for additive manufacturing?	dichotomous	open-ended
AOT2	Does the final product that you develop or market contain additively manufactured parts?	categorical	not applicable
AOT3	Is the procurement of additive manufacturing equipment linked to a planned development of in-house DfAM expertise?	dichotomous	open-ended
AOT4	Have you established in-house methods within your company to provide appropriate support to the people involved in component design for AM?	dichotomous	open-ended
AOT5	Have customers expressed a demand to your company for explicitly additively manufactured components?	dichotomous	open-ended
AOT6	Do you make targeted use of the potential of additive manufacturing for faster and more frequent production of components?	dichotomous	open-ended
AOT7	Is additive manufacturing used in your company for any other specific applications?	dichotomous	open-ended

Item AOT2 (Table 5) serves to distinguish between the applications of AM for direct manufacturing and rapid prototyping, as the demand for strategic-organisational DfAM artefacts is driven by the manufacture of series products via AM. The following response categories are suggested for this purpose:

- Yes, the final product is manufactured entirely using additive manufacturing (all essential physical components of the product).
- Yes, the final product contains parts produced using additive manufacturing (individual components/assemblies; other parts are manufactured conventionally or sourced externally).
- No, the final product does not contain any additively manufactured parts.
- I don't know / I can't say.

Table 6
Formulated survey items to assess HEB characteristics.

Item	Statement	Value	Follow-up
HEB1	The design potential of additively manufactured components is significantly limited by insufficient coordination between the organisational units involved.	Likert (5-point)	not applicable
HEB2	Expert knowledge of component design for additive manufacturing is concentrated in just a few individuals.	Likert (5-point)	not applicable
HEB3	During the design process, those involved find it difficult to carry out component design while considering the specific opportunities and constraints of additive manufacturing.	Likert (5-point)	not applicable
HEB4	Expectations regarding the design potential of additively manufactured components are not being met.	Likert (5-point)	not applicable
HEB5	The specific expertise in component design for additive manufacturing (DfAM) is never incorporated into product development early enough in the process.	Likert (5-point)	not applicable

5. Discussion

The method proposed in this paper for the identification and characterisation of stakeholders for strategic-organisational DfAM offers various possible applications, and associated benefits, for the development of DfAM artefacts in the field of design methodology:

1. Application as a standalone method using the presented items in the form of a questionnaire to identify and characterise potential stakeholders for strategic-organisational DfAM artefacts.
2. Application as a complementary method alongside, or prior to, a lead user workshop for the further development and/or validation of strategic-organisational DfAM artefacts.
3. Application for sample validation in studies in the context of strategic-organisational DfAM artefacts, based on rare manifestations of characteristics among the surveyed individuals (i.e. high *lead-userness*).

5.1 Application as a standalone method through questionnaires (Case I)

When applying the method in the context of an empirical survey, by utilising the presented AOT and HEB (see Tables 5 and 6) items as outlined in case I, it should be recognised that the purpose of the survey is to identify, assess, and characterise distinct expressions of characteristics (i.e. high *lead-userness*) that

may be present among individual members of the sample within the target group. The needs (HEB) and innovative behaviours (AOT) identified in this paper, derived from theory and grounded in empirical data, provide a basis for identifying individuals who exhibit the characteristics of high expected benefit and ahead of trend in the context of strategic-organisational DfAM. However, it is not intended to support inferential statistical generalisation of these expressions to the broader population based on the results of such survey. Against this background, the sample size (the number of respondents) should also be interpreted accordingly. It would not be meaningful to determine the required sample size based on conventional methods used to calculate the sample size necessary for inferential statistical generalisation, for example following Mayer [35]. A larger sample merely increases the statistical likelihood of detecting rare trait expressions (i.e. high *lead-userness*). However, this does not alter the fact that the very first respondent may already exhibit strong expressions of both lead user characteristics, ahead of trend (AOT) and high expected benefit (HEB), whereas even after analysing hundreds of responses such expressions may still not be observed. The latter is particularly likely when the questionnaire is distributed without moderation through public channels. It may therefore be advisable to treat a questionnaire based on the items specified in this paper as an explicit measurement instrument and to distribute it to individuals for whom, on the basis of objective criteria, a particular suitability in terms of (some of) the needs and behaviours of a theoretical lead user for strategic-organisational DfAM (see Table 2) can already be assumed. Search strategies such as ‘pyramiding’ may also be considered as an option for finding such participants [18]. Furthermore, researchers intending to apply the presented questionnaire items should consider which additional sociodemographic items are required, as these may depend strongly on the artefact to be further developed or validated. For example, item HEB 2 should be combined with a measure of company size, since the concentration of DfAM know-how in individual persons may be less problematic in the context of small and medium sized enterprises (SMEs) than in large corporations.

