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Investigating designers' preferred learning media to design for additive manufacturing

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Abstract

In this exploratory study, designers' preferred learning media in learning to design for Additive Manufacturing was explored. Furthermore, by deploying an online survey questionnaire, factors such as years of experience, and the categories of products designed were explored to understand how they influence designers' learning media with a response from 201 respondents. The results show that designers have learned how to design for AM through experimentation and present the first step towards developing an appropriate Design for Additive Manufacturing knowledge dissemination approach.

Keywords: design for additive manufacturing, design knowledge, learning media, knowledge dissemination, design practice

1. Introduction and background

Over the years, the knowledge base in Design for Additive Manufacturing (DfAM) has continued to expand and there have been efforts to classify this knowledge into a coherent and structured manner, to make it easily accessible and comprehensible (Kumke et al., 2016: Pradel et al., 2018a: Obi et al., 2022). The dynamics involved in the maturity of Additive Manufacturing (AM) technologies leading to its adoption as a mainstream manufacturing process gives rise to not only the development of a coherent knowledge base, but a means of acquiring the knowledge (Obi et al., 2022). Generally, it has been established that learning to design can take place through various learning media (Yilmaz et al., 2014; Evans, 2015). However, in the context of designing for AM, such generalisations may not have been firmly established. Nevertheless, some attempts have been made by researchers to continuously develop new means of acquiring DfAM knowledge. For instance, a feature database that supports the knowledge to design for AM was developed by Maidin et al (Maidin, Campbell and Pei, 2012). Similarly, design principles used in the form of a computer database was developed by Watschke et al., (2019) and Valjak and Bojčetić, (2019). While DfAM knowledge on multi-materials was captured by Watschke et al., (2019), Valjak and Bojčetić, (2019) focused on capturing comprehensive DfAM knowledge. Other forms of learning that have been developed and validated for the dissemination of DfAM knowledge include design heuristics (Blösch-Paidosh and Shea, 2019), functional artefacts (Valjak and Bojčetić, 2019) and the use of workshop-based training (Prabhu et al., 2020). Studies have developed frameworks that support designing for AM (Qi et al., 2018; Uz Zaman et al., 2018; Pradel et al., 2018a; Vaneker et al., 2020). However, either the frameworks are inconsistent and attempts to focus on a particular design phase, or they are not intended for the dissemination of detailed DfAM knowledge.

As the expertise of designers continues to evolve, there is a possibility of a change in the learning media, given the complexities involved in designing for AM. Furthermore, preferences may change due to

factors such as cost, availability, skill level, etc. However, what is most important is to understand which learning media are effective in learning to design for AM from the designers' perspective, thus understanding AM designers' learning media preferences.

To date, very few studies have deployed a bottom-up approach to understanding how designers learn to design. Laverne, et al., (2016) investigated the typology of knowledge support required to design for AM. In addition to the small sample population deployed for the investigation (n<50), the learning approaches/media were limited to text, artefacts, videos, and pictures. Hence, the investigation did not present detailed options to the respondents, and further limited their choices. More detailed work was performed by Pradel et al., (2018b) where the authors attempted to investigate how designers gathered their knowledge to design for AM. Again, in addition to the limited study population and focus on only industrial practitioners, the work only dealt with the designers' past design projects and failed to consider the future needs or preferences of designers. The investigation of the future preferences of AM designers has become imperative due to the continuous evolution of AM processes, and consequently, DfAM techniques. In this paper, we deployed an online survey to investigate designers' preferred learning media, the usefulness of the learning media in their future projects, and the impact of their number of years of experience in the choice of designers' learning media, focusing on industry practitioners, researchers, and academics.

2. Online Survey: the questionnaire

In this study we focus on reporting the outcome of the investigation into the past and future learning media preferences and the impact of experience in the choice of learning media of Designers who design for AM. A routing system was used to screen respondents based on their experience of DfAM. The questionnaire began by asking the question; have you ever designed for Additive Manufacturing? Respondents who answered 'YES' were redirected to more specific DfAM questions. Respondents without DfAM experience were asked to immediately identify their preferred learning media and state their usefulness for future projects. Online Surveys (formerly BOS) (https://www.onlinesurveys.ac.uk/) was used to design the survey because it allowed for rapid development of the survey, it is affordable, has an automatic routing system, and is flexible enough to allow respondents to make choices.

