

3D Printing Systems: An innovation for small-scale manufacturing in home settings?

- Early adopters of 3D printing systems in China

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Abstract

This study investigates Chinese consumers' adoption of the innovative 3D printing systems for small-scale manufacturing in home settings. Empirical studies were conducted in a survey with 256 participants. The number of significant determinants that affect an individual's decision to adopt 3D printing systems has been identified by applying a model that integrates the Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT). A number of moderation effects of demographic variables (e.g. gender, design background) on the association between motivational variables and participants' adoption have also been analysed with factor analysis, structural equation modelling and hierarchical regression. Our results shed some light on the characteristics of early adopters of home 3D printing systems in China. This study contributes to the early understanding of Chinese consumers' adoption of innovative 3D printing systems.

Keywords: 3D printing systems, Moderation effect, Hierarchical regression, Structural equation modelling

1. Introduction

Since the Industrial Revolution, conventional manufacturing techniques such as cutting and forming have been much refined resulting in sophisticated numerical lathes and milling machines for cutting, and injection moulding and die-casting machines for forming. The costly and extremely complicated machine tools make it very challenging for users to operate the same. 3D printing technology provides an innovative alternative to the traditional manufacturing procedure, where a 3D physical model of any shape can be generated directly from a computer aided design model (Noorani 2005). It creates objects from the bottom-up by adding material to each cross-sectional layer. It allows individual users to print complicated engineering parts automatically from design files, and this technology has simplified communication between different actors involved in the development of a product (Lipson and Kurman 2013).

The growth of 3D printing systems in the personal consumption market is gaining speed in China. There are currently approximately 17,000 home 3D-printers in operation in China being used to make prototypes and quirky objects, closely following the U.S, in leading the 3D printing revolution (Davidson and Trentmann 2013). Indeed, China is an important market for 3D printing systems not only because it has one of the largest consumer bases but also because China is still the manufacturing centre of the world (Nahm and Steinfeld 2014). As China is transforming from a low cost production economy to a middle-to-higher income economy, it will gradually lose its low cost advantage in manufacturing to neighbouring countries such as India and Vietnam. To sustain its economic growth, China needs to transform itself from a low-skilled production economy to one with more value added

production emphasizing its creative and technological industries. Home 3D printing systems enable a user-led open design approach to bring innovative products and services to the public. Public acceptance serves to further incentivize the users to continuously innovate for both private and social reasons. This virtuous cycle both reduces research and development wastage and promotes social and economic benefits. Despite the growing popularity and importance of 3D printing technology in the Chinese market, there is a gap in our understanding of how Chinese consumers understand this innovative technology. There are very few studies which have been conducted from a Chinese consumers' perspective to investigate their perceptions and acceptance of 3D printing technology.

While there seems to be an implicit assumption that 3D printing systems provide a means to manufacture customized products which have the precise features an individual user requires, there is also some debate over whether a 3D printing system can be used successfully by individual consumers for small scale production in a home setting. Berman (2012) points out that there are huge potential market opportunities for home 3D printing system providers who can meet the needs of the evolving consumers. Some authors have argued that price (Ratto and Ree 2012), performance (Forrest 2014) and software associated with 3D printing systems (Ariadi et al., 2012; Campbell et al. 2011) are not developing fast enough to make 3D printing systems appealing to consumers for use in a home setting. To develop successful new products and systems, new product development managers should have a good understanding of their consumers' adoption process (Mugge and Dahl 2013). Although 3D printing systems enable users to do things they were not able to do with traditional manufacturing systems, research has shown that consumers are initially reluctant to adopt innovative products 'that provide novel benefits but involve high learning costs' (e.g. Zhao et al. 2009). Consumers may have difficulties in understanding the benefits of novel

products, therefore, intentions to adopt such innovative products may remain low (Feiereisen et al. 2013).

Very few studies have investigated the adoption of 3D printing systems and even fewer studies have empirically tested how much individuals' characteristics, and their perceptions towards home 3D printing systems, can explain people's adoption of such systems in China. This study combines IDT with the TAM to explore the factors affecting users' intentions to use home 3D printing systems and to investigate the moderation effects of individual characteristics (e.g. demographic variables) on their intention to use the system. This study contributes to the design of home 3D printing systems for Chinese consumers, the development of product management strategies in the Chinese market for 3D printing manufacturers, and the opportunity of using consumer-led design approaches to unleash the potential social and economic transformational impact that 3D printing systems may have on creativity and social innovation.

