Business model patterns for 3D printer manufacturers

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Abstract

Purpose – The purpose of this paper is to analyze the business models that 3D printer manufacturers apply to commercialize their technologies. The authors investigate these business models and analyze whether there are business model patterns. The paper describes the gestalt of the business model patterns and discusses differences and similarities.

Design/methodology/approach – The authors review the literatures on business models and 3D printing technology. The authors apply a componential business model approach and carry out an in-depth analysis of the business models of 48 3D printer manufacturers in Europe and North America. The authors develop a framework focusing on value proposition, value creation and value capture components. Cluster analysis is used to identify business model patterns.

Findings – The results indicate that there are two distinct business model patterns in the industry. The authors termed these patterns the "low-cost online business model" and the "technology expert business model." The results demonstrate that there is a relationship between business model and technology. The identified patterns are independent of age, company size and country of origin.

Research limitations/implications – The empirical results complement and extend existing literature on business models. The authors contribute to the discussion on business models in the context of novel technology. The technology seems to influence the gestalt of the business model. The sample is limited to European and North American companies and the analysis is based on secondary data.

Originality/value – This is the first empirical study on the business models of 3D printer manufacturers. The authors apply an original mixed-methods approach and develop a framework that can function as a starting point for future research. 3D printer manufacturers can use the identified business model patterns as blueprints to reduce the risk of failure or as a starting point for business model innovation.

Keywords Innovation, 3D printing, Technology implementation, Additive manufacturing, Small- and medium-sized enterprises

Paper type Research paper

1. Introduction

Manufacturing companies are facing severe challenges. Advances in technology, global competition and readily available information led to an increased comparability of offers. As a result, power shifted away from the manufacturers toward the customers. In addition, also customer preferences changed significantly. For instance, individualization has become a major trend (Rachinger *et al.*, 2018). Furthermore, customers frequently demand the simultaneous improvement of quality and a reduction of costs (Brettel *et al.*, 2014). As a response, companies

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promote the implementation of digitalization, automation and ICT (Oesterreich and Teuteberg, 2016). In order to fulfill this shift companies also have to alter their production technologies (Rylands *et al.*, 2016).

3D printing is considered a major technological driver fostering this paradigm shift (Petrick and Simpson, 2013; Ghobakhloo, 2018) as it might enable more efficient and effective production of prototypes and goods (Hannibal and Knight, 2018). Regarding the extent of its potential future impact, scholars have already drawn comparisons between 3D printing and ICT (Rayna and Striukova, 2016). However, 3D printing has yet to live up to expectations (Maresch and Gartner, 2018). The 3D printing industry is still small but rapidly growing. In 2016, 3D printer manufacturers' industry revenues grew by 17.4 percent and were an estimated $6.063 billion (Wohlers Associates, 2017). Despite increasing market shares (Manyika *et al.*, 2013), overall technology diffusion is still slow (Wohlers Associates, 2017; Holzmann *et al.*, 2018; Yeh and Chen, 2018). Lately, also several governments, such as the USA, UK (Schniederjans, 2017), Germany, the Netherlands, China and South Korea started to actively promote the adoption of 3D printing technology (*Forbes*, 2018).

Besides its primary application in rapid prototyping and for small production runs, 3D printing started to enter also consumer households (Hannibal and Knight, 2018). 3D printing allows manufacturers to shift productive activities at least to some extent to consumers (Bogers *et al.*, 2016). Major drivers that enable this development are the expiration of critical patents for fused deposition modeling (FDM) and stereolithography (SLA) printers and the advent of the Replication Rapid (RepRap) Prototyper project (Wohlers and Caffrey, 2014). The literature refers to individual 3D printing as home fabrication (Rayna and Striukova, 2016). Home fabrication deals, for instance, with the production of appliances, tools or replacement parts (McKinsey, 2017).

Research on economic and business effects of this novel technology is still insufficient (Weller *et al.*, 2015; Rayna and Striukova, 2016; Öberg *et al.*, 2018). Previous research primarily aims to investigate 3D printings potential for manufacturing optimization (Öberg *et al.*, 2018) and technology entrepreneurship (Gartner *et al.*, 2015). However, there is limited research on business models in the 3D printing industry (Öberg *et al.*, 2018). Bogers *et al.* (2016), for instance, showed that 3D printing can enable consumer goods manufacturers to shift toward more consumer-centric business models. Rayna and Striukova (2016) investigated how 3D printing is affecting business model innovation. Holzmann *et al.* (2017) identified business models for user entrepreneurs. Öberg *et al.* (2018) analyzed current literature on business models and 3D printing. They conclude that there is a need for more holistic views, especially on business model components.

We seek to address this research gap by shedding further light on the relationship between business models and novel technology. Previous research has concluded that business models are crucial in the adoption of new technology (Chesbrough, 2010; Morris *et al.*, 2013). Scholars (e.g. Gambardella and McGahan, 2010; Teece, 2010; Zott *et al.*, 2011) argue that business models are important to unlock technology's full commercial potential. However, developing a viable business model to commercialize especially novel technology is a challenging task and the risk of failure is high (Cavalcante, 2013).

We aim to investigate the business models that companies are using to commercialize 3D printers for rapid prototyping and home fabrication purposes and formulate the following research questions:

RQ1. How do 3D printer manufacturers commercialize their products?

RQ2. Which business model patterns do 3D printer manufacturers apply?

RQ3. What is the gestalt of these business model patterns?

To answer these research questions, we introduce 3D printing and briefly discuss the technology's advantages. In addition, we present prerequisites for its usage. We then address business models and their constituting components as well as the nexus between business models and technology. We apply a componential business model approach and carry out an in-depth analysis of the business models of 48 3D printer manufacturers located in North America and Europe. The results of our analysis provide insights into constitutional variables for novel technology commercialization. Our findings indicate that there are two distinct business model patterns. We extract the gestalt of these business model patterns and identify differences and similarities. Finally, we discuss if these patterns can function as blueprints for other 3D printer manufacturers by highlighting potential advantages and disadvantages. Our study contributes to a better knowledge base of the nexus between business model and novel technology. Thus, this paper extends existing literature in business model research and technology entrepreneurship. Finally, we derive managerial implications, discuss the limitations of our work and suggest potential future research directions.