5.2 Application as a complement to a lead user workshop (Case II)

When applying the method in the sense of use case II, the logical sequence of lead user workshop activities would differ from that defined and applied by Schmidt [22]. The method presented here effectively consolidates the content of the first two phases of the workshop process (see Fig. 6). In Schmidt’s approach, these phases serve first to open the problem space through discussion and the use of creativity methods (divergent thinking), and subsequently to refine this broad perspective by converging on the main problems before starting with solution development, in line with the logic of the Double Diamond approach [36]. In the present study, the divergent exploration of the problem space was undertaken through the analysis of 15 distinct industrial perspectives derived from the interview data (see Chap. 3). Convergence was then achieved through the interpretation of coding frequencies within the higher-level relevant characteristic expressions (HEB and AOT), enabling the identification of the main aspects to be addressed in the workshop. In the subsequent phase, in which solution development would normally begin with the workshop participants, the researchers’ own proposals for solution approaches stemming from the strategic-organisational DfAM artefact to be further developed or

validated would additionally be introduced and opened up for discussion. A schematic comparison between the logical sequence of a lead user workshop according to Schmidt [22] and a sequence adapted through application of the method presented in this paper is provided in Fig. 6.

5.3 Application for sample validation (Case III)

The application of the method presented in this paper in the sense of case III makes a direct contribution to the well-known problem that development methodological artefacts, as typical outcomes of PhD projects in the field of design science, often require too much time in practice for their effects to become visible and to be used for success evaluation [37]. This problem is further compounded by the definitional uniqueness of development projects in practice [38]. Even where a methodological artefact would allow for a success evaluation, the question of comparability with other project contexts remains unresolved. It is therefore evident that the evaluation and validation of development methodological artefacts, including work in the field of strategic-organisational DfAM, require pragmatic approaches that can also be applied outside real project contexts without compromising scientific reliability. By characterising individuals within a sample about specific characteristics (AOT & HEB), which act as proxies for valid need holders with high *lead-userness* in relation to the artefact, the method presented here provides such a basis.

6. Conclusion and outlook

This paper presents a method for the characterisation and identification of suitable stakeholders for the development and validation of strategic-organisational DfAM artefacts. To this end, the two characteristics derived from lead user theory [20], high expected benefit and ahead of trend [23], were contextualised for the context of strategic-organisational DfAM. Content analysis of 15 individual accounts from industrial DfAM experts showed that specifically developed approaches for the systematic identification of DfAM potential in development, as well as the use of AM for series production, can be regarded as strongly differentiating features of industrial stakeholders in terms of trend leadership (i.e. AOT). Equivalent characteristics for the HEB dimension include mindset barriers within the workforce and the organisational fragmentation of DfAM expertise. The latter can be observed, for example, when employees trained in DfAM are consulted only at the end of the development process, once sub-optimal designs are already about to be printed (cf. [27]). These and other specific characteristics of industrial stakeholders exhibiting a high degree of '*lead-userness*' for strategic-organisational DfAM artefacts (see Table 2) were translated into corresponding questions and statements (see Tables 5 and 6) to operationalise these theoretical dimensions.