2. Literature review

IDT (Rogers 1995) and the TAM (Davis 1989) are two leading theories with which to study users' adoption of technology. IDT has been used extensively for information technology and system research (Hong et al. 2008; Suh 2004). Rogers (1995) defined diffusion as 'the process by which an innovation is communicated through certain channels over time among the members of a social system', and defined innovation as 'ideas, customs or objects that are perceived as new by individuals who use them'. IDT focuses on product characteristics to explain the adoption of an innovation. It studies the factors of relative advantage, compatibility, complexity, divisibility, and observability to determine their effects on the adoption of innovative products.

The TAM was introduced by Davis (1989) to provide an explanation of the determinants of technology acceptance. The model suggests that perceived ease of use and perceived

usefulness are the primary determinants to explain the variance in users' intentions to use new technology. The model hypothesizes users' intention to use is also influenced by users' attitudes toward using, while users' attitude is directly affected by the perceived ease of use and perceived usefulness of new technology.

Both TAM and IDT have been applied broadly in studies of computing, the Internet, E-commerce, online games, Internet shopping and mobile commerce (Yeh and Li 2009; Chong 2013). Studies using IDT have focused on product characteristics, such as relative advantage, compatibility, complexity, divisibility, and observability, to determine their effects on the adoption of innovative products (Rogers 1995; Hong et al. 2008; Suh 2004). Other studies in the TAM have investigated technology acceptance from a consumer-centric perspective by incorporating perceived usefulness and perceived ease of use (Davis 1989; Oh 2010). There have also been some attempts made to integrate IDT into the TAM to investigate users' technology acceptance (Chang and Tung 2008). Chen et al. (2002) integrated the TAM and IDT to explain consumer behaviour in virtual store settings. Suh (2004) used a combined model of TAM and IDT to examine the adoption of supply chain management system by enterprises. These studies suggest there is a complementary relationship between the IDT and TAM because these two models share conceptual bases that make them ideal for complementary uses (Chen et al. 2002). The complexity construct in IDT can be replaced by the perceived ease of use in the TAM, while the relative advantage from the IDT is often considered to play the same role as perceived usefulness in the TAM (Liebermann and Stashevsky 2002).

By applying the TAM and IDT, this research takes an extended new perspective from which to examine Chinese consumer adoption of home 3D printing systems. The study also investigates the moderating effects of demographic variables on Chinese consumers' system adoption to identify the characteristics of earlier adopters. A number of studies (Teo 2001;

Cutler 2003; Wei et al. 2009) have found that technology users tend to possess certain demographic characteristics that can moderate the adoption of technology. For example, Chong (2013) identified the moderating effects of demographic profiles in the perceived usefulness and perceived ease of use of m-commerce.

3. Research model and hypotheses

Primarily based on two well-established TAM and DIT theories, our research provides both theoretical and empirical analysis to explain the direct factors and moderating effects that determine consumers' adoption of 3D printing systems.

3.1 Constructs from the TAM

3.1.1 Perceived Ease of Use

Perceived Ease of Use (PEOU) is defined as the degree to which people consider the use of a new system requires little effort (Davis 1989; Jeyaraj et al. 2006). Gould and Lewis (1985) recommended all designers should strive for usability and suggested that any systems designed for people should be easy to use, easy to learn and helpful to users. From the users' point of view, it is reasonable to expect that systems which are user friendly and easy to use are more likely to be adopted and used. Thus, we propose the following hypothesis:

H1: PEOU is positively related to users' intention to use home 3D printing systems.

3.1.2 Perceived Usefulness

Perceived Usefulness (PU) is defined as the extent to which one person considers whether or not a new technology could increase their productivity and work-related performance (Kim et al. 1985). Jeyaraj et al. (2006) suggested that perceived usefulness has a far-reaching effect on adoption of new technology. Previous research has shown that perceived usefulness will have a significantly positive impact on behavioural intention (Jeyaraj et al. 2006; Venkatesh and Morris 2000). This leads to the following hypothesis:

H2: PU is positively related to users' intention to use home 3D printing systems.

3.2 Constructs from IDT

Tomatzky and Klein (1982) found the product characteristics of relative advantage, compatibility and complexity have strong influences on individuals' adoption of new products and technologies, whereas divisibility and communicability showed inconsistent findings on their effects on the adoptions of new technologies. For this reason, divisibility and observability were excluded in this study. We replaced the construct of complexity by perceived ease of use and the relative advantage construct by perceived usefulness, based on previous studies (e.g. Moore and Benbasat 1991).