2. Theoretical background

2.1 A brief introduction to 3D printing

3D printing is an additive manufacturing process that builds objects by adding layer upon layer of a material (e.g. ceramics, metals and polymers) (Steenhuis and Pretorius, 2017; Wohlers Associates, 2017). Thus, it differs significantly from injection molding and subtractive manufacturing processes. Areas of application are primarily rapid prototyping and small production runs (Appleyard, 2015; Weller *et al.*, 2015). Due to its specific characteristics, 3D printing technology is considered a major driver for digitalization (Rayna and Striukova, 2016). For instance, 3D printing has major advantages regarding cost-effective production and production speed (D'Aveni, 2015). First, applying 3D printing processes can reduce the costs of setting up a venture, since they do not require expensive tools, forms, or punches (Holmström *et al.*, 2010; Berman, 2012). Second, 3D printers enable short setup time. Thus, they are able to reduce time-to-market and allow swift order processing. Third, economies of scale are not applicable to 3D printing, thus increasing the attractiveness to manufacture individualized products (Berman, 2012; Holmström *et al.*, 2017). In addition, in-time production circumvents the need to stockpile huge numbers of products (Holmström *et al.*, 2010; Berman, 2012; Lipson and Kurman, 2013). Fourth, 3D printing allows for printing almost any form, thus overcoming design or construction-related constraints (Petrovic *et al.*, 2011; D'Aveni, 2015). Fifth, 3D printing can also positively affect environmentally friendly production due to a reduction of input material needed and the amount of waste (Berman, 2012; Holmström *et al.*, 2017). Furthermore, biodegradable filaments are becoming more widely available. Taken together 3D printing technologies might enable more efficient and effective production of prototypes and individualized goods (Hannibal and Knight, 2018).

However, companies can only attain these advantages if their organizations fulfill certain requirements. First, manufacturing complex parts in one part is a challenging task (Holmström *et al.*, 2010; Berman, 2012) that assumes the successful combination of hardware and software (Petrick and Simpson, 2013). Compared to the traditional way of casting and assembling various parts, this approach requires CAD-designs that are more sophisticated. Thus, there is a pressing need for designers that master the requirements and challenges of designing fully printable complex objects. Second, the design and production of complex 3D printed parts can be time consuming. Thus, companies that adopt 3D printing technology also have to be aware to adjust and intensify their value creation processes toward digitalization. Consequently, these companies need to implement a fundamentally different logic of thinking based on the principles of digitalization (Holzmann *et al.*, 2018).

Besides its primary application in rapid prototyping and for small production runs, 3D printing started to enter also consumer households (Hannibal and Knight, 2018).

Currently, several companies target the consumer markets with affordable printers (Holzmann *et al.*, 2017). Target customers for these inexpensive 3D printers are primarily makers and tinkerers. The literature refers to individual 3D printing as home fabrication (Rayna and Striukova, 2016). Home fabrication deals, for instance, with the production of appliances, tools or replacement parts (McKinsey, 2017). Teenage Engineering a Swedish synthesizer manufacturer altered its value creation by eliminating warehousing of replacement parts. The company offers customers to purchase 3D printable files. Customers can now print as many parts as they want at home or use a 3D printing service. In addition, they can even modify the parts and can thus create a unique appearance for their synthesizers (3D printing, 2012).

3D printing has the potential to transform manufacturing and alter services (Gartner *et al.* 2015). Due to its specific characteristics, 3D printing technology provides novel ways for companies to create value for customers. However, capturing value from 3D printing is crucial. Prior research (e.g. Rayna and Striukova, 2016) highlighted that this can be a challenging task. There is a pressing need for viable business models that underscore the technology's advantages and enable profitable commercialization (Bogers *et al.*, 2016). Hence, the question that remains is what value based on 3D printing can companies provide to customers? How can they create this value and how can they successfully capture value for themselves through their business models?

2.2 On the nexus of business models and technology

Business models have evolved as a distinct unit of analysis (Zott and Amit, 2013; Tongur and Engwall, 2014). Special issues on business models and business model innovation in top-tier academic journals, such as *Long Range Planning* (2010, 2013, 2018), *R&D Management* (2014) and *Strategic Entrepreneurship Journal* (2015), acknowledge the topic's importance for the scientific community. Further, various studies (e.g. Aspara *et al.*, 2010; Brettel, *et al.*, 2012; Hu, 2014; Velu, 2015) have concluded that a business model is of value to companies, since it can positively influence their performance. Despite the fields growing importance, empirical research on business models is still scarce. Several scholars (e.g. Spieth *et al.*, 2014; Wirtz *et al.*, 2016; Teece, 2018) have therefore underlined the importance of a reasonable knowledge base of business models.

Business models aim to provide holistic and structured templates of how companies do business (Zott *et al.*, 2011; Zott and Amit, 2013). Following the componential approach, business models comprise particular business model components that provide explanation of a company's business model (Baden-Fuller and Mangematin, 2013). Scholars consider the concept of value as the common element in business model research (George and Bock, 2011). There is a growing consensus that business models consist of value proposition, value creation and value capture components (e.g. Shafer *et al.*, 2005; Desyllas and Sako, 2013; Bocken *et al.*, 2014; Holzmann *et al.*, 2017). The value proposition comprises bundles of products and services (Osterwalder *et al.*, 2005; Morris *et al.*, 2005; Morris *et al.*, 2006). It defines the benefits that potential customers attain from these bundles (Mason and Spring, 2011). The value proposition can contain a portfolio of valuable benefits for customers (Morris *et al.*, 2005, Johnson *et al.*, 2008). The value creation component specifies the key processes and external partners, as well as the communication and distribution channels (Johnson *et al.*, 2008; Bocken *et al.*, 2014) required to create value and ultimately to harness the value proposition. The value capture component encompasses revenue generation options, cost structures and profits (Bolton and Hannon, 2016; Rayna and Striukova, 2016). These three components are inextricably linked with each other and need to be aligned (Foss and Saebi, 2017; Kiel *et al.*, 2017). Taken together the combination of these three business model components defines the gestalt of a business model (Shafer *et al.*, 2005).