2.1. Survey structure

The study focused on investigating designers' preferred learning media and the inclusion criteria was that the respondents should identify as designers and possess relevant and adequate design experience. The survey was structured into three sections as shown in figure 1. In the first section, participants were introduced to the study and provided with specific information on data protection. Furthermore, the demography of the participants, which included years of experience, area of design practice and type of product designed was collected. The screening question was asked in the second section to create a segregation between designers with and without experience of DfAM. Following this, questions regarding the designers' learning media were asked. In the third section, information about a follow-up study was provided and respondents had the opportunity to state if they were interested in participating in follow-up studies. This section brought the survey to an end.

2.2. Respondents sample

A total number of 201 respondents completed the questionnaire within two months (March-May). A non-probabilistic convenience sample, although not a representation of all designers, was considered the most effective way to recruit participants. It was almost impossible to randomly sample the whole design community, moreover, there are no publicly available databases containing the contact details of designers with AM experience, hence, the use of the selected sampling and distribution method. The selection is justified as the aim was to investigate designers' preferred learning media and not to test a potential hypothesis around the topic. To ensure a large pool of respondents was recruited, the survey was actively distributed online through 1. LinkedIn Posts, 2. Identifying potential participants via websites and newsletters in the AM industry, and 3. Private messaging to existing contacts on social media platforms with updated biographical data showing a relevant design background. A snowball

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approach was adopted, and the respondents were encouraged to refer the link to other potential respondents.

