Exploring creativity management of design for additive manufacturing

Angelica Lindwall and Åsa Wikberg Nilsson

Department of Social Sciences, Technology and Arts, Luleå University of Technology, Luleå, Sweden

ABSTRACT
While many argue that Additive Manufacturing (AM) opens up new possibilities in design due to its higher degree of design freedom, it is also suggested that it can increase creativity in product design. It has been further proposed that creative outcomes are limited by the imagination of the designer: designers are often asked to take full advantage of the new design potentials given by AM, yet without having the supports that are needed to increase their creativity. Current literature focuses neither on supporting creative perspectives in Design for AM (DfAM) nor on how to manage the higher degree of design freedom that can be present. As a consequence of this noticeable gap in the literature, this paper continues to explore what areas that need to be considered in creativity management, to fully support designers in utilising their creative abilities in relation to AM in design. The paper proceeds through a literature study on creativity in DfAM and presents a case study with experienced designers who are just starting to work with AM in their design practices. This paper contributes to the field with the notion of a creativity layer laid upon DfAM, visualized by three characteristics of creativity (expertise, creative thinking skills and motivation) drawn from previous research. This results in three concrete propositions of areas that need to be considered in future research on how to include a creativity management perspective in DfAM.

1. Introduction
The focus of this paper is to explore how creativity management during implementation of new technologies impacts the creative abilities among designers in an organisation. One such new technology is Additive Manufacturing (AM), the layer-upon-layer manufacturing method, which often is considered to bring a higher degree of design freedom (e.g. Gibson, 2017), compared to traditional product development and manufacturing methods. In itself, design freedom is generally considered to open up possibilities for creative ideas and solutions in design practices, to create higher values in the end product and expectantly result in product innovations. To our knowledge, however, current research on Design for Additive Manufacturing (DfAM) does not seem to have a common framework to assist designers in making the most of their creative abilities (Krantz et al., 2015; Kumke et al., 2016), during implementation of such new technologies. It has been suggested that the design freedom given by AM can actually lead to an overwhelming feeling amongst some designers who are new to the technique (Campbell et al., 2012; Klahn et al., 2015; Yang & Zhao, 2015). Experienced designers might already be used to certain regulations and limitations, yet they
are asked to create new designs that are ‘out of the box’ at the same time, as the boundaries of the box are completely changed with this new technique. Many companies want to create product innovations to stay competitive, and they see the potential to do so with the assistance of AM. Designers are consequently asked to take full advantage of the new design potentials given by AM, but often without being supplied with the support on how to approach the new possibilities. To meet those needs, various DfAM methods and frameworks have been developed to assist designers seeking to incorporate this new technology in their design practices (e.g. Kumke et al., 2016; Maidin et al., 2012; Ponche et al., 2014). However, these frameworks do not seem to focus on supporting creativity in DfAM, neither on the individual nor on the organizational, level of managing the higher degree of design freedom that becomes available. It should be noted that even though AM is often considered to have revolutionized the way products are designed and manufactured, it is also argued that manufacturing methods are still in their infancy (Bermano et al., 2017). Therefore, there seem to be some persistent uncertainties regarding how to adopt and fully utilize the ‘new’ manufacturing techniques both creatively and efficiently.

Industries such as aerospace are often considered as potential beneficiaries of AM (Gibson, 2017) since products are often produced in low production volumes but with high geometrical complexity. However, such industries are generally highly regulated through a high number of reviews along the design process, in terms of stringent quality demands, high safety requirements, and generally have a high degree of routine design work. Such highly regulated work can sometimes be a drive for creativity, but research has also identified that it sometimes has negative effect on an individual’s motivation, expertise, and creative thinking skills (Amabile, 1998). Therefore, designers in the space industry could need extensive support while including a new technology such as AM. The empirical case study presented in this paper has therefore been conducted in the highly regulated context of the space industry, to bring important insights on how creativity is experienced in situations where a designer is starting to adopt AM in his or her own design practice.

The aim of this paper is to identify important areas that need to be part of a future framework of creativity management in AM. The idea of such a framework is to support organisations to utilize their own creative resources, such as creative abilities amongst their designers, and hence assimilating AM in their design practices. Creativity management, in this paper, specifically refers to a system of practices and methods to manage creativity in design practices. It is important to acknowledge that creative management needs to simultaneously be considered from organizational, team and individual level. Drawing on a case study in the aerospace industry, together with literature studies in creativity and AM, the overall objective of the current paper is to make initial propositions for creativity management in DfAM.

2. Creativity in design practices

There is a general idea that innovation (i.e. breakthrough solutions) requires creativity. Creativity often refers to both idea generation and problem-solving and the actual idea or solution (Weisberg, 1988). Creativity can therefore be seen as the ability to both find and solve problems; in short, searching for a problem can also result in finding creative solutions (Runco, 2007; Sawyer, 2012). However, an activity is often not considered creative unless it breaks familiar routines. In line with this, Runco and Jaeger (2012) discuss the need for originality (sometimes also called novelty) when discussing creativity. With respect to these views, we in this paper define design creativity as the search for breakthrough solutions to a specific design problem.

According to Amabile (1998), it is of great importance to provide people with autonomy, e.g. to be able to handle the process and tasks in whatever way is preferred, but still have clearly specified goals. According to Amabile, creativity can be killed with tough or impossibly tight deadlines – indeed, imposing demands of this sort can result in deep distrust or burnout amongst individuals. In this view, if people feel over-controlled or discouraged, the motivation to be creative will most likely not appear. It is also proposed that creativity involves a high level of performance; the intense
feeling of being creative makes people feel that they are at the peak of their abilities (Sawyer, 2012). In the 1950s, creativity was considered to be a by-product of high intelligence rather than a practiced skill. However, it has now been said that intelligence requires convergent thinking while creativity requires the addition of divergent thinking (Sawyer, 2012). With this in mind, it can be said that everyone has the potential to be creative even though far from everyone fulfils their creative potential (Runco, 2007).

Two types of creativity can be distinguished: firstly, making new connections where known ideas or solutions are combined in new ways and secondly, working with conceptual spaces though thinking outside the box (Boden, 2004; Taura & Nagai, 2017). The importance of such connections is also in line with established explanations of creativity. For example, creativity can be seen as combining a certain set of As (problems) with a certain set of Bs (knowledge), resulting in C (innovation) (Haefele, 1962).

However, all of these accounts of creativity mostly deal with individual abilities and cognitive thinking skills – and seems to neither recognize the need for a change of approach to creativity when the design practice changes, for example, by implementing new technologies, nor how the organization can manage creativity and new technologies as grounds for breakthrough solutions. Some of the characteristics of design creativity are therefore further outlined in the upcoming section.