Research on the nexus between technology and business models is still in progress (Cavalcante, 2013). Baden-Fuller and Haefliger (2013) note that literature has frequently disregarded the importance of business models as enablers for value creation through novel technology. A growing number of studies assumed the existence of strong interdependencies between technology and business model (e.g. Kodama, 2004; Tongur and Engwall, 2014). The discussion is driven by the assumption that mere technology development is no longer sufficient for firm success (Doganova and Eyquem-Renault, 2009). For Chesbrough (2007) a technology *per se* has no inherent value. Scholars point out that the business model provides an important link from technology to firm performance (Baden-Fuller and Haefliger, 2013). Christensen (2006) concludes that the business model is the fundamental challenge when marketing technologies. The business model can open novel opportunities for technology application and exploitation that lead to previously inaccessible profit generation (Suoto, 2015). However, the number of studies that empirically investigate the nexus between business model and technology is still insufficient. The present study aims to contribute to a better understanding of the role of business models in commercializing novel technology.

3. Empirical study

3.1 Data collection

Due to the gestalt of our research questions, we employed an explorative research design. We decided to apply a mixed-methods approach (Tashakkori and Teddlie, 2003). A mixed-methods approach combines qualitative and quantitative research. Further, it incorporates a unique set of ideas and practices (Creswell, 2014), and allows creating a more comprehensive and complete picture of the focal phenomenon through a combination of strengths of different research methods (Tashakkori and Teddlie, 2003). In line with previous research on business models (Morris *et al.*, 2013; Holzmann *et al.*, 2017; Täuscher and Laudien, 2018), we chose to collect secondary data. First, we consulted the Wohler's Report to identify relevant 3D printer manufacturers (Wohlers and Caffrey, 2014). We searched for North American and European 3D printer manufacturers that target rapid prototyping or home fabrication applications. In a next step, we checked whether these companies provide sufficient information about their business models. We gathered information from websites, company profiles (e.g. from the chamber of commerce) and official media releases. We identified 16 companies listed in the Wohler's Report that fulfilled all criteria. In addition, we applied a web search to identify further companies. We used online search engines to identify additional 3D printer manufacturers that fulfill our criteria. This search resulted in 32 companies increasing our final sample to 48 companies. Prior research has shown that this methodology is suitable for analyzing business models (Holzmann *et al.*, 2017; Täuscher and Laudien, 2018). The whole data collection period lasted from 2014 until end 2015.

We apply a componential business model approach (Baden-Fuller and Mangematin, 2013). Our focus on a single industry allowed us to emphasize the more relevant variables that constitute the business models. Further, this approach allows identifying potential business model patterns and drawing comparisons between these patterns in order to detect similarities and differences (Morris *et al.*, 2013). We developed a framework for our analysis focusing on value proposition, value creation and value capture components. We analyzed these components and their potential specifications. Two raters systematically categorized the collected information by means of qualitative content analysis (Mayring, 2000). We followed a mixed coding approach and a clear predefined coding strategy. First, raters systematically searched for information on the three business model components. Second, we assigned collected information to business model subcomponents (e.g. partner integration, distribution channels and communication channels) and variables derived from the literature (deductive category assignment). Third, raters screened the collected content for further subcomponents and variables (inductive category formation). In case a rater identified a new subcomponents or variable, the raters discussed the meaning, interpretation and assignment to business model components and checked for ambiguity. After raters reached common agreement about the new variable, they repeated the entire process and again analyzed the content. In line with previous research (Morris *et al.*, 2013; Holzmann *et al.*, 2017; Täuscher and Laudien, 2018), we used binary variables to assess whether a specification is present in a respective company's business model or not. This approach allowed the setup of a category system that describes the three business model components for the quantitative part of the analysis. We controlled the data coding for consistency by calculating the interrater agreement. Interrater agreement was 91.25 percent and Cohen's κ was 0.760. Thus, there was substantial agreement between the two raters (Landis and Koch, 1977).

3.2 Methodology

We identified cluster analysis as an appropriate statistical method to analyze business models. The method is an appropriate explorative approach to identify distribution patterns in a data set and to summarize cases with similar specifications into homogenous clusters (Ketchen and Shook, 1996). In our case, cluster analysis enables discovering distinct business model patterns from the overall data set of business model specifications. Business models within a cluster are homogeneous and distinct from business models in other clusters. The applied method allows discovering and describing the identified similarities and differences in the business models.

We applied a TwoStep Cluster approach in IBM SPSS Statistics 23. TwoStep Clustering is applicable even in case of large data sets, with categorical data and results with an optimal number of clusters (SPSS Inc., 2001). Due to the binary-scaled variables in our data set, we calculated distances between business model specifications based on Log-Likelihood distance measure. Further, TwoStep Clustering allowed us to include all identified business model variables in our analysis. Thus, it enabled a more precise cluster description. We selected the most appropriate cluster model based on the Bayesian information criterion (BIC). The BIC is a global goodness of fit statistic allowing the comparison of different cluster solutions and identifying the cluster model that best describes the data (Magidson and Vermunt, 2002). We also ran robustness checks with alternative clustering approaches. We applied latent class analysis (LCA) and hierarchical cluster analysis (complete linkage method with Russel and Rao similarity measure). These alternative clustering approaches led to comparable results.

In order to describe the cluster solution, we calculated mean values of clustering variables. This calculation further allowed us to draw profile plots. These plots highlight the similarities and differences concerning business model specifications. To test for statistical differences concerning business model specifications as well as descriptive variables we applied independent-sample *t*-test, χ^2 test, Fisher's Exact test and non-parametric Mann–Whitney U test.

3.3 Measurement

To measure the three business model components we generated dichotomous variables for all identified business model specifications. Regarding the value proposition component, we build on the forms of value proposed by Kim and Mauborgne (2000) and Morris *et al.* (2006). Further, we found that companies in our sample propose additional forms of value. Taken together, our framework comprises sixteen variables (see Table I). We assigned a value of 1 (yes) for fulfilled conditions, otherwise 0 (no).