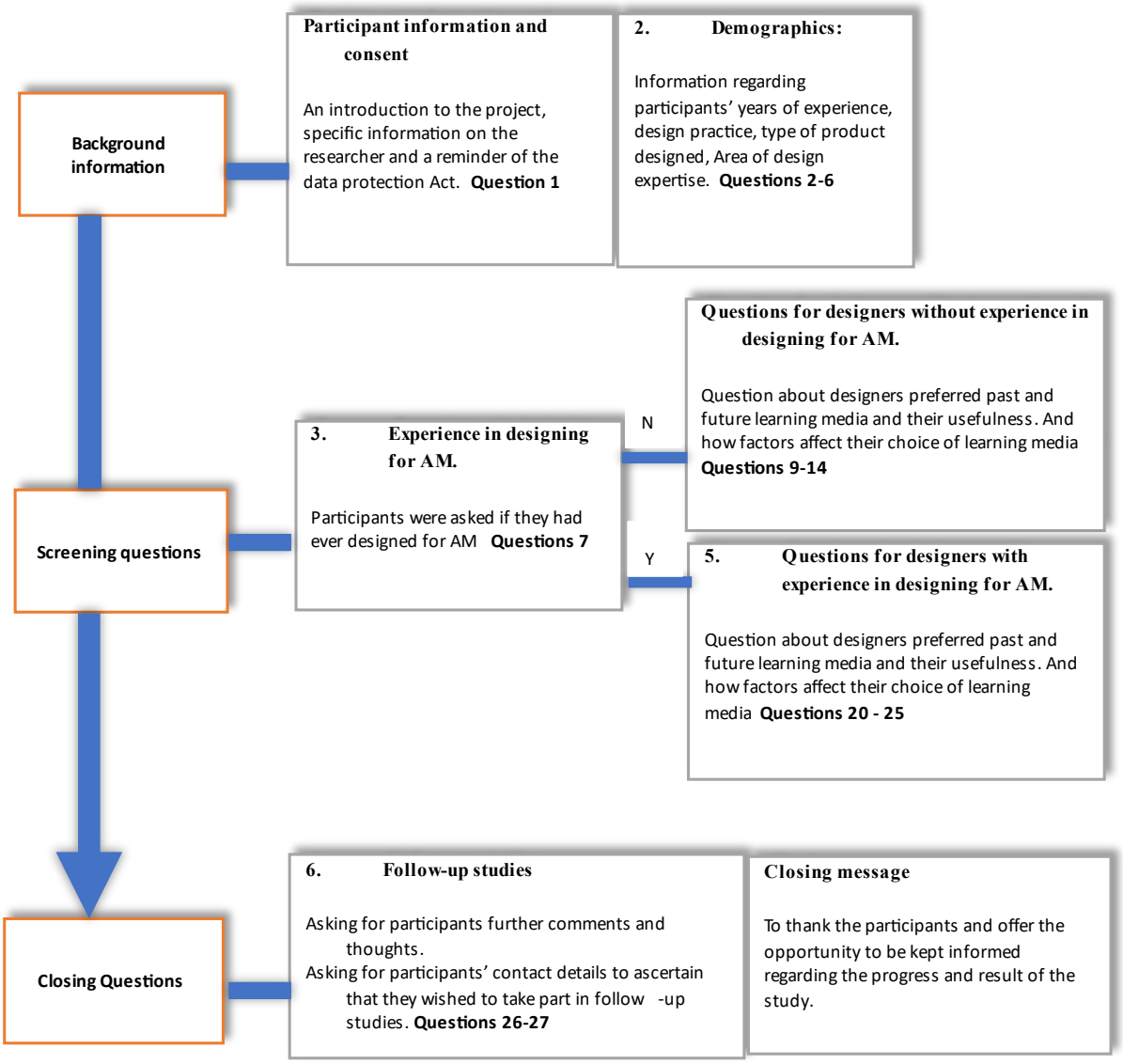

Figure 1. Survey structure

3. Results

A total of 201 successful respondents completed the questionnaire with 42% (n=84) identifying as designers without DfAM experience and 58% (n=117) as designers with DfAM experience. To gain insights into the preferred learning media that respondents have employed to learn in their past design projects, questions regarding their preferred past learning media, the usefulness of these learning media for both past and future projects, and their years of experience were asked. Where appropriate, respondents were asked to pick from a Likert scale ranging from "not at all useful" to "extremely useful" representing a five-scale choice.

3.1. Data analysis

A mixed method was adopted for the analysis of the results. Descriptive analysis was deployed to create a visual representation of the results and Pearson correlation was used to ascertain the

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correlation between the respondents' past and future learning media for both groups, participants with AM design experience and those without AM design experience. The size of that sample population and the type of questions and responses enabled further statistical analysis (Cohen et al., 2011). The findings were exported from SPSS (version 23) to Microsoft Excel 2016 for coding, including the analysis and development of the visuals (Bar charts). Pearson's correlation was conducted to determine the correlation between the past and future preferred learning media for both AM and non-AM designers. Furthermore, the frequency of response to a question was used to create an index for analyses.

3.2. Designers' preferred learning media

The respondents were asked to select the learning media they have used in their past projects. Generally, the result showed that designers (100%, n=201) have learnt with one or more of the listed learning media. However, "learning from experts/colleagues", videos, design books, and CAD tools (58%, n=49 respectively) appeared to have been substantially employed as learning media for designers without DfAM experience, while Artefact/product (18%, n=15) was least utilised.