2.1. Characteristics of design creativity

The current study aims to understand the management of creativity in engineering design, and will therefore not address the cognitive perspectives of creativity. However, various aspects circuit around a designer when discussing creativity in design practices. Nine characteristics of creativity have been identified in current reviews of design creativity: Expertise, Motivation, Goal orientation, Values, Creative thinking skills, Flexibility, Design thinking, Individual traits and Thinking styles. Expertise is determined by knowledge and intellectual abilities (Amabile, 1998) and often refers to specific knowledge or the learning process that has been used to build knowledge (Nagai & Taura, 2015). Motivation is considered to be the reasoning behind an action taken towards a desired goal (Nagai & Taura, 2015); it can often be created through cultivating inner passion or the offering of external rewards such as public recognition or money. However, an inner drive to solve a problem can result in more creative solutions when compared to solutions produced solely by the promise of external rewards (Amabile, 1998). In relation to Motivation, Anderson et al. (2014) also discuss Goal orientation and Values as important attributes of creativity. Goal orientation is considered to be the motivational mechanisms that influence how individuals address situations, while Values are the guiding principles of an individual that direct them towards a specific action (Anderson et al., 2014). Goal orientation and values are therefore in this paper considered to be part of a greater overall Motivation.

Creative thinking skills are said to stem from approaching problems in a flexible and imaginative manner (Amabile, 1998). In relation to Creative thinking skills, Nagai and Taura (2015) and Anderson et al. (2014) also discuss Flexibility, Design thinking, Individual traits and Thinking styles as important characteristics. Flexibility is defined as the capacity to change during a design process, while Design thinking is considered to be the use of practical knowledge from various perspectives combined into one situation (Nagai & Taura, 2015). Individual traits are considered to be specific aspects of cognitive thinking, such as conscientiousness and openness, and Thinking styles are seen as the ways in which individuals manage their cognitive thinking to increase creative behaviour (Anderson et al., 2014). These characteristics are therefore in this paper considered to be part of overall Creative thinking skills. With these perspectives and characteristics in mind, we chose to adopt the three components of creativity described by Amabile (1998): expertise, creative thinking skills and motivation (Figure 1) as summarized characteristics of creativity. Therefore, this paper explore creativity management specifically in the intersection between these components.
3. Research method

To explore creativity perspectives that are of great importance while designing a framework of creativity in DfAM, the research described in this paper have been designed in two steps. Firstly, previous DfAM literature was reviewed to explore how it describes aspects of creativity management. Secondly, a case study was conducted within the space industry to explore how designers inexperienced with AM approaches DfAM from a creativity perspective.

3.1. Literature study

In general terms, a literature review is defined as a systematic, explicit and reproducible method to explore the theoretical field by identifying, evaluating and interpreting existing research documents (Fink, 2020). The literature review presented in this paper is based on the seven tasks outlined by Fink (2020): 1) Setting up a research question; 2) Selecting appropriate databases; 3) Choosing relevant search keywords; 4) Applying practical screening criteria; 5) Applying methodological screening criteria; 6) Doing the review; and 7) Synthesizing the results.

The literature review was based on the research question ‘How is creativity management treated in the literature dealing with state-of-the-art design for AM?’ and was conducted through the databases Scopus and Web of Science. The purpose of the literature review was to explore how aspects of creativity are described in current DfAM literature. The main keywords were creativity and creative, together with Additive Manufacturing and synonymous historical terms such as those described by Wohlers et al. (2019): Layer Manufacturing; Additive Fabrication; 3D Printing;

Figure 1. Three components for creativity (adapted from Amabile, 1998).

These components are of importance for individual designers’ creative abilities, as well as the collective creative skill of a design team and the creative resources within the organisation.
Additive Processes: Additive Techniques; Additive Layer Manufacturing; and Solid Freeform Fabrication. We acknowledge the risk of excluding papers that do not specifically use ‘creative’ or ‘creativity’ in their keywords, title or abstract, but which still could be relevant. However, the aim of the literature review was to explore how the current literature specifically addresses these areas in DfAM, and hence a majority of such texts were considered as likely to include keywords relating to the word creativity and its derivations.

The literature review was limited to peer-reviewed journal papers in English, the aim being to secure high-quality papers with in-depth material and discussions of the subject area. The screening criteria also limited inclusion to those papers published after 2000 since it was approximately around this time that AM started to be considered mature enough for end-use production (e.g. Wai, 2001). Papers were considered appropriate for the literature review if they included specific discussions on creativity and creative activities in relation to DfAM, or presented tools or methods that seek to specifically increase creative activities in DfAM. Since the study presented in this paper focuses on exploring how experienced designers relate to DfAM from a creative perspective, papers addressing studies on students or how to design university courses were excluded. Finally, since the study focused on creativity management in what was considered to be highly regulated industries which does not work with end-users, papers that addressed the inclusion of the end-users were also excluded. Papers were initially evaluated according to the stated criteria in the title and abstract. If considered relevant in the first screening, the paper was thoroughly read and then finally included or excluded in the overview of the study. Results were synthesized into a descriptive summary for each paper. The total number of relevant publications for all historical terms was 16; six additional papers were also found among the reference lists of these 16 relevant papers. A document with a descriptive summary of the findings from the literature study was then used as a basis for presenting findings, which related to the previously summarized three components of creativity (Amabile, 1998).

### 3.2. Case study

Case studies are considered to bring high values in explorative research studies, and can clarify poorly understood aspects in processes (Yin, 2014). To evaluate how designers approach DfAM from a creativity perspective, a case study was therefore seen as a relevant approach to gain rich information and good insights regarding designers’ needs. The case study was conducted at a company working with product development for space applications (Table 1), and included eight interviews with experienced designers who are relatively inexperienced with AM. Insights from designers being relatively new to AM was seen to bring rich information of insecurities, expectations and limitations that need to be considered in creativity management. In addition to the interviews, steering documents on general product development at the case company was studied to bring insights on how respondents referred to product development within the company. This contributed with a higher degree of understanding between respondent and interviewers during discussions.

#### 3.2.1. Sampling

The case company was chosen due to (1) their established expertise on product development for space applications and (2) recently started explorations of how AM might be used in their designs.

| Table 1. Information about the case company. |
|---------------------------------------------|
| Company description                        | Size of company |
| The company is developing complex and high-performance components for the aerospace sector. The studied part of the company focuses on products designed for space applications, such as nozzles or sub-system components for launcher applications. | Approximately 18,000 |
Respondents for the interviews were chosen from a pool of 60 designers working with product development for space applications. Eight respondents were selected based on their leading roles and experience in product development in the company (Table 2) and due to their connection to projects starting to involve DfAM.

3.2.2. Data collection

Interviews were used as the main data collection method, since it is seen as an efficient approach to collect rich empirical data (Eisenhardt & Graebner, 2007). Interviews were conducted at the Swedish site of the case company and lasted between 45 and 70 minutes. All eight interviews followed the same interview guide, with 18 questions (Figure 2) with a focus on exploring how AM was approached and experienced in relation to design and qualification aspects. The questions were designed to be open-ended, with the opportunity to have a more dynamic and relaxed discussion. This was made to ensure that respondents could easily discuss the topic from their personal point of view, and to fully capture their own thoughts and feelings regarding adopting AM in their design practices.

Interviews were audio recorded and transcribed for analysis. The transcriptions included notes on laughter and interruptions as an attempt to include at least a part of the non-verbal reactions that otherwise could easily be missed (Kvale & Brinkmann, 2009). The non-verbal reactions were then used to note hesitations and/or confusion while discussing certain areas, to interpret interests amongst respondents. Note that it is mainly the discussions from the second part of the interviews (additive manufacturing) that brought insights for this paper.