The value creation component comprises three subcomponents (integration of partners into the value chain, distribution channels and communication channels) (e.g. Osterwalder *et al.*, 2005). These three subcomponents comprise 12 variables (see Table II). The integration of partners into companies' value creation processes comprises three variables: the company cooperates with companies, customers (Osterwalder and Pigneur, 2010) or

Variable	Source	Description
Convenience	Kim and Mauborgne (2000)	The 3D printer is very convenient for its users (e.g. a simple, easy-to-use printer)
Customer productivity	Kim and Mauborgne (2000)	The company claims that the 3D printer is able to increase customers' productivity
Customer service	Morris *et al.* (2006)	The company focuses on customer service (e.g. a 24/7 service hotline)
Environmental friendliness	Kim and Mauborgne (2000)	The company has a special focus on environmental issues (e.g. usage of biocompatible filament, low emission printers)
Expertise	Morris *et al.* (2006)	The company claims that it has much expertise (e.g. industry experience, expertise in printer development, filed patents)
Flexibility	Inductive formation	The 3D printer is flexible (e.g. it can handle different printing materials/filaments)
Innovation leadership	Morris *et al.* (2006)	The company claims that its products are innovative and novel (e.g. its printers being the first that provide a specific feature)
Low cost	Morris *et al.* (2006)	The company claims that it offers its 3D printers at low prices
Quality	Morris *et al.* (2006)	The company offers high-quality 3D printers (e.g. printers with high accuracy, award-winning product)
Reliability	Kim and Mauborgne (2000)	The 3D printer is very reliable (e.g. printers need little or no maintenance)
Security	Kim and Mauborgne (2000)	The 3D printer is secure (e.g. usage of its printer is safe for everyone)
Software	Inductive formation	The company provides its own specific software for the best printing results
Speed	Inductive formation	The 3D printer is fast (e.g. it produces objects faster than the industry standard)
Training	Kim and Mauborgne (2000)	The company offers special trainings to operate its 3D printers
Variety	Inductive formation	The company offers a variety of different products (e.g. a broad range of printers, upgrades for printers, or additional accessories such as scanners)

Table I.
Variables measuring value proposition

academic institutions (inductive category formation). There are three distribution channels: retailers, stores and web shops (Osterwalder and Pigneur, 2010). According to literature (Osterwalder and Pigneur, 2010) emails and web pages can be used for communication. In addition, we found the following communication channels: advertisements, blogs, press releases and social media (inductive category formation). Every company in our sample has a web page and provides an e-mail address; therefore, we had to exclude these two variables from the analysis due to missing variance. Again, we assigned the value of 1 to fulfilled conditions and 0 to those not applicable to the company's business model.

The value capture component comprises two subcomponents (revenue sources, payment methods) (e.g. Timmers, 1998; Osterwalder *et al.*, 2005) and ten variables in total (see Table III). There are various revenue sources, for instance, leasing, rental and sales (Osterwalder and Pigneur, 2010). In addition, we found reselling of consumables (Inductive category formation). The payment methods address which options companies offer and how customers prefer to pay (Osterwalder and Pigneur, 2010). We found bank transfer, Bitcoin, cash, cash on delivery (COD)/invoicing, credit card and PayPal (inductive category formation). Again, we assigned the value of 1 to fulfilled conditions, and 0 to those that did not apply.

Subcomponent (source)	Variable	Source	Description
Partner integration (Osterwalder *et al.*, 2005)	Academic partners	Inductive formation	The company cooperates with academic institutions
	Company partners	(Osterwalder and Pigneur, 2010)	The company cooperates with other companies (e.g. manufacturers of consumables)
	Customer partners	(Osterwalder and Pigneur, 2010)	The company integrates customers into its value creation (e.g. through a forum)
Distribution channels (Osterwalder *et al.*, 2005)	Retailer	(Osterwalder and Pigneur, 2010)	The company uses retailers to market its printers
	Store	(Osterwalder and Pigneur, 2010)	The company sells printers in its own physical store
	Web shop	(Osterwalder and Pigneur, 2010)	The company sells printers via its own web shop
Communication channels (Osterwalder *et al.*, 2005)	Advertisements	Inductive formation	The company uses online advertisements
	Blog	Inductive formation	The company uses a blog
	E-mail	(Osterwalder and Pigneur, 2010)	The company provides an e-mail address.
	Press releases	Inductive formation	The company offers provides press releases
	Social media	Inductive formation	The company uses social media channels (e.g. Facebook)
	Web page	(Osterwalder and Pigneur, 2010)	The company has a web page

Table II.
Variables measuring value creation

Subcomponent (source)	Variable	Source	Description
Revenue sources (Osterwalder *et al.*, 2005)	Leasing	(Osterwalder and Pigneur, 2010)	The company offers to lease printers
	Rental	(Osterwalder and Pigneur, 2010)	The company offers to rent printers
	Reselling consumables	Inductive formation	The company offers third-party consumables
	Sale	(Osterwalder and Pigneur, 2010)	The company sells its printers
Payment methods (Osterwalder *et al.*, 2005)	Bank transfer	Inductive formation	The company accepts bank transfer
	Bitcoin	Inductive formation	The company accepts bitcoin payments
	Cash	Inductive formation	The company accepts cash
	COD/Invoicing	Inductive formation	The company accepts COD/invoicing
	Credit card	Inductive formation	The company accepts credit cards
	PayPal	Inductive formation	The company accepts PayPal payments

Table III.
Variables measuring value capture

3.4 Descriptives

Our sample consists of 23 (47.9 percent) European companies and 25 (52.1 percent) from North America (see Table IV). They are on average 5.8 years old (SD = 7.24), with the youngest companies one year and the oldest company 33 years old. There are no significant differences ($t = 1.574$; df = 31.51; $p = 0.125$) in the firm age between the European companies (mean = 4.13; median = 3.0; SD = 3.58) and those from North America (mean = 7.28;