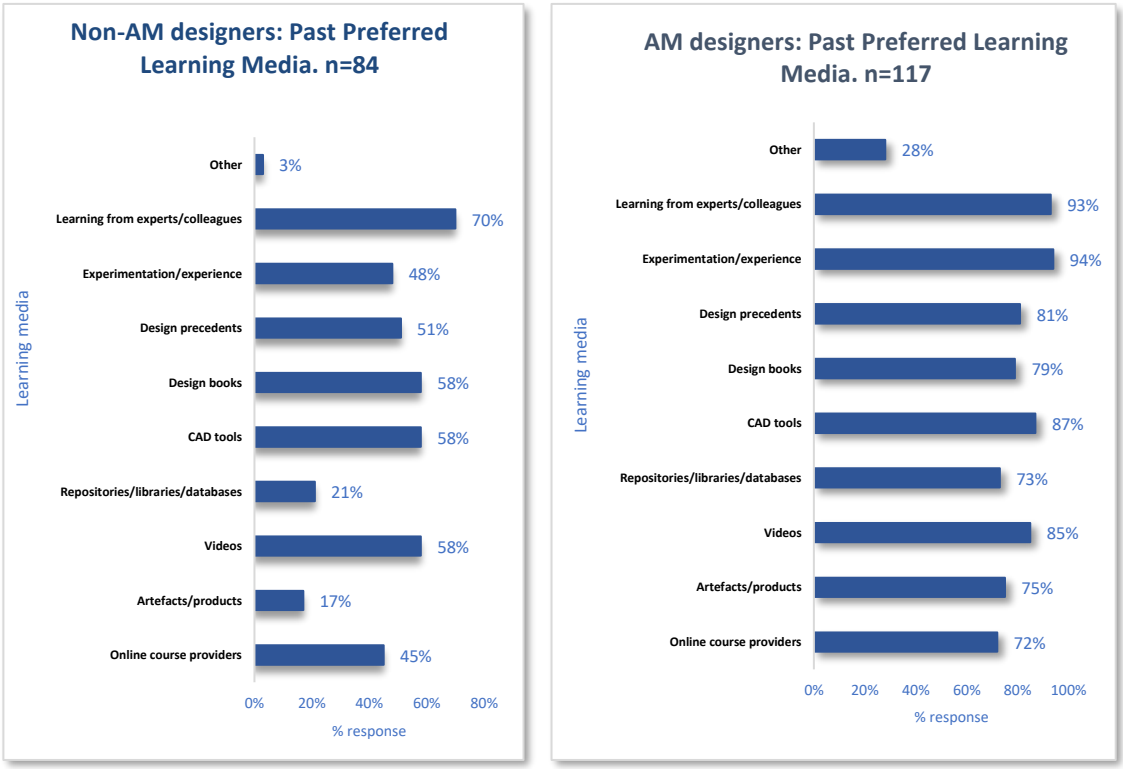

Figure 2. Past preferred learning media for AM and non-AM designers

For respondents with AM design experience, a slightly different result is revealed. Of the 117 respondents, AM designers have used "experimentation/experience" (94%, n=110) the most. This was followed by "learning from experts/colleagues" (93%, n=109), CAD tools (87%, n=102), and videos (85%, =100). Although reported as the least preferred, "online course providers" was considered by most AM designers (73%, n=85) as a learning medium.

3.3. Designers' preferred future learning media

To gain more insight into the respondents' preferred learning media, they were asked to state the usefulness of the listed learning media for future projects. The results for designers without DfAM experience showed that 87% (n=73) think that learning from experts/colleagues would be most useful in the future. This was followed by experimentation/experiment (80%, n=67) and videos (74%, n=63). Similarly, Artefact/products (48%, n=40) was considered to be least useful in the future, which may

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suggest that the knowledge gained from the artefact/knowledge is limited because in addition to the aesthetics and properties of the product being designed, designers are curious about learning the design process.

For designers with DfAM experience, the results showed a slight contrast. More respondents thought that experiments and experiential knowledge (91%, n=107) will be most useful to learn how to design for AM, followed by "learning from experts" (90%, n=106), then videos and CAD tools (65%, n=76) respectively. Designers with DfAM experience think that learning media such as design books (37%, n=44) and repositories/libraries/databases (39%, n=46) will be least useful in the future. Interestingly, and unlike designers without DfAM experience, designers with DfAM experience considered that Artefacts/products (44%, n=51) could be useful in the future. This may suggest that Artefacts/products embody, to some extent, the knowledge of AM potentials which are essential for AM design.