3.3. Analysis

The analysis followed the three steps of qualitative research as described by Miles and Hubermann (1994): reduction of data, data display and drawing conclusions (Figure 3). Since transcriptions provided a variety of data related to adopting AM in products designed for space applications, there was a need to capture designers discussions specifically related to creativity and AM in design. Therefore, to reduce data, quotes were extracted from the transcriptions through the application of pre-decided categories (as suggested by Flick, 2014). The categories were formed in two steps: 1) interpretations of what areas were discussed in the interviews in relation to the interview guide and 2) those areas were then explored in current general AM literature to clarify the following six categories:

(A) Adopting AM in design (mentioned in Campbell et al., 2012; Gibson et al., 2015)
(B) Design for AM methods (mentioned in Klahn et al., 2015; Kumke et al., 2016)
(C) Responsibility of the designer (mentioned in Klahn et al., 2015)
(D) Supports in design (mentioned in Gao et al., 2015; Krantz et al., 2015)
(E) AM knowledge (mentioned in Thompson et al., 2016; Yang & Zhao, 2015)
(F) Organizational support for creativity/innovation (mentioned in Khorram Niaki & Nonino, 2018)
The categories were designed to extract quotes that specifically addressed the central areas of creativity and AM in design, as experienced by the individual designer. Both authors were involved in defining the categories, but one did the initial extraction of quotes in relation to the categories. The other author, an associate professor in design research, then verified the extraction in comparison to the transcribed data.
To put a layer of creativity upon the empirical data of AM in design, the established model with three characteristics of creativity (expertise, creative thinking skills and motivation) developed by Amabile (1998) was used to display data in relation to the six pre-defined categories of AM in design. A data display table was produced in two steps. Firstly, the extracted quotes were distributed into the table. To further provide with an overview of discussions, the second step clustered the quotes into collected descriptions of discussion areas that respondents highlighted throughout the interviews. Table 3 presents the final data display table that was used for the final step of conclusion drawing. Conclusions were drawn from the displayed data in relation to the three components of creativity. These components have been used to visualize findings, discussion and conclusions of this paper.

4. Literature review of creativity in design for additive manufacturing

This section presents a summary of the findings from the literature review in relation to Amabile’s (1998) three characteristics of creativity. The literature mainly discussed DfAM methods in relation to the possible solution space, support tools and limitations for designers. It should be noted that even though AM is often considered to have revolutionized the way products are designed and manufactured, it is also argued that manufacturing methods are still in their infancy (Bermano et al., 2017). Therefore, there seem to be some persistent uncertainties regarding how to adopt and fully utilize the ‘new’ manufacturing techniques both creatively and efficiently.

4.1. Expertise in design for additive manufacturing

As previously mentioned, expertise in creativity has been defined as knowledge and intellectual abilities, where designers need to have a firm knowledge base to be able to utilize their creative abilities in design (Amabile, 1998). In line with this, it is often argued that designers need directed education and training to fully explore the possible solution space of AM (Krugelis, 2018). When it comes to new technologies such as AM, the knowledge base needs to consider various perspectives, such as material, process and geometrical freedom, to fully understand both possibilities and limitations in specific design practices. AM guidelines have been designed to support designers in utilizing the different limitations of the various AM processes; for example, Allison et al. (2019) propose a web tool to assist designers in making design choices in relation to materials and part orientation. It has, however, been suggested that giving designers AM knowledge will impact their creative process, and that too much information at once seems to hinder designers’ creative solution space (Laverne et al., 2015). Therefore, going through a traditional creative design process – where elements of AM are introduced at certain stages in the process – could assist designers in utilizing their creative potentials using AM in design (ibid.).

In relation to this, a study regarding the available DfAM methods resulted in the identification of three categories of DfAM: opportunistic DfAM; restrictive DfAM; and dual DfAM (Laverne et al., 2015). Opportunistic DfAM focuses on the possibilities with AM in design, excluding many of the limitations, to assist designers in opening up their creative minds. On the other hand, restrictive DfAM focuses on knowledge of limitations and exploring, for example, geometric variations due to the AM process (ibid.). It is suggested that dual DfAM methods are most suitable for designers, as both possibilities and limitations of AM in design are addressed simultaneously (ibid.): this can increase creative thinking skills and contribute to expertise simultaneously. The development of DfAM methods are, conversely, often focused on optimizing parts for AM with support of structured frameworks, to assist designers in utilizing the full potential of AM. For instance, Francois et al. (2019) propose a framework that considers specific AM limitations within, for example, mechanical and thermal properties. Such approaches are also of great importance for designers to develop AM expertise. As previously mentioned, there are various aspects that need to be considered in DfAM to create a knowledge base for designers, such as part orientation and
Table 3. Displaying data for conclusion drawing with the six categories (extracted data) in relation to the three components of creativity (adopted from Amabile, 1998).

| Expertise | Creative Thinking Skills | Motivation |
|-----------|-------------------------|------------|
| Adopting AM in design | • Challenges with material properties and not having enough material data available (resp 1, 6, 7 & 8). • Highlights the change in design boundaries, compared to traditional methods (resp 3 & 7). • Initial theoretical explorations of what AM can bring in their designs (e.g. build a part in one print) (resp 8) | • Higher freedom in design (resp 1, 4, 6 & 7) • Great interest in new ways to design and produce products (resp 1 & 5) • New ways of thinking in design (resp 5 & 7) | • Great interest to include AM in many projects (resp 1, 2, 5, 7 & 8) • Many designers feel that they want to adopt AM in their design practices (resp 3, 4, 5 & 6) • Big step before we can put AM in reality (resp 6) |
| Design for AM methods | • Support to manage new solutions and complex geometries (resp 1, 5 & 6) • New boundaries in design need to be addressed, such as material properties (resp 2 & 6) • There is a need for a new internal design system for AM, as they have for e.g. casting (resp 3) • Need to know what investigations that need to be made with AM (resp 3 & 4) | • High demands in the space industry (resp 2 & 6) • Quick changes in design, with fast prototyping (resp 3, 4, 6 & 8) • Change from traditional design thinking to a new thinking, to enable drastic changes (resp 3 & 4) • Having higher freedom in design with diverse concept solutions (resp 3 & 7) | • No fun or challenge to print a design that looks exactly as traditionally manufactured (resp 3) • A big willingness to design for a new manufacturing method (resp 4) • Need to have a concrete direction for the design phases (resp 4) • Good to be free while designing, and working with various concepts simultaneously (resp 5 & 7) |
| Responsibility of the designer | • Too little focus on how to design for AM – but more on manufacturing side (resp 1) • Give input to software developers (resp 1) • Don’t know enough of limitations and possibilities of AM (resp 2, 4, 5, 7 & 8) | • New way of thinking (resp 1, 2 & 5) • Fully utilize the degree of freedom (resp 1, 4 & 5) • Not to look too much on old solutions for traditional methods (resp 2, 4 & 7) • Need to know about possibilities of AM in design (resp 3 & 4) • Risk to make too late design decisions due to possibility to do late changes (resp 5) | • There is a need to find the potential and added value of AM in the design (resp 2) • There is a lot of uncertainties and ignorance of both limitations and possibilities of AM (resp 3) • Similar reaction towards AM as previously with composites, many designers are excited for new possibilities (resp 4) |
| Supports in design | • What parts of a product could gain higher potential and added value through AM? (resp 2, 3 & 5) • Choosing materials – choosing specific material properties? (resp 2, 3, 5 & 6) • Make sure that an AM product meet requirements (resp 3) • Need to have educational manners, e.g. an expert who can teach (resp 3) • Use rapid prototyping to learn (resp 4) | • Understand the potentials to get a design thinking towards AM (resp 2) • Testing different geometrical shapes (resp 3) | |
| AM knowledge | • Need complementary processes to understand e.g. surface finish, material properties effect on the design (resp 2, 4 & 7) • Designers need clearer knowledge of AM in design (resp 3) | • Risk to fixate on limitations (e.g. Size of AM machines) and hence not continue developing a concept for AM (resp 2) • Possibility to make fast and late changes in design (resp 3, 4, 5 & 6) • It is only the fantasy that sets the limits (resp 3 & 6) | • Limited by the size of AM machines, but a hope for them to eventually become larger (resp 2, 3, 5 & 6) |
support material (Leutnecker-Twelsiek et al., 2016; Thompson et al., 2016); several tools and methods have emerged to assist designers in adopting such knowledge in DfAM. One example is a method to decrease the gap between the CAD model and the printed part that has been proposed to assist designers in understanding the use of the AM process in DfAM (Ponche et al., 2014). Another study presents a methodological framework through structured guidelines to fully make use of AM potentials (Kumke et al., 2016). However, despite these advances it is argued that there is still a need to further develop design guidelines for DfAM to support designers in developing their creative skills on how to make use of AM to reach innovations (Ranjan et al., 2017).