No.	Country	Foundation year	Application	Technology	Business model pattern
1.	USA	2013	RP	Embedded Electronics from Layered Assembly	Technology expert
2.	NLD	2014	RP/HF	Extrusion	Low-cost online
3.	BEL	2014	HF	Extrusion	Low-cost online
4.	CAN	2014	HF	Extrusion	Low-cost online
5.	BEL	2014	RP	Extrusion	Technology expert
6.	CAN	2014	HF	Extrusion	Low-cost online
7.	CAN	2014	HF	Extrusion	Low-cost online
8.	GBR	2013	HF	Extrusion	Low-cost online
9.	BEL	2013	HF	Extrusion	Low-cost online
10.	CAN	2013	HF	Extrusion	Low-cost online
11.	USA	2013	RP	Extrusion	Technology expert
12.	USA	2013	HF	Extrusion	Low-cost online
13.	AUT	2013	RP	Extrusion	Technology expert
14.	SWE	2013	RP	Extrusion	Low-cost online
15.	USA	2012	HF	Extrusion	Low-cost online
16.	USA	2012	HF	Extrusion	Low-cost online
17.	USA	2012	RP / HF	Extrusion	Low-cost online
18.	FIN	2012	HF	Extrusion	Low-cost online
19.	GER	2012	RP	Extrusion	Low-cost online
20.	BEL	2012	HF	Extrusion	Low-cost online
21.	GER	2012	RP	Extrusion	Low-cost online
22.	USA	2012	HF	Extrusion	Low-cost online
23.	CAN	2012	HF	Extrusion	Low-cost online
24.	CAN	2012	HF	Extrusion	Low-cost online
25.	BEL	2012	HF	Extrusion	Low-cost online
26.	GBR	2012	HF	Extrusion	Low-cost online
27.	USA	2011	HF	Extrusion	Low-cost online
28.	BEL	2011	HF	Extrusion	Low-cost online
29.	BEL	2011	HF	Extrusion	Low-cost online
30.	GER	2011	HF	Extrusion	Technology expert
31.	CAN	2011	HF	Extrusion	Low-cost online
32.	CAN	2011	HF	Extrusion	Low-cost online
33.	USA	2011	RP	Stereolithography	Technology expert
34.	AUT	2011	RP	Lithography-based ceramic manufacturing	Technology expert
35.	GER	2010	HF	Extrusion	Low-cost online
36.	USA	2009	HF/RP	Extrusion	Low-cost online
37.	USA	2009	HF	Extrusion	Low-cost online
38.	CAN	2009	HF	Extrusion	Low-cost online
39.	BEL	2009	HF/RP	Extrusion	Low-cost online
40.	BEL	2009	RP	Extrusion	Low-cost online
41.	DK	2009	RP	Sintering	Low-cost online
42.	GER	2006	RP	Sintering	Technology expert
43.	USA	2005	RP	Sintering	Technology expert
44.	SWE	1997	RP	Electronic beam melting	Technology expert
45.	USA	1994	RP	Smooth curvature printing	Technology expert
46.	USA	1989	RP/HF	Extrusion	Technology expert
47.	USA	1986	RP/HF	Stereolithography	Low-cost online
48.	USA	1982	RP	Stereolithography	Low-cost online

Notes: Application – RP, Rapid prototyping; HF, Home fabrication

Table IV. Sample descriptives

median = 3.0; SD = 9.28). The majority (51.4 percent) has less than ten employees. Three companies (8.1 percent) have more than 500 employees. We also found no significant differences in the employee size classes between the companies in Europe and those in North America (Mann–Whitney $U = 206.0$; $p = 0.254$).

3.5 Results

The TwoStep Cluster algorithm selects based on the BIC a two-cluster solution (BIC 1 Cluster: 1796.5; BIC 2 Cluster: 1792.7; BIC 3 Cluster: 1841.9). Thus, a two-cluster solution best describes the data. There are significant differences regarding certain business model specifications between the two identified business model clusters (see Table V).

Table V. Cluster solution

Variable	Total ($n=48$)	Total (mean) ($n=48$)	Technology expert (mean) ($n=12$)	Low-cost online (mean) ($n=36$)	Diff	Fisher's Exact test
Value proposition						
Quality	42	0.88	0.92	0.86	0.06	0.254
Convenience	30	0.62	0.42	0.69	0.27	2.963
Reliability	24	0.5	0.33	0.56	0.23	1.778
Expertise	22	0.46	0.83	0.33	0.5	9.063*
Variety	20	0.42	0.33	0.44	0.11	0.457
Low cost	19	0.4	0	0.53	0.53	10.483**
Flexibility	18	0.37	0.67	0.28	0.39	5.807*
Speed	18	0.38	0.17	0.44	0.27	2.963
Training	17	0.35	0.58	0.28	0.3	3.674
Environmental friendliness	15	0.31	0.42	0.28	0.14	0.808
Security	14	0.29	0.42	0.25	0.17	1.210
Software	12	0.25	0.42	0.19	0.23	2.370
Customer service	10	0.21	0.17	0.22	0.05	0.168
Innovation leadership	8	0.17	0.42	0.08	0.34	7.200*
Customer productivity	3	0.06	0	0.08	0.08	9.063
Value creation						
Partner integration						
Company partners	34	0.71	0.58	0.75	0.17	1.210
Customer partners	9	0.19	0.08	0.22	0.14	1.140
Academic partners	6	0.12	0.33	0.06	0.27	6.349*
Distribution channels						
Web shop	37	0.77	0.25	0.94	0.69	24.570**
Retailer	23	0.48	0.33	0.53	0.2	1.363
Store	11	0.23	0.25	0.22	0.03	0.039
Communication channels						
Social media	42	0.87	0.75	0.92	0.17	2.286
Blog	19	0.4	0	0.53	0.53	10.483**
Press releases	10	0.21	0.25	0.19	0.06	0.168
Advertisements	2	0.04	0	0.06	0.06	0.696
Value capture						
Revenue sources						
Sale	47	0.98	0.92	1	0.08	3.064
Reselling consumables	8	0.17	0.08	0.19	0.11	0.800
Leasing	2	0.04	0	0.06	0.06	0.696
Rental	1	0.02	0	0.03	0.03	0.340
Payment methods						
PayPal	29	0.6	0.08	0.78	0.7	18.149**
Credit card	27	0.56	0.08	0.72	0.64	14.928**
Bank transfer	18	0.38	0.25	0.42	0.17	1.067
COD/invoicing	6	0.13	0.17	0.11	0.06	0.254
Cash	4	0.08	0	0.11	0.11	1.455
Bitcoin	1	0.02	0	0.03	0.03	0.340

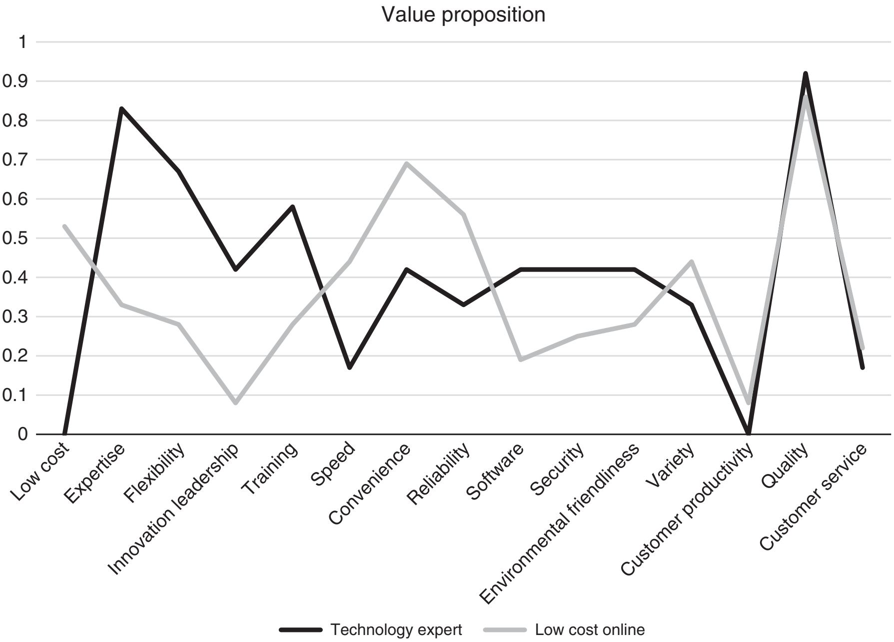
Notes: Level of significance: $*p < 0.05$; $**p < 0.01$