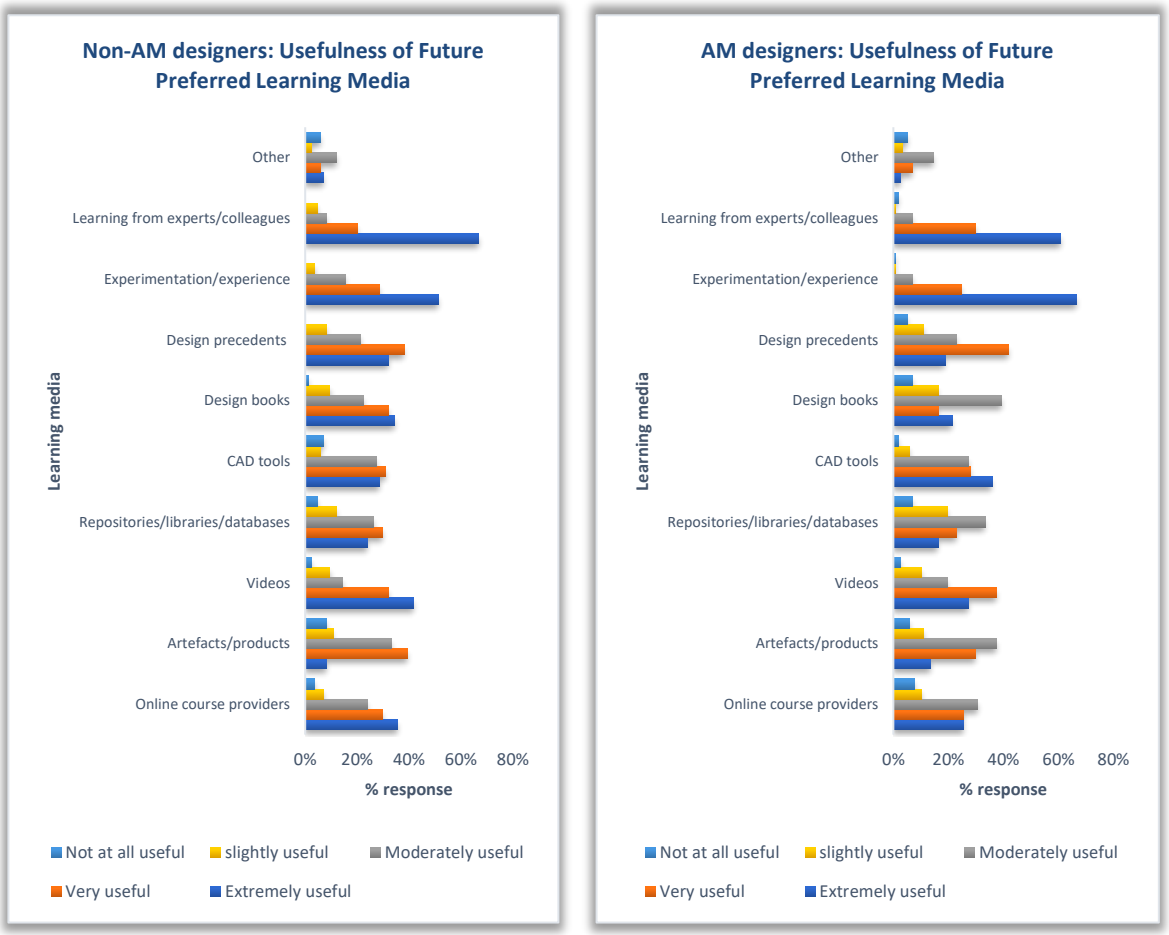

Figure 3. Designers' preferred future learning media for AM and non-AM designers

Furthermore, it may that artefacts/products as a learning media may trigger designers' creative concepts in AM, especially in redesigning for AM.

The outcome of the correlation illustrated in tables 1 and 2 reveals a positive correlation between the past and future preferred Learning media for AM designers df (115) = r (0.541), $p<0.05$ where df is the degree of freedom, r is the Pearson correlation coefficient; used to measure the linear correlation, and P is denoted as the p-value, showing the probability of observing a non-zero correlation coefficient in the sample data when the null hypothesis is true and is significant at $p<0.05$.

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Table 1. Correlations - AM designers

		AM designer Past Learning Media	AM designer future Learning Media
AM designer Past Learning Media	Pearson Correlation	1	0.541**
	Sig. (2-tailed)		0.000
	N	116	116
AM designer future Learning Media	Pearson Correlation	0.541**	1
	Sig. (2-tailed)	0.000	
	N	116	117

**. Correlation is significant at the 0.01 level (2-tailed).

This implies that there are no substantial changes between the past and future preferred learning media by designers with DfAM experience, therefore, designers still think that their preferred past learning media will be useful in the future. The same trend was observed for the non-AM designers df (82) = r (.984), p>.05.

Table 2. Correlations: non-AM designers

		Non-AM Designer past LM	Non-AM Designers future LM
Non- AM designer past LM	Pearson Correlation	1	0.984**
	Sig. (2 tailed)		0.000
	N	84	84
Non- AM Designers future LM	Pearson Correlation	0.984**	1
	Sig. (2-tailed)	0.000	
	N	84	84

**. Correlation is significant at the 0.01 level (2-tailed).

The outcome showed a strong positive correlation between their past and future preferred learning media, implying that non-AM designers would still prefer their past learning media in future design projects. Moreover, this may also depict that designers are satisfied with the choice of their learning media and are not eager to explore the use of others.

3.4. Years of experience Vs. preferred learning media

The influence of years of experience on the preferred learning media for designers without DfAM experience revealed slight disparities between the years of experience. Designers at an early stage of their careers (0 – 3 years' experience) preferred "learning from experts" (88%, n=30), followed by experimentation/experience (79%, n=27), and videos (71%, n=24) as being useful future learning media. The same trend was observed for designers with 4-8 years' experience. Indeed, the respondents thought that "learning from experts" and design precedents (84%, n=27 respectively), experimentation/experience (81%, n=26), videos, online course providers, CAD tools, and design books (75%, n=24 respectively) were more useful as future learning media. For designers with experience of 9 years and above, "learning from experts" (89%, n=16), design books and CAD tools (83%, n=15 respectively), and videos and experimentation/experience (78%, n=14) respectively were thought as the more useful future learning media. Artefacts was selected as the least useful future learning media across all years of experience (50% n=17, and 44% n=8 for respondents with 0-3 and 9 years and above, respectively). Equally, this may suggest that Artefacts only embody the knowledge of the outcome of a design activity rather than informing designers about the design process.