AM is sometimes regarded as an ‘automated process’, one where software programs such as topology optimization support designers to find an optimal design. This does not replace the skill of designers – they still possess great experience in design but need more expertise in specific AM design (Ratto & Ree, 2012). It is argued that to fully exploit the creative potentials of AM, there is a need for ‘hybrid’ designers who can creatively address both technical and aesthetical aspects of DfAM (Campbell et al., 2012), and hence fully address these dual DfAM perspectives. Such so-called hybrid designers that master more than one discipline are seen to have a great potential in making an impact (Gartner & Fink, 2018) and create new possibilities in design. Knowledge regarding DfAM amongst designers can be increased by including AM in the curriculum for students and through workshops amongst practitioners (Campbell et al., 2012). It is, however, important to acknowledge that novice and experienced designers have different needs when implementing new knowledge in the design process. Novice designers seem to have a greater need for automated computational support (e.g. CAD programs), whilst expert designers need to have more control of their own creative process (Bermano et al., 2017). This suggestion is also supported by a study where novice designers showed more need for support in order to increase their design creativity for AM when compared to professional designers (Maidin et al., 2012). It has been shown that designers are supported to create AM knowledge through a combination of videos, pictures and artefacts – textual support was less appreciated (Laverne et al., 2017). With this in mind, experienced designers seem to need illustrated examples to realize creative potentials of AM in design.

Even though there is a need for more education in relation to DfAM, it is also important to see how this affects the roles of designers. A study by Ratto and Ree (2012) showed that some designers see AM merely as another tool in the toolbox, and that they address AM just as any other manufacturing technology in their daily work. One respondent in Ratto and Ree (2012) study used a metaphor that if a friend had a really good pair of scissors, the person would still not let the friend cut his/hers hair without having any knowledge or experience. This illustrates the need for more and broadened competence within new manufacturing technologies as well. It is also

| Expertise | Creative Thinking Skills | Motivation |
|-----------|--------------------------|------------|
| Organizational support for creativity/innovation | The company have put one person responsible to organize AM activities (resp 2 & 3) | Customer interests which highlights e.g. the need to lower production cost (resp 2, 3 & 6) |
| | Need for a new internal design system (resp 3) | Designers have tried to buy AM machines for in-house research, and many are interested in this (resp 3 & 6) |
| | Use AM as a way to produce prototypes for a closer collaboration with the customer and for testing (resp 3 & 4) | High interest of AM in other sites of the company, collaborations are ongoing (resp 3, 5, 6 & 8) |
| | | Not all instances in the organization are interested in AM (resp 6) |

Table 3. (Continued.)
suggested that a dynamic team with various skills such as industrial design, mechanical engineering, AM processes, ergonomics and eco-design can cover the need for AM knowledge within a design project (Markou et al., 2017). Experts in this view tend to build on each other’s expertise areas through creative synergies, and therefore increase the possibility to succeed in realizing the creative potentials of AM (ibid.). In that way, a designer does not necessarily need to have in-depth knowledge of all DfAM perspectives, but rather a general knowledge base of the possibilities and limitations of AM, in combination with their own design expertise.

4.2. Creative thinking skills in relation to additive manufacturing

Creative thinking is directed by how people approach problems in a flexible and imaginable manner (Amabile, 1998); AM is often argued to open up creative opportunities that historically have not been possible before (Krugulis, 2018). It is suggested that AM can support designers to express themselves creatively and hence find innovative solutions in their designs (Krugulis, 2018; Wai, 2001). Nevertheless, it has also been proposed that researchers and designers should be cautious when discussing creative potentials of AM, since it does not always correlate with high-quality design (Abdelall et al., 2018b). To reach such a level of product quality and to create designs that were unthinkable in the past, it is proposed that designers should take inspiration from elsewhere (Campbell et al., 2012). For designers to fully utilize their creative thinking skills in relation to AM, it is in this view suggested that they need support in opening up their minds to imagine the unimaginable. It has also been proposed that current DfAM methods are not sufficient to generate creative designs, since most of them focus on adapting existing designs to AM possibilities and limitations (Segonds, 2018). Rias et al. (2017) advocate a creative design approach in the early phases of DfAM, where designers are guided through five steps. This approach guides designers through features discovery, idea exploration, idea evaluation, concept generation and concept evaluation. However, Segonds (2018) suggests that to fully exploit the creative potentials of designers using AM, the early phases of DfAM need to be conducted in a collaborative way. One of the major limitations in design for AM is the designers’ own creative thinking skills (Campbell et al., 2012); designers need to possess high creative ability to fully take advantage of the design freedom of AM (Fuwens et al., 2018). This puts the responsibility on designers working with AM, and imposes high demands on them, while they are being introduced to this new manufacturing technology.