We drew profile plots of the variables in the cluster model, to illustrate cluster differences and similarities (see Figures 1–3).

3.6 Cluster descriptions

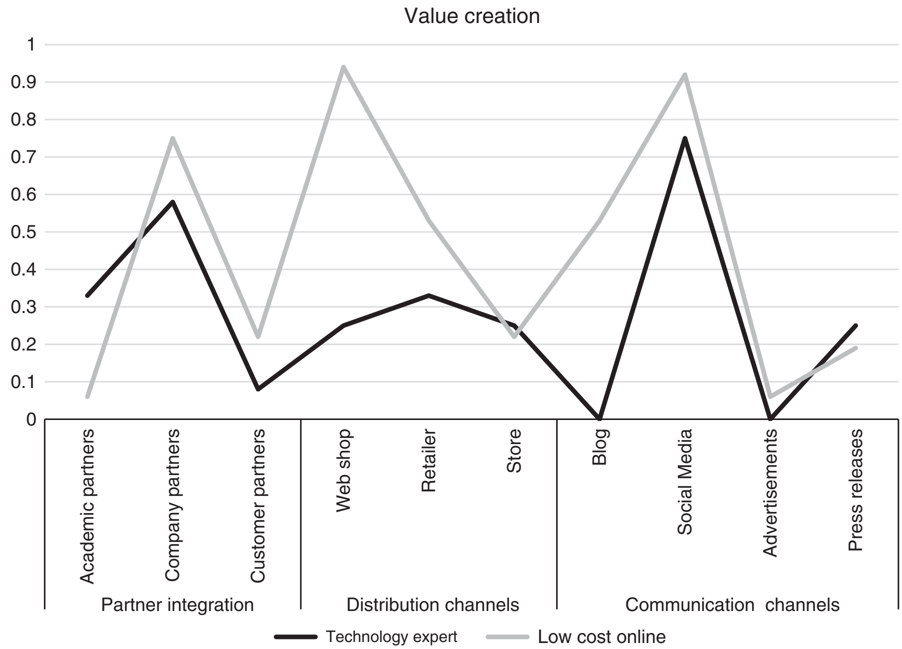
The companies in the larger cluster (75 percent) apply the "low-cost online model." These companies aim to provide value for customer through quality printers at low cost. In addition, they emphasize convenience by offering easy-to-use printers. Further, they propose fast and durable printers. On the other hand, they put little effort on innovation leadership. In line with this, they seldom offer specific software to operate the printers. Security, flexibility, environmental friendliness, training and expertise are less characteristic (see Figure 1). Regarding the value creation component, these companies prefer to do business online via web shops. In addition, they also sell their printers via retailers. They often use social media and their own blogs for communication. Advertisements and press releases are less frequent. They primarily cooperate with other companies. Some companies integrate customers into their value creation processes. They seldom cooperate with academic institutions (see Figure 2). Regarding the value capture component, the low-cost online business model relies on selling printers. Further, some companies are reselling consumables. Two companies offer leasing options. Another company rents out its printers. Due to their online business model, these companies also focus on digital and online payments, for instance, PayPal, credit cards and bank transfers. Cash payments and COD/invoicing are less frequent. One company also accepts bitcoin payments (see Figure 3).

The smaller cluster (25 percent) applies a business model termed the "technology expert model." Technology experts emphasize to provide value via expertise, innovation leadership and quality. Further, they focus on flexible printers for which they offer specific trainings. In addition, they often provide specific software. They mind security and environmental friendliness.



Note: All values represent means of binary variables (percentage) within clusters

Figure 1.
Plotted means of value proposition variables



Note: All values represent means of binary variables (percentage) within clusters

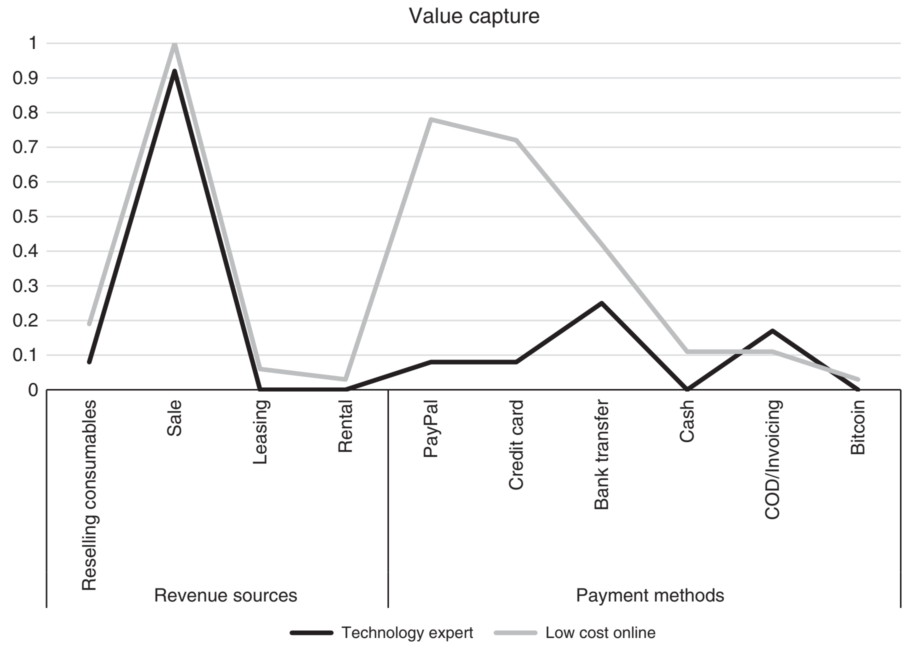
Figure 2. Plotted means of value creation variables