As part of this analysis AOT-to-HEB ratios based on coding frequencies were proposed for the first time as a measure for quantifying the degree of *lead-userness*. In this study, these ratios were very close for both coders (see Table 4), which is indicating a conceptually similar perception of the analysed interview material regarding the two theoretical dimensions, HEB and AOT. Furthermore, the fact that the prevalence of segments coded for AOT is approximately a factor of 1.7 higher than for HEB also

suggests that the sample used here can be regarded as particularly innovative in the field of strategic organisational DfAM. Whilst a desirable AOT-to-HEB ratio for lead users, as defined by the method presented here, cannot be precisely quantified, we nevertheless recommend using 1.5 as a rough guideline based on our experience with the analysis presented here. For AOT-to-HEB ratios below 1.5, researchers wishing to use the method presented here should critically reassess the suitability of the subjects for participation in subsequent activities, such as lead user workshops. If the AOT characteristic is too weak compared to HEB, participants in lead user workshops may be more likely to complain rather than to contribute the knowledge of potential solutions associated with the AOT characteristic [39].

In summary, this paper presents a new theory-driven approach for systematically and reliably supporting both current and future proposals of strategic-organisational DfAM artefacts, as well their empirical validation.

Declarations

Author Contribution

F.G. developed the study design, defined the research problem and objective, specified the methodology and conducted the interview series. F.G. wrote all chapters. F.G. and M.K. analysed the data and developed the proposed approach. M.K. designed Fig. 1. A.K. provided academic supervision, contributing to all stages of the study. All authors reviewed the manuscript.

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Data Availability

The primary publication reporting the interview study on which this work draws is available open access at: <https://doi.org/10.1017/pds.2025.10120>

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Figures

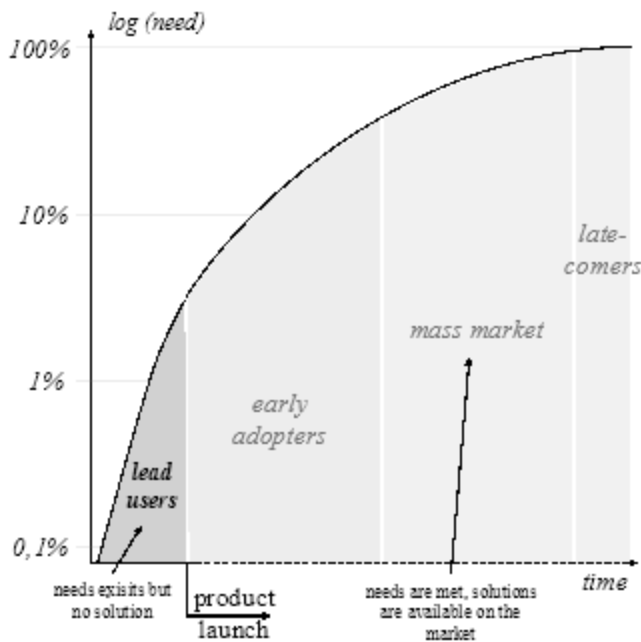


Figure 1

Locating lead users on the schematic need diffusion curve for new products based on Schmidt [22].



Figure 2

Work areas of the 15 interview participants. Orange highlighting indicates role titles that include 'additive manufacturing'.