Many DfAM methods seem to mainly focus on optimizing product performances rather than managing creativity for designers, which can result in designers having a hard time adopting all of the possibilities and limitations that need to be considered in design (Maidin et al., 2012). One answer to this is a design feature database that is intended to assist designers in the creative utilization of AM, and which in this view has showed great potential for novice designers. To support designers to fully exploit creativity in DfAM, Sass and Oxman (2006) suggest using design information models. Such printed models include details for designers to assess design features and bring opportunities for assessing the design from the perspectives of details, internal spaces and form (ibid.). While addressing DfAM and handling the high pressure of being creative, there is also a risk of influencing designs in a negative way through, for example, design fixation (Abdelall et al., 2018b). It has been shown that novice designers in particular can create design fixation, when first designing for AM and then redesigning for traditional manufacturing methods (ibid.). Another study, however, did show that manufacturability software in the concept design phase could assist designers to avoid such design fixation (Abdelall et al., 2018a). In addition to this, the concept of a feature graph has been designed to assist both novice and experienced designers in creating manufacturable designs (Ranjian et al., 2017). Similarly, a study tested designers in creating ideas before and after using design principles for AM as a support tool (Perez et al., 2019): the study showed that such principles improved both the quality and novelty of ideas. Design fixation and having the support to break free from it, hence has to be addressed when discussing creative
thinking skills. It is important to foster the ability to solve problems in a flexible and imaginable manner, so that designers understand how to create novel ideas using AM.

4.3. Motivation to include additive manufacturing in design practices

Motivation in design creativity is in this paper defined as goal-oriented reasoning lying behind actions, as proposed by Amabile (1998). Work motivation is in some organizations a challenge for managers, and is handled through counting on the intrinsic passions and drive of individuals or through the granting of external rewards such as public recognition or money. Amabile (1993) describes how unmotivated employees expend little effort in their jobs and produce low-quality work, whilst motivated employees are more likely to be creative and produce high-quality work. In this view, creativity management can support managers to foster synergy in the motivation systems of both teams and individuals. Since AM is said to enhance the probability of creating innovations (Wai, 2001), there are often great incentives for both companies and individuals to approach AM in their design practices. However, even though AM seems to have its own motivational power, design creativity is not considered to be managed while handling AM in design (Francois et al., 2019). There is therefore a need to retain encouragement and motivational perspectives in creativity management in order to support designers in utilizing their creative potential.

Amabile (1993) puts forward various critical aspects of creativity management from a motivational perspective. To address extrinsic motivation, managers need to use informal feedback and direct individual designers’ motivational orientation appropriately in the creative process. Managing intrinsic motivation can be achieved through involving designers with motivation for a specific task, and matching them to tasks where they have both skills and interest, thus nurturing each individual’s inner passions. Finally, it is in this view important to combine diverse expertise in design teams and to provide tasks where designers can increase their feeling of competence, skill and flexibility. To support creativity management in AM there should be a focus not only on AM knowledge and interpersonal skills, but also on the design practice and tasks in themselves, the nature of the design teams, as well as understanding individuals’ motivation and drives, and the connection between these informal systems (cf. Amabile, 1993). A motivator for industries and organizations taking on these changes is of course the drive for innovation.

It is suggested that it is not feasible to fully exploit the full design space of AM, and that there is a need to design in a directed approach (Bermano et al., 2017): designers need to specify the desired objectives and constraints to be able to realize the creative potentials. This is in line with what Amabile (1998) suggests – that clearly defined goals, together with flexibility in how to work with the process towards such goals, are of great importance for creativity. Conversely, according to Taura & Nagai (2017), modularization, standardization, automation and such efficiency-oriented technologies such as AM, has resulted in quantitative, rather than qualitative, changes. One could always argue that the space industry needs to be, and should be, controlled and regulated for safety reasons. One could also argue that in order to come up with breakthrough products and production abilities, there is a need to also release the creative mindsets which the regulations seems to have imposed. It has therefore been argued that there is a need for ambidextrous management systems (Larsson, 2020) that simultaneously can manage creativity, innovation, and high safety and other regulations for the particular industry.

5. Empirical results from the case study

This section presents findings from the case study where experienced designers, with limited experience of AM, expressed their views on including DFAM in their design practices. Data from the interviews have been displayed through Table 3. On one hand, the table presents discussions highlighted by respondents in relation to six categories of AM in design: (1) Adopting AM in design, (2) Design for AM methods, (3) Responsibility of the designer, (4) Supports in design, (5)
AM knowledge, and (6) organizational support for creativity/innovation. On the other hand, the table display the extracted data in relation to the three components of creativity described by Amabile (1998): Expertise, Creative thinking skills and Motivation. The following sections present the empirical findings in relation to the three components of creativity.

5.1. Expertise in design for additive manufacturing

The interviewed experienced designers already had a knowledge base concerning traditional manufacturing methods – of what possibilities and limitations there are and how the manufactured material behaves. When talking about AM, they express uncertainties when it comes to both possibilities and limitations, and also concerns about robustness of the printed part. In the respondents view, this leads to insecurities while adopting AM in their design practices. Since they are already familiar with the behaviour of traditionally manufactured materials in their designs, they asked for more knowledge and experience on how AM printed material behaves. Since the space industry has such high regulations, respondents expressed that these aspects are of a great importance for them in their design practices. They are all just starting approaching AM, and therefore requested more knowledge, expertise and experience of AM in their particular design practices. To attain this expertise, these respondents asked for different kinds of support, here summarized into seven parts: (1) to manage the new design freedom; (2) a procedure to understand when AM is appropriate for a product; (3) extensive understanding of AM printed materials, and having such 'basic' information available; (4) an AM expert available for discussions and learning opportunities; (5) having a AM coordinator at the company site to organize joint activities; (6) a specific AM design system (they already had such system, e.g. casting); (7) using prototyping for learning and having in-house AM machines.

In having the previously stated supports together with availability for experimentation with the technology, they believed that they would be able to learn about the various elements that are needed to understand the new boundaries. Some of these respondents stated that the focus tends to be on developing the AM process, adding that they needed more knowledge on how to utilize AM in their design practices before that. Respondents did not demonstrate any pronounced expertise in relation to AM in design, since they were new to the technology, but clearly asked for possibilities to increase their understanding and knowledge about AM in design. They expressed a need for expertise covering both an AM process perspective and in the creative design freedom perspective. As mentioned earlier, the respondents had a considerable interest in the creative design freedom and complex geometries that AM is supposed to provide. However, they did not have any answers on how they could create such complex geometries, or even why they were desired. Most respondents hesitated while discussing the inclusion of AM in design, and did not know how to gain such AM knowledge and understanding; they didn’t know where to start when involving AM in their own design practices. Simultaneously, they asked for supports both from an organizational and individual perspective, to fully take advantage of AM in their specific designs.

5.2. Creative thinking skills in relation to additive manufacturing

Respondents wanted to gain a better understanding of the potentials of DfAM where they specifically asked for design thinking linked to AM, in other words, understanding how they can create new solutions that have not previously been an option. They stated that they need to rethink their own design practice, and for example, not use features from old designs as a design base as much as they do with traditional manufacturing technologies. They expressed a need to know how they should think in order to be able to both design a product while using AM, and how to take advantage of the creative potentials given by AM.

Respondents discussed the possibilities and the constraints for thinking in new ways, but had no ideas on how to address these issues or how to change their own design an approach, as they said,
AM seemed quite abstract. Many respondents expressed a feeling of not knowing how to address AM in design, and to adapt to the ‘design for AM-thinking’ that they felt was necessary to fully exploit the creative potential. However, respondents that expressed that they were highly motivated to use AM also showed a higher interest in the new parameters in design, such as different limitations or the complexity of the higher degree of creative freedom. The possibilities of thinking in new ways when designing for AM hence seem to make many designers confused, and they don’t really know how to handle the new creative design freedom that comes with AM.