Conversely, there is no focus on low-cost offerings and customer productivity. These companies put less emphasize on customer service, speed, convenience, reliability and variety (see Figure 1). Regarding, the value creation component, companies show higher probabilities to integrate academic institutions into their value creation. Further, they cooperate with other companies but seldom with customers. Their primary distribution channels are retailers. Some companies operate physical stores. They are less likely to do business online and seldom run a web shop. Social media is the most common communication channel followed by press releases. Advertisements and blogs were not found in this cluster (see Figure 2). Regarding the value capture component, selling printers are used most frequently. In addition, some companies are reselling consumables. They do not offer leasing and rental options. Bank transfer is the most widespread payment option followed by COD/invoicing. PayPal and credit card payments are less frequent. None of the companies offers cash or bitcoin payments (see Figure 3).

We found no significant differences between the low-cost online and the technology expert business model concerning country of origin ($\chi^2 = 0.028$, df $= 1$, $p = 0.868$). There are also no significant differences between the two clusters regarding employee size classes (Mann–Whitney $U = 102.0$, $p = 0.181$) and company age ($t = 1.768$, df $= 45$, $p = 0.084$). In total, 91.6 percent of companies in the low-cost online cluster manufacture extrusion-based 3D printers, while in the technology expert cluster 41.6 percent offer products based on this technology ($\chi^2 = 13.642$, df $= 1$, $p < 0.001$). The technology expert cluster predominantly (75 percent) offers 3D printers that utilize other processes like stereolithography or sintering compared to 8.3 percent of companies in the other cluster ($\chi^2 = 21.333$, df $= 1$, $p < 0.001$).

4. Discussion

Based on the business model specifications we are able to describe the business models of 3D printer manufacturers. The most commonly used specifications regarding value



Note: All values represent means of binary variables (percentage) within clusters

Figure 3. Plotted means of value capture variables

proposition are quality ($n = 42$), convenience ($n = 30$) and reliability ($n = 24$) (see Table V). The least frequent specifications are customer service ($n = 10$), innovation leadership ($n = 8$) and customer productivity ($n = 3$). Regarding the value creation component, the integration of company partners in the value chain is most frequent ($n = 34$). The preferred distribution channel is the web shop ($n = 37$) and social media is the most frequent communication channel ($n = 42$). Selling printers is the most frequent source of revenue ($n = 47$). Interestingly, PayPal ($n = 29$) is the most frequent payment method followed by credit card ($n = 27$). It is interesting to see that, 3D printer manufacturers commercialize their novel products through business models that are rather traditional. Previous research has shown that companies are able to develop novel products based on new technology. However, they frequently fail to develop new business models to market their products (Cavalcante, 2013).

Further, our results indicate that there are two distinct business model patterns to commercialize printers that serve rapid prototyping and/or home fabrication applications. The majority of companies in our sample applies the low-cost online pattern. Their primarily extrusion-based printers do not differ significantly in terms of specifications (e.g. build volume). Thus, they create value for customers through focusing on convenience and reliability. They aim to provide simple plug-and-play solutions that need little setup time and maintenance. Previous research concluded that user friendliness is still low which can lead to bad experiences. Especially for new technology, this hinders or even prevents adoption (Steenhuis and Pretorius, 2016). However, convenient and user-friendly printers provide pleasant experiences and potentially stimulate further purchases. In the manufacturing industry, these printers are primarily used for rapid prototyping purposes. Consumers apply them for home fabrication applications. Lately, this market is growing even more rapidly than industrial systems (Wohlers and Caffrey, 2014). Due to an already relatively large and further growing number of companies in this market, price competition between companies is fierce. Thus, the low-cost online pattern requires cutting costs to remain competitive. Companies applying this pattern aim to cut costs through a strong emphasize on digital aspects in their business models. Thus, this business model may function also as role model for digitalization within and across industry borders. The majority of companies are “born digital.” They were founded after important patents expired. The advent of the RepRap project catalyzed the emergence of affordable printers. These printers targeted primarily tinkerers and hobbyists online. Later, companies such as Makerbot started to address home fabrication on a larger scale. Today, these companies are also supporting their customers’ digitalization efforts with their inexpensive 3D printers. These printers are often the first customers acquire. They offer the possibility to get familiar with the novel technology at reasonable prices. For instance, trial-and-error learning enables customers to understand and master the digital value chain from designing to manufacturing. Thus, they foster not only the diffusion and adoption of 3D printing but also the shift toward digitalization.

The technology expert pattern aims to provide value through innovation leadership. These companies frequently market novel features that are new to the industry (e.g. automatic bed levelling). Often companies delineate their expertise through the number of filed patents and awards they have won. Due to their expertise, there printers are able to handle, for instance, various input materials. In order to secure optimal printing results, they provide specific trainings for customers. In these trainings, customers learn about the various possibilities and settings. Some manufacturers provide specific software for their printers. The correct usage of this software is also part of the training programs. In order to provide state-of-the-art technology, these companies often cooperate with academic institutions. However, this approach is also a major cost driver and affects the price structure. Focusing on lower prices is thus not the preferred option. This business model follows rather conventional value creation logics. Selling the printers is the most frequent revenue source. Interestingly, none of the companies in this cluster seeks to circumvent charging high prices by leasing printers to their customers. This approach would enable them to address customers’ expectations regarding high quality and lower prices simultaneously. Learnings from other industries, for instance, the automotive industry where companies achieved cutting costs without necessarily lowering quality (Williamson, 2010), for instance through value innovation (Kim and Mauborgne, 2005), could be a viable option also for 3D printer manufacturers.