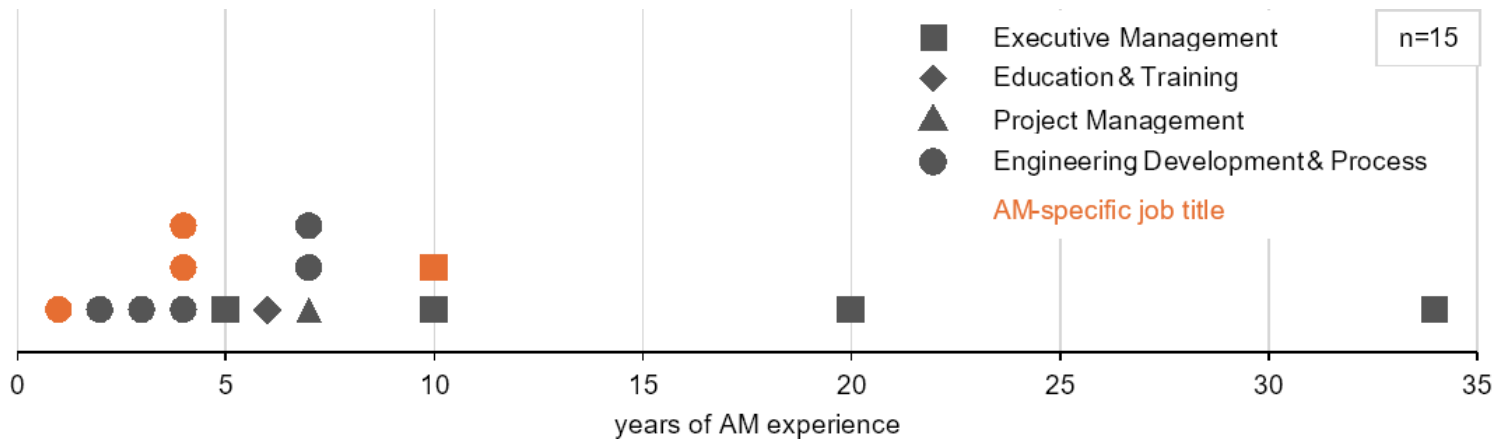


Figure 3

Professional experience with AM in years. Different symbols distinguish the participants' areas of work. Orange highlighting indicates role titles that include 'additive manufacturing'.

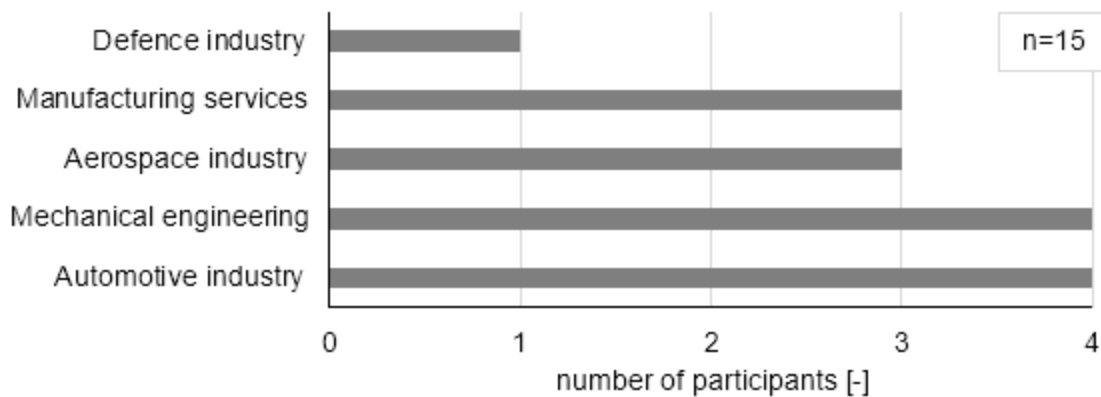


Figure 4

Industry sectors of the interview participants.