5.3. Motivation to include additive manufacturing in design practices

Respondents showed varying levels of interest in AM. Some were quite enthusiastic and really wanted to absorb the new knowledge and creative thinking aspects as soon as possible. On the other hand, others were more reluctant and wanted to take it slow and learn more before they could say if and when they would be able to include it in their daily practices. Conversely, these respondents expressed a feeling of longing for new ways to design and to increase the creative possibilities in their design work. AM is a technology in which these respondents do see the potential to reach such goals, but there seems to be an insecurity in how to address AM and/or fully exploit the creative possibilities that they seek. Respondents stated that there is a clear external interest in AM, both of others within the organization at other sites and amongst customers. But according to respondents, some instances did not show the same motivation to explore AM. This gave the feeling of having some kind of resistance while, e.g., trying to buy AM machines at the site. A summary of this is that since the space industry traditionally works in incrementally small steps, taking the big leaps and radically changing the design practice and its products seem to be a complex business: there is a need to qualify products and to be able to rely on the manufacturing technologies fully. Even though respondents expressed some uncertainties with qualifying products, most of them were interested and motivated to learn more about AM and its creative potentials for their design practices. We should acknowledge that some of the expressed uncertainty could be due to their relative unfamiliarity with AM.

6. Discussion

The aim of the paper has been to identify important areas that need to be part of a future framework of creativity management in AM. The idea of such a framework is to support organisations to utilize their own creative resources, such as creative abilities amongst their designers, and hence assimilating AM in their design practices. When we looked at how current design for AM literature address the issue of creativity, it was obvious that it is generally not a commonly addressed area. This could be due to this not being interesting for design for AM researchers, however, we rather found it to be intriguing to explore how creative potentials are approached with this new technology. Various researchers in the field argue that more knowledge and expertise is needed while designing for AM (e.g. Krugelis, 2018; Laverne et al., 2015), and several methods have been designed to support designers seeking to take full advantage of its potential during a design process (e.g. Kumke et al., 2016; Maidin et al., 2012; Ponche et al., 2014). However, most methods aim to increase product value, and often seem to focus on optimizing a product rather than supporting designers in embracing their creative potentials. Additionally, our interviews suggest that when experienced designers start to approach AM in their design practices they don’t know where to start, but yearn for learning opportunities and new ways of creative thinking.

There is a need for a balance between the three components of creativity: expertise, creative thinking skills and motivation. The responding designers experienced feel that their expertise level was low, and hence they didn’t know how to manage the new boundaries in design, related to their own creative thinking skills. Also, our interviews suggest that these aspects also affect designers inner motivation to assimilate AM in their design practices. Our respondents felt that they needed to learn
about the possibilities and limitations inherent in this new manufacturing method, before they could feel confident enough to fully exploit its creative potential. They asked for support from AM experts and wanted the space for exploration to be able to appreciate the new creative freedom. This is in line with what Amabile (1998) suggests is of great importance for creativity: individuals need to have flexibility and space to handle a task themselves. However, it is important to acknowledge that this case study was conducted in a highly regulated industry, and designers could therefore be more concerned about ensuring quality controls with the new technology, than other industries might be.

Designers in the space industry might, with good reason given what is at stake, be cautious when it comes to AM process limitations. But to also generate breakthrough solutions there is a need to nurture creative thinking, for example, through ambidextrous management systems (Larsson, 2020) that manage innovation and traditional product development simultaneously. Campbell et al. (2012) proposes that the designer in some ways can be considered as the ultimate limitation of AM in design, since they need to think the unthinkable, together with the need to manage their own creative thinking skills to adapt to the new freedom. This corresponds to how respondents discussed the need to think in new ways when designing for AM and their uncertainty of how to approach and implement this in their design practices. With this in mind, respondents also showed a mix of both high motivation and more restrained attitudes towards DfAM. Highly motivated attitudes were often related to the exited feelings of working with a new and inspiring tool in the toolbox that could disrupt the way they conduct their current design practices. On the other hand, cautious attitudes mainly related to the lack of understanding and knowledge of the AM process.

Finally, it is important to acknowledge the special setting of this study in a highly regulated industry where experienced designers find themselves in the paradoxical and unsettling situation of being simultaneously experienced in traditional routines and inexperienced in AM. One might argue that on one hand, highly regulated industries do not have the same opportunities for creativity. On the other hand, one might argue that designers have potentials of realizing their full creative potentials even within AM and with regulations, if their creativity is managed properly within the organization, and there is a good balance between being motivated, having expertise at hand, and having creative thinking skills.

With respect to previous research within the field, we consider the distinctive study parameters, and the results they produced, contribute to further knowledge of creativity management areas that need to be considered while introducing new technology such as AM. It is important to support designers through these areas, to assist them to realize their full creative potentials. Hence, organizations increase their possibilities to utilize their own creative resources and fully adopt AM in their design practices. If managers want designers to create breakthrough solutions for AM, they need to support them in increasing their specific AM expertise, expand their creative thinking skills and keep their motivation levels up.

7. Conclusions

To increase the understanding of how to nurture creativity when approaching new technologies such as AM, this paper contributes with insights of creativity management in AM. Previous research show a great focus on the AM technology itself, with a highly limited involvement of creativity management in current design for AM support tools, models and frameworks for design practices. This paper contributes with an initial model of propositions needed to further develop a creativity management for AM framework. The findings of the study presented in this paper are synthesized into the following three propositions of areas that need to be considered for a future framework of creativity for AM. Each proposition is linked to the three components of creativity, and shows directions for both managers and for future research.

Proposition (1) involves the need for a creativity management system in place that enables designers to increase their expertise level when approaching new technology such as AM. By doing so, they have a higher likelihood to take advantage of their creative abilities.
Such a creativity management system also needs to ensure that designers have room for exploring constitutions of AM, which in turn will give them the opportunity to expand their expertise. Since there are a high variety of information that need to be considered in AM designs (such as part orientation, support materials, material properties, and so forth), some kind of synthesis could be beneficial for designers approaching AM in their design practices. In relation to this, designers need support in relation to having AM machine availability and/or AM expertise available for discussions (or an AM coordinator which interlink AM activities in the organization for extensive learning opportunities).

Proposition (2) involves management of the new creative boundaries in design for AM related to individuals creative thinking skills. Designers need support in approaching design for AM, to fully adopt a creative AM thinking approach. One way to support designers is by visualizing possibilities in solutions designed for AM, and by providing guidelines such as design heuristics, design methods and design principles, specifically developed for AM. Some research has already been made to formulate and test design supports for the creative perspectives of DfAM (e.g. design heuristics, e.g. Blösch-Paidosh & Shea, 2019; Lindwall & Törllind, 2018, and design principles, e.g.; Perez et al., 2019; Lauff et al., 2019), but more research is needed on how to fully include these in industrial design practices.

Proposition (3) illustrate the motivational perspective for a designer approaching a new technology such as AM, to be able to meet the design freedom they are confronted with in a flexible and creative manner. A creativity management system needs to ensure that teams and individual designers learn some creative basics of AM, both through increasing their knowledge base as well as providing room for exploring new ways of creative AM thinking. Also, a creativity management system through an AM coordinator, available AM machines and access to important information (such as material properties or machine parameters) need to be considered.