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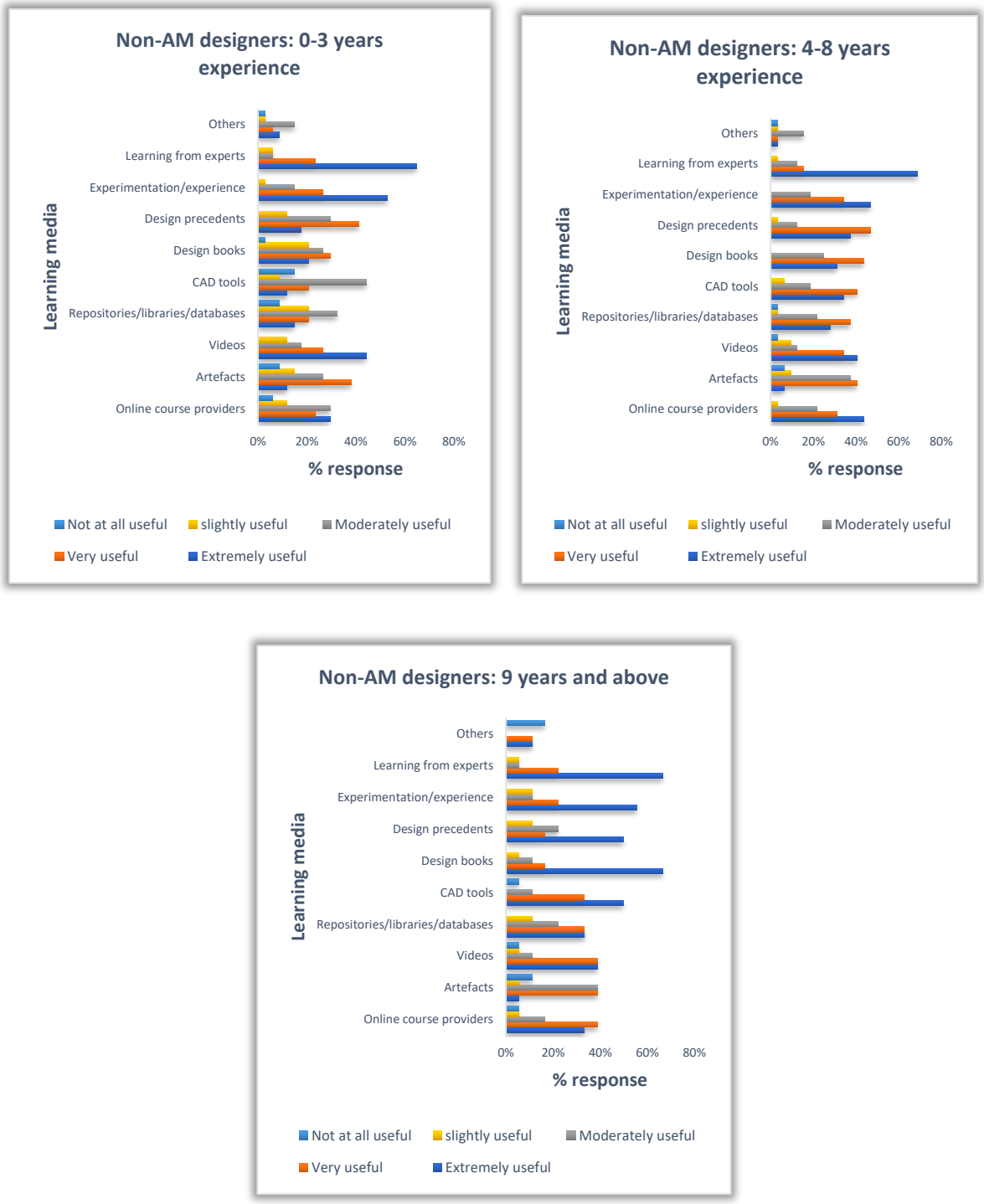

Figure 4. Years of experience Vs. preferred learning Media - non-AM designers

The results of the analysis for AM designers showed some disparities between designers' years of experience. A greater proportion of designers with 0-3 years' experience, chose "learning from experts" (57%, n=52), experimentation/experience (56%, n=51) and videos (45%, n=41) as being generally useful as learning media in the future. A slight difference is observed in the result of designers with 4-8 years' experience. More respondents chose experimentation/experience (55%, n=42), followed by learning from experts (52%, n=40), and design precedents (39%, n=30). Furthermore, more experienced designers – 9 years and above chose both "learning from experts" and experimentation/experience (42%, n=14) respectively to be useful as future learning media as illustrated in Figure 5.