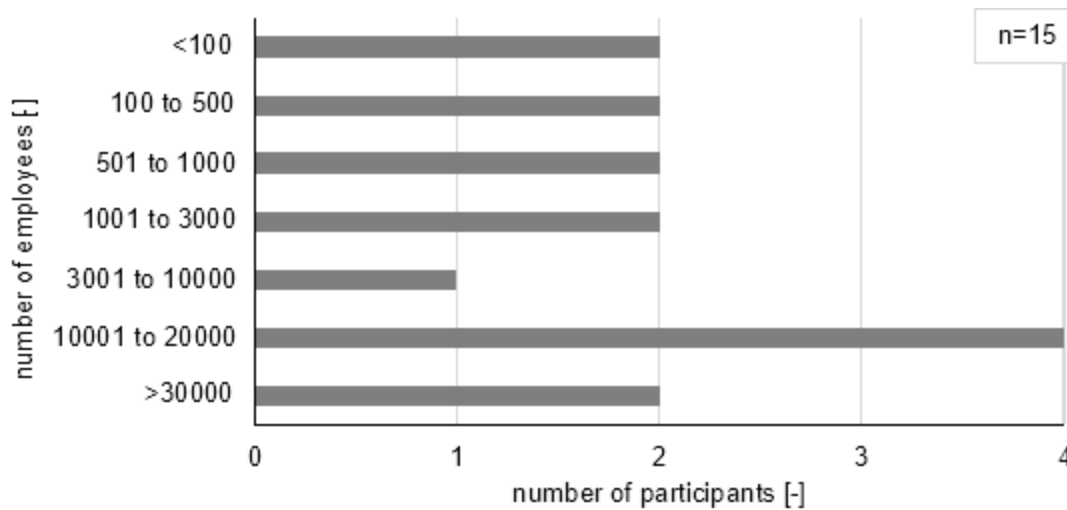


Figure 5

Company sizes differentiated by number of employees.

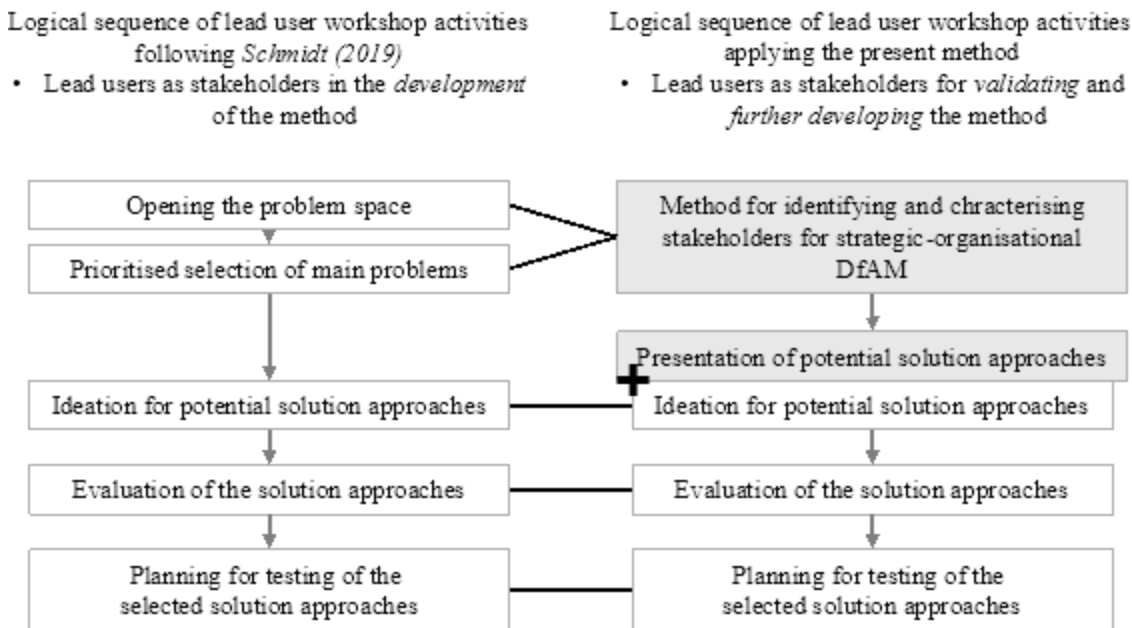


Figure 6

Sequence of lead user workshop activities following Schmidt [22] (left) and adapted sequence incorporating the proposed method for identifying and characterising individuals exhibiting high *lead-userness* in the context of strategic-organisational DfAM artefacts (right).

Supplementary Files

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- [Appendix.docx](#)