For organisations to be able to adopt AM in design practices and exploit its potentials for creativity, the propositions aims to support a future framework of creativity management for AM. Supporting designers in utilising their creative abilities in relation to a new technology, in this study exemplified by AM, is crucial to reach creativity both in a design team and within an organization. To be able to achieve breakthrough innovations that are considered to be ‘out of the box’, designers need to first understand the ‘new’ box that a new technology such as AM brings. Figure 4 illustrates how the three propositions are related to each other in such box, and that they need to be addressed in a creativity management framework. The shape of the box, and the way it needs to be handled, varies due to the extent of how each proposition in the box is addressed. With the support of a creativity management

![Figure 4](image-url)
framework that supports the organizational, team, and individual AM implementation, the box can be expanded and designers can utilize their creative abilities related to the new manufacturing technology.

### 7.1. Implications for theory and practice

Findings from this study show the current theoretical gap in current literature on DfAM connected to creativity. These findings highlight important areas that need to be considered for future research related to creativity management for DfAM, and are seen as building blocks for a future creative framework for AM in design. These findings also highlights the important areas that creativity management need to address to adopt new technologies such as AM in design from the three perspectives expertise, creative thinking skills and motivation, all related to supporting the organization, the team and individual designer in creativity for AM. This understanding is specifically useful for organizations which are in the midst of adopting AM in their design practices, to manage a smooth transition from traditional manufacturing approaches towards utilizing the possibilities of AM in design.

### 7.2. Limitations and future research

This study presents important insights for future research, as well as areas for managers to pay attention to in DfAM. However, the research presented in this paper has been limited to a single case study with a relatively small sample size (n = 8) for the interview study. It is important to acknowledge that studying a highly regulated industry such as the space industry, also brings limitations. Future research should include multiple cases spanning over several industries to make it possible to do generalizable analyses. Additionally, future research should include studies on various levels of AM experienced designers, to not only capture insecurities and resistance while adopting AM, but also to capture how designers have successfully or unsuccessfully approached these problems. The study shows a strength in having interviews designed as a broad discussion of DfAM, capturing several aspects in adopting AM in design. However, further research should also include studies which are specifically designed to explore DfAM from a creative perspective, capturing the essence of the three components of creativity (expertise, creative thinking skills and motivation).

### Acknowledgments

We acknowledge the LTU Graduate School of Space Technology and the EU project RIT (Space for Innovation and Growth) for financial support. We would also like to express our gratitude to the designers who participated in this study and shared their knowledge and experiences of both their design practice and AM. Finally, we would like to acknowledge comments and suggestions from reviewers, which have contributed to the development of this paper.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

### Funding

This work was supported by the Fondo Europeo de Desarrollo Regional (FEDER) [Vols 10240897].

### ORCID

Angelica Lindwall  [http://orcid.org/0000-0002-8760-9139](http://orcid.org/0000-0002-8760-9139)

Åsa Wikberg Nilsson [http://orcid.org/0000-0001-8992-9470](http://orcid.org/0000-0001-8992-9470)
References

Abdelall, E. S., Frank, M. C., & Stone, R. T. (2018a). Design for manufacturability – based feedback to mitigate design fixation. *Journal of Mechanical Design, 140*(9). https://doi.org/10.1115/1.4040424

Abdelall, E. S., Frank, M. C., & Stone, R. T. (2018b). A study of design fixation related to additive manufacturing. *Journal of Mechanical Design, 214* (4). https://doi.org/10.1115/1.4039007

Allison, J., Sharpe, C., & Seepersad, C. C. (2019). Powder bed fusion metrology for additive manufacturing design guidance. *Additive Manufacturing, 25*, 239–251. https://doi.org/10.1016/j.addma.2018.10.035

Amabile, T. M. (1993). Motivational synergy: Toward new conceptualizations of intrinsic and extrinsic motivation in the workplace. *Human Resource Management Review, 3*(3), 185–201. https://doi.org/10.1016/1053-4822(93)90012-8

Amabile, T. M. (1998). How to kill creativity. *Harvard Business Review, 76*(5), 76–87.

Anderson, N., Potocnik, K., & Zhou, J. (2014). Innovation and creativity in Organizations: A State-of-the-science review. *Prospective Commentary and Guiding Framework, 40*(5), 1297–1333. https://doi.org/10.1177/0149206314527128

Bermano, A. H., Finkhouser, T., & Rusinkiewicz, S. (2017). State of the art in methods and representations for fabrication-aware design. *Computer Graphics Forum, 36*(2). https://doi.org/10.1111/cgf.13146

Blösch-Paidosh, A., & Shea, K. (2019). Design heuristics for additive manufacturing validated through a user study. *Journal of Mechanical Design, 141* (4), 041101. Article nr: Article number. https://doi.org/10.1115/1.4041051

Boden, M. A. (2004). *The Creative Mind: Myths and Mechanisms*. Basic Books.

Campbell, I., Bourell, D., & Gibson, I. (2012). Additive manufacturing: Rapid prototyping comes of age. *Rapid Prototyping Journal, 18*(4), 225–258. https://doi.org/10.1108/1355254121231563

Eisenhardt, M. K., & Graebner, M. E. (2007). Theory building from cases: opportunities and challenges. *The Academy of Management Journal, 50*(1), 25–32.

Fink, A. (2020). Conducting research literature reviews: From the internet to paper SAGE publications, 5th edition, ISBN: 9781544318479.

Flick, U. (2014). *An introduction to qualitative research* (5th edition). SAGE publications.

Francois, M., Segonds, F., Rivette, M., Turpault, S., & Peyre, P. (2019). Design for additive manufacturing (DfAM) methodologies: a proposal to foster the design of microwave waveguide components. *Virtual and Physical Prototyping, 14*(2), 175–187. https://doi.org/10.1080/17452759.2018.1549901

Fuwen, H., Jiayian, C., & Yunhua, H. (2018). Interactive design for additive manufacturing: A creative case of synchronous belt drive. *International Journal on Interactive Design and Manufacturing, 12*(3), 889–901. https://doi.org/10.1007/s12008-017-0453-5

Gao, W., Zhang, Y., Ramanjuan, D., Ramani, K., Chen, Y., Williams, C. B., Wang, C. C. L., Shin, Y. C., Zhang, S., & Zavattieri, P. D. (2015). The status, challenges, and future of additive manufacturing in engineering. *CAD Computer Aided Design, 69*(1), 65–89. https://doi.org/10.1016/j.cad.2015.04.001

Gartner, J., & Fink, M. (2018). The magic cube: Towards a theoretical framework to explain the disruptive potential of additive manufacturing. *Translational Materials Research, 5*(2). https://doi.org/10.1088/2053-1613/aa5ca3

Gibson, I. (2017). The changing face of additive manufacturing. *Journal of Manufacturing Technology Management, 28*(1), 10–17. https://doi.org/10.1108/JMTM-12-2016-0182

Gibson, I., Rosen, D. W., & Stucker, B. (2015). *Additive Manufacturing Technologies: Rapid prototyping to Direct Digital Manufacturing* (2nd Edition). Springer.