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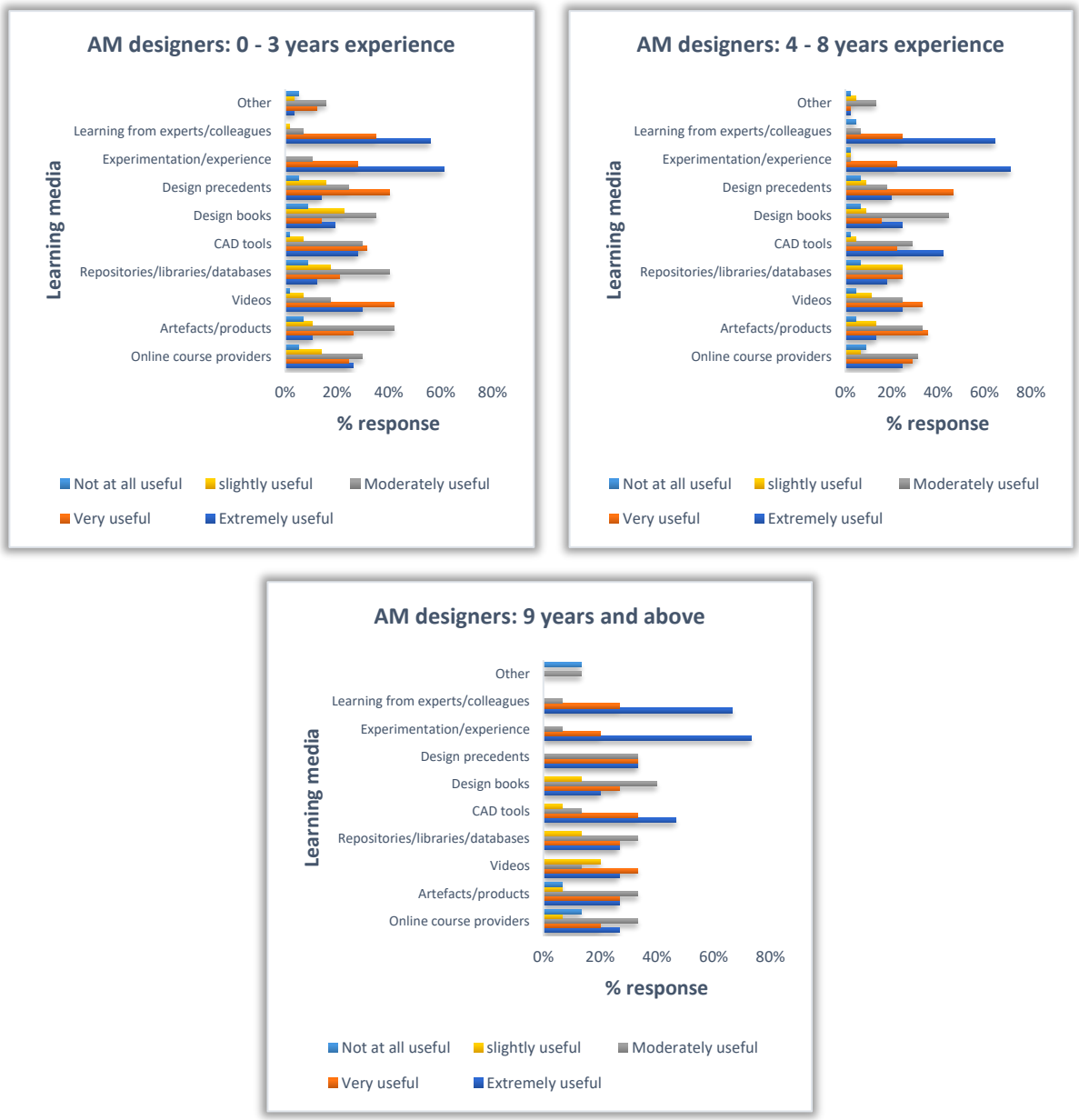

Figure 5. Years of experience Vs. preferred learning media - AM designers

4. Discussion

It is imperative to state that the sample is not fully representative of the population of designers. However, it was observed that "learning from experts" was the most preferred media in design for designers with and without DfAM experience. Although this study was focused on eliciting information from designers with DfAM experience, it was important to investigate the preferred learning media of designers without DfAM experience to gain an understanding of any possible similarities and or differences between the two groups. Moreover, it would help to draw some inferences and if possible, test the applicability of preferred learning media in different contexts.