Besides the differences between the two business model patterns, there are also some similarities (see Table V). Regarding the value proposition, both patterns focus strongly on quality. The correct assessment of potential and performance of a novel technology can be a difficult task. The companies might aim to diminish customers’ risk to spend money on a printer that cannot meet their performance expectations through a strong emphasize on quality. A rather surprising finding is that customer service is not a major aspect in either of the two business model patterns. This finding is even more surprising for the technology expert pattern. Previous research (e.g. Mellor *et al.*, 2014) has shown that customer service is important for technology adoption. Companies applying low-cost online pattern focus strongly on printers that are reliable and easy to use. That might affect their customer service. Maybe companies assume that convenience and reliability at least partly substitute customer service. For low-cost online companies it might also be a strategic decision to cut costly customer service activities. It is possible, that technology experts assume that they can at least partly substitute customer service through their specific training. Another possible explanation could be that manufacturers assume that customers interested in buying a 3D printer have the required technical expertise that enables them to solve at least minor issues themselves. Further, there are strong online 3D printing communities (e.g. RepRap Wiki) and a growing number of local Fab labs and maker spaces where likeminded people provide hints and advice. Lately, a growing number of companies (e.g. Makerbot, Ultimaker) have taken advantage of expert users by hosting their own 3D printing communities. The companies might assume that these communities can at least partially replace the tasks of internal customer service departments. However, this lack of customer service might be a major factor that technology adoption is still below expectations.

Concerning the value capture component, companies in both clusters rely primarily on rather conservative revenue sources. Almost all companies are only selling their printers. Currently, only three companies utilize other revenue sources such as leasing (two companies) or renting (one company). This finding opens up possibilities for business model innovation. Leasing and renting are common revenue sources in other industries (e.g. car and truck industry) and highly appreciated by customers, because they enhance their flexibility. Offering leasing and renting options might attract more customers and again foster technology adoption. Further, companies could transfer and adapt successful business model patterns from other industries. For instance, the famous razor-and-the-blade model originally created by Gillette has been transferred to various other industries (e.g. Nespresso coffee machines; inkjet printers and cartridges). This model might also be applicable to 3D printing. This could be a viable option especially for manufacturers producing also consumables. In addition, companies could contemplate about adopting successful business models from the service industries. Software-as-a-service, for instance, might function as inspiration for "printer-as-a-service" or other novel options.

5. Implications, limitations and future research

There is a growing literature stream on business models in the context of new technology (e.g. Kodama, 2004; Tongur and Engwall, 2014). However, the overall number of empirical studies within this research domain is still limited. Our empirical findings contribute to the discussion on business models in the context of novel technology, complementing existing research within this stream (e.g. Doganova and Eyquem-Renault, 2009; Simmons *et al.*, 2013; Bohnsack *et al.*, 2014; Tongur and Engwall, 2014). Prior research aimed to address the nexus between business model and technology and assumed that the two closely related. However, there is a lack of empirical investigations. The present study aims to contribute to a better understanding of this relationship by providing empirical results. In line with previous research (e.g. Christensen, 2006; Cavalcante, 2013), our empirical results show that there is indeed a link between business models and technology. Companies commercialize extrusion-based printers primarily using the low-cost online pattern. On the other hand, manufacturers of, for instance, sinter or stereolithography printers more frequently apply the technology export pattern. Thus, the technology seems to affect also the gestalt of the business models used for technology commercialization. We extract the gestalt of the business models within 3D printing and thus contribute to further clarification of the nexus between technology and business model.

3D printing is a prominent topic in many research domains. However, research on business and economic aspects of the technology is still limited (Weller *et al.*, 2015; Rayna and Striukova, 2016; Öberg *et al.*, 2018). We complement and extend previous studies on business models in 3D printing (Bogers *et al.*, 2016; Holzmann *et al.*, 2017, Öberg *et al.*, 2018). Prior research has primarily addressed the potential business model innovations that 3D printing technology can trigger in different contexts (e.g. consumer goods manufacturing or user entrepreneurship). This research takes a step back and presents the business models that 3D printer manufacturers apply to market the technology. Thus, this research extends the perspective on business models within the 3D printing context. The successful commercialization of the technology is an essential precondition in the development of further 3D printing applications and technology-related services. Thus, the business model is of paramount importance. To the best of our knowledge, this study is the first to investigate the business models of 3D printer manufacturers empirically.

Further, our work contributes to the extensive literature on business models in general. Business models have evolved as a topical unit of analysis, however capturing and evaluating business models requires further clarification (Morris *et al.*, 2013). Despite the growing number of business model research, empirical studies are still scarce. There is a lack of quantitative and mixed-methods studies on business models (Wirtz *et al.*, 2016). Empirical research relies primarily on qualitative methodologies examining either single or few case studies. Thus, results only provide limited ability for generalization (Zott and Amit, 2007). The present study enlarges the number of empirical studies by applying a rigorous mixed-methods approach to investigate the business models. We provide an original approach to measure and analyze business models. The applied approach permitted the discovery of business model patterns using a componential approach. Thus, contributing to the call for more holistic views on business model components (e.g. Öberg *et al.*, 2018). The applied design including the developed framework and the identified business model specifications could be a starting point for further business model research and further mixed-methods studies.

Our findings are important for managerial practice. The identified business model patterns can function as blueprints for new entrants and existing companies. However, sticking to these blue prints provides advantages as well as disadvantages. On the positive side, companies can potentially reduce their risk of failure by using these patterns as blueprints. Replication of already proven business model patterns can significantly shorten the development process and reduce the number of trial-and-error iterations. Thus, relying on proven patterns can be an efficient and effective strategy. On the downside, an exact imitation of business model patterns prevents the creation of novel and unique business models. Thus, when applying business model patterns companies face an inherent trade-off between risk reduction and innovativeness. To circumvent this trade-off, companies might use these patterns as starting points for business model innovation. For instance, companies could modify or extend existing patterns by focusing on previously uncovered customer needs or revenue sources. This might be a viable strategy to differentiate from competition. Another potential option could be the acquisition of companies that apply a different business model. Stratasys, the inventor of FDM, for instance, acquired the rapidly growing consumer-grade printer manufacturer Makerbot.

We are fully aware that our study has limitations. The results of this study are based on a European and North American sample. Thus, they might not be applicable to other regions. Future research could target additional regions and draw comparisons to our study. Further, studies on the business model design of 3D printing service providers would complement to our study and would foster the development of a holistic picture of the 3D printing industry. Another constraint is tied to our data. Our analysis is based on secondary data, thus, limiting the number of variables in the analysis. For instance, we could not assess financial aspects and cost structures. Further, due to the usage of secondary data we had to rely on dichotomous dummy variables. Thus, limiting the richness of the data.

Future research endeavors could further investigate the decision making on why and when companies decide to apply proven business model patterns instead of developing novel business models. In addition, future research should also examine whether the identified business model patterns remain stable over time. In the case of changes in the patterns, scholars should investigate the reasons for the change as well as the gestalt of the change.

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