Haefele, J. W. (1962). *Creativity and Innovation*. Reinhold Publishing Corporation.

Khorram Niaki, M., & Nonino. (2018). *The Management of Additive Manufacturing: Enhancing Business Value*. Springer.

Klahn, C., Leutenecker, B., & Meboldt, M. (2015). Design strategies for the process of additive manufacturing. *Procedia CIRP, 36*, 230–235. https://doi.org/10.1016/j.procir.2015.01.082

Krantz, J., Herzog, D., & Emmelmann, C. (2015). Design guidelines for laser affitive manufacturing of lightweight structures in TiAl6V4. *Journal of Laser Applications, 26*. https://doi.org/10.2351/1.4885235

Krugelis, L. (2018). 3D printing technology as a method for discovering new creative opportunities for architecture and design. *Landscape Architecture and Art, 13*(13), 87–94. https://doi.org/10.22616/j.landarchart.2018.13.10

Kumke, M., Watschke, H., & Vietor, T. (2016). A new methodological framework for design for additive manufacturing. *Virtual and Physical Prototyping, 11*(1), 3–19. https://doi.org/10.1007/17452759.2016.1139377

Kvale, S., & Brinkmann, S. (2009). *Interviews: Learning the craft of qualitative research interviewing* (2nd ed). SAGE publications.

Larsson, L. (2020). A Conceptual Framework for Production Innovation (Doctoral Thesis) Lulea University of Technology.

Lauff, C. A., Perez, B., Camburn, B. A., & Wood, K. L. (2019). Design principle cards: toolset to support innovations with additive manufacturing. *Proceedings of the ASME 2019, August 18–21, Anaheim, CA, USA.*
Laverne, F., Segonds, F., Anwer, N., & Le Coq, M. (2015). Assembly based methods to support product innovation in design for additive manufacturing: an exploratory case study. *Journal of Mechanical Design*, 137(12). https://doi.org/10.1115/1.4031589

Laverne, F., Segonds, F., Gianluca, D., & Le Coq, M. (2017). Enriching design with X through tailored additive manufacturing knowledge: A methodological proposal. *International Journal on Interactive Design and Manufacturing*, 11(2), 279–288. https://doi.org/10.1007/s12008-016-0314-7

Leutnecker-Twesieck, B., Klahn, C., & Medboldt, M. (2016). Considering part orientation in design for additive manufacturing. *Procedia CIRP*, 50, 408–413. https://doi.org/10.1016/j.procir.2016.05.016

Lindwall, A., & Törlind, P. (2018). Evaluating design heuristics for additive manufacturing as an explorative workshop method. *Proceedings of the international design conference 2018*, 1221–1232. DOI: 10.21278/idxc.2018.0310

Maidin, S. B., Campbell, I., & Pei, E. (2012). Development of a design feature database to support design for additive manufacturing. *Assembly Automation*, 32(3), 235–244. https://https://doi.org/10.1108/0144515121244375

Markou, F., Segonds, F., Rio, M., & Perry, N. (2017). A methodological proposal to link design with additive manufacturing to environmental consideration in the early design stages. *International Journal on Interactive Design and Manufacturing*, 11(4), 799–812. https://doi.org/10.1007/s12008-017-0412-1

Miles, M. B., & Hubermann, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed). Sage Publications.

Nagai, Y., & Taura, T. (2015). Studies of design creativity: A review and its prospects. *Journal of the Indian Institute of Science*, 95(4), 341–351.

Perez, B., Hilburn, S., Jensen, D., & Wood, K. L. (2019). Design principle-based stimuli for improving creativity during ideation, Proceddings of the Institution of mechanical engineers. *Part C: Journal of Mechanical Engineering Science*, 233(2), 493–503. https://doi.org/10.1177/0954406218809117

Ponche, R., Kerbrat, O., Mognos, F., & Hascoet, J.-Y. (2014). A novel methodology of design for additive manufacturing applied to additive laser manufacturing process. *Robotics and Computer-Integrated Manufacturing*, 30 (4), 389–398. https://https://doi.org/10.1016/j.rcim.2013.12.001

Ranjan, R., Samant, R., & Anand, S. (2017). Integration of design for manufacturing methods with topology optimization in additive manufacturing. *Journal of Manufacturing Science and Engineering*, 139(6). https://doi.org/10.1115/1.4035216

Ratto, M., & Ree, R. (2012). Materializing information: 3D printing and social change. *First Monday*, 17(7). https://doi.org/10.5210/fm.v17i7.3968

Rias, A.-L., Segonds, F., Bouchard, C., & Abed, S. (2017). Towards additive manufacturing of intermediate objects (AMIO) for concepts generation. *International Journal on Interactive Design and Manufacturing*, 11(2), 301–315. https://doi.org/10.1007/s12008-017-0369-0

Runco, M. (2007). *Creativity Theories and Themes: Research, Development and Practice*. Elsevier Academic press.

Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal*, 24(1), 92–96. https://doi.org/10.1080/10400419.2012.650092

Sass, L., & Oxman, R. (2006). Materializing design: The implications of rapid prototyping in digital design. *Design Studies*, 27(3), 255–325. https://doi.org/10.1016/j.destud.2005.11.009

Sawyer, K. R. (2012). *Explaining Creativity: The Science of Human Innovation*. Oxford University Press.

Segonds, F. (2018). Design by additive manufacturing: An application in aeronautics and defence. *Virtual and Physical Prototyping*, 13(4), 237–245. https://doi.org/10.1080/17452759.2018.1498660

Taura & Nagai. (2017). Creativity in innovation design: The role of intuition, synthesis and hypothesis. *International Journal of Design Creativity and Innovation*, 5(3–4), 131–148. https://doi.org/10.1080/21650349.2017.1313132

Thompson, M. K., Moroni, G., Vaneker, T., Fadel, G., Campbell, R. I., Gibson, I., & Martina, F. (2016). Design for additive manufacturing: trends, opportunities, considerations, and constraints. *CIRP Annals - Manufacturing Technology*, 65(2), 737–760. DOI: 10.1016/j.cirp.2016.05.004.

Wai, H. W. (2001). RP in art and conceptual design. *Rapid Prototyping*, 7(4), 217–219. https://doi.org/10.1108/EUM0000000005895

Weisberg, R. W. (1988). Problem solving and creativity. In R. J. Sternberg (Ed.), *The nature of creativity: Contemporary psychological perspectives* (pp. 148–176). Cambridge University Press.

Wohlers, T., Campbell, I., Diegel, O., Huff, R., Kowen, J., Bourell, D. L., Fidan, I., & Sander, P. (2019). Wohlers Report: 3D printing and Additive Manufacturing State of the Industry, *Wohlers Associates INC*, ISBN: 978-0-9913332-5-7.

Yang, S., & Zhao, Y. F. (2015). Additive manufacturing-enabled design theory and methodology: A critical review. *International Journal of Advanced Manufacturing Technology*, 80(1–4), 327–342. https://doi.org/10.1007/s00170-015-6994-5

Yin, R. K. (2014). *Case Study research: Design and methods* (5th edition). SAGE publications.