Experimentation/experience was not as popular for designers without DfAM experience as it was for designers with DfAM experience, which contradicts a previous study (Dorn and Guzdial, 2010). The authors found that the learning process for web designers (without DfAM experience) was largely motivated by project works and followed a pattern of experimentation to produce experiential knowledge. The use of experimentation/experience as a learning medium by designers with DfAM experience may imply that AM and its associated processes are still new and evolving, therefore, designers are following

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a trial-and-error pattern to develop experiential knowledge for further capacity building. Moreover, since AM is predominantly known as a prototyping technology, it is relatively easy to experiment with. This corroborates the findings by Pradel and Previtali, (2012) and Pradel et al., (2018) who found that designers alluded to having developed their DfAM capacity through experiential learning. A possible justification for the use of CAD tools as a learning medium in past design projects by both designers with and without DfAM experience might be due to the technicalities involved in designing for AM. Moreover, according to Jonassen (1994), CAD software and technologies provide an opportunity for designers to function as learners, as cognitive tools for analysing data in pictorial forms, interpreting, and organising their personal knowledge, and representing what they know to others.

The similar trend captured in the preference of future learning media further confirms the assumptions stated in the designers' choice of past learning media. However, the choice of least preferred learning media by both designers with and without DfAM experience showed a mixed result. For instance, it might be deduced that the choice of design books as least preferred future learning media suggests that designing for AM entails more than reading books, it is most often driven by practical experiences, or it may be due to a lack of suitable books. Studies have shown that designers do not prefer "texts" as a typology of knowledge support tools (Evans, 2015; Floriane et al., 2017). Similarly, the selection of repositories/libraries/databases as the least preferred future learning media did not validate the claims by Maidin, Campbell and Pei, (2012) where the authors developed a design feature database and stated that it has the potential to support the acquisition of DfAM knowledge. It was interesting that designers at the early stage of their career (0-3 years' experience) for both groups considered video as a useful future learning medium. The outcome complements the work by Floriane et al., (2017). The authors conducted a study that gathered information on the typology of design support required for DfAM. Although there were no segregations in terms of years of experience, the outcome showed that designers working in AM preferred video as the best AM knowledge support. This may suggest that they are eager to learn from existing documented processes rather than invent new ones, which may also influence their level of creativity. Of interest was that, except for "learning from experts" and experimentation/experience, other learning media were considered as being useful future learning media by designers without DfAM experience in the early stage of their design experience. A potential justification could be that the diverse design expertise of the respondents may have influenced this outcome, suggesting that different design practices may require different learning media for knowledge transfer.

Although the aim of this study was not to primarily compare the outcome between designers with and without DfAM experience, it was important to see how designers without DfAM experience would want to learn to design and how designers' years of experience could impact their choice of learning media. Moreover, it would help to draw inferences and see how outcomes could be potentially adapted and tested in other contexts.

5. Conclusion

"Learning from experts" and experimentation/experience were the most preferred media by both AM and non-AM designers in their past projects and for future projects. Both AM and non-AM designers think that "learning from experts" and experimentation/experiment would be the most useful learning media. The years of experience did not significantly impact on designers' choice of learning media. For instance, experts who design for AM still suggested "learning from experts" and experimentation as useful learning media in the future. This may be due to the experience they have gathered over time through experimentation and the fact that AM is continuously evolving. As this is the first step to developing a suitable DfAM knowledge dissemination approach, more insight is needed on this topic to further validate the outcome of this work through a qualitative study. The outcome of this exploratory work forms a solid foundation on designers' learning media preferences, specifically for design for AM, but also indicates generally, how designers prefer to learn. This work forms the basis from which we can rethink DfAM training strategies for industry practitioners and DfAM curriculum development in academia. However, there is a need for further research to more fully understand how learning takes place when designers learn from experts (such as mentors and or more experienced colleagues) and their own experience (such as self-directed learning and or practical experimentation). Follow-up research is in progress to address the learning requirements and further validate the outcomes of this study

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through a comprehensive qualitative study. By deploying a qualitative research method, the ongoing research will draw from expert designers' experiences of teaching/mentoring other designers, and the learning experiences of novice designers to develop a more effective learning approach that will capture the designers' learning journey and reflect the application and development of DfAM knowledge to advance their growth to becoming expert DfAM designers.

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