Perceived Compatibility refers to the extent to which an innovation is perceived to be consistent with the adopters' beliefs, lifestyle, existing values, experience, and current needs (Moore and Benbasat 1991). Perceived Compatibility is found to be significantly related to users' intention to use e-learning (Liao and Lu 2007), a specific groupware application (Lotus Domino) discussion database (Van Slyke et al. 2002), Web-based shopping (Van Slyke et al. 2004), innovation adoption (Tornatzky and Klein 1982), and Internet Banking Services (Tat et al. 2008). We propose the following hypothesis:

H3: Perceived Compatibility is positively related to users' intention to use home 3D printing systems.

3.3 Extended construct – perceived enjoyment

3D printing systems inherently possess both practical and hedonic characteristics that are critical for innovation adoption. The importance of perceived enjoyment has long been established in studies of workplace computing (Webster and Martocchio 1992) and computer games (Holbrook et al. 1984). 3D printing systems have quickly become an affordable option and they can now be purchased at a very reasonable price for end users. The potential advantage of using a 3D printing system the capability to produce physical objects at a much lower cost and more rapidly than traditional manufacturing methods. This advantage may be

likely to bring enjoyment to users, for example in terms of realizing their creativity in design. Hobbyists and professional users are now able to design, download, and print out a broad range of three dimensional physical objects. College undergraduates and high school students, and even younger children are beginning to use the technology in the realm of education (Eisenberg 2013). Perceived enjoyment has been found to have positive and significant effects on people's intention to use technologies, including word processing systems, mobile games, website usage, Internet related activities such as messaging, television commerce, e-commerce and m-commerce, and blog usage (Chong 2013; Davis et al. 1992; Hsu and Lin 2008; Teo 2001). In this study, Perceived Enjoyment (PE) is defined as the extent to which the process of using a 3D printing system to realize design ideas into real products is perceived to be fun or enjoyable. Hence, we posit:

H4: PE is positively related to users' intention to use home 3D printing systems.

3.4 Moderators

3.4.1 Age

Age has been identified to have a moderating effect between technology use and perceptions (Yi et al. 2005). As age increases it becomes more difficult to process complex information and to allocate attention to information (Li et al. 2001). In studies of the adoption of the Internet, researchers have claimed that consumers tend to be young people because they perceive lower risks when compared to older people (Libermann and Stashevsky 2002). Age has been found to have a negative relationship with skill level (Elder et al. 1987) and with computer usage (Zeffane and Cheek 1993). Older workers were reported to be more likely to experience technology stress than younger workers (Harrison and Rainer 1992). Age has also been found to have moderation effects on effort expectancy related constructs (e.g., ease of use) on users' intentions to make use of mobile applications in their learning (Wang et al. 2009). New technology that is perceived to be easy to use will become more critical in

technology adoption for aged people (Kubeck et al. 1996). These points lead to the following hypothesis:

H5a: The relationship between PEOU and intention to use home 3D printing systems is moderated by age, such that the relationship is stronger for older people.

Previous research suggests that younger workers are more concerned about job-related achievement, task accomplishment and external rewards than older workers (Kuo and Chen 2004). Perceived usefulness is also closely related to outcomes such as task accomplishment and extrinsic reward (Venkatesh and Morris 2000). Hence, we also expect the moderation effect of age on the interaction between perceived usefulness and intention to use will be more salient to younger people than to older people. It follows that:

H5b. The relationship between PU and intention to use home 3D printing systems is moderated by age, such that the relationship is stronger for younger people.

Age has been found to have significant negative effects on perceived enjoyment in Internet usage when perceived ease of use is not included in the regression, however, “in the presence of perceived ease of use, the result is no longer significant” (Teo and Lim 1999). This may suggest that perceived ease of use dominates perceived enjoyment in the case of Internet usage for older users. We do not intend to study perceived enjoyment in the isolation of perceived ease of use, hence, based on the previous research, we posit:

H5c. The relationship between PE and intention to use home 3D printing systems is not moderated by age.

According to Xue et al. (2012) if the elderly regard technology as being compatible with their current usage habits, then they would perceive that using the technology would be beneficial and would have higher intentions to use the same. Since older people are more reluctant to adopt new technologies (Wang and Sun 2015), we hypothesise that:

H5d. The relationship between PC and intention to use home 3D printing systems is moderated by age, such that the relationship is stronger for older people.

3.4.2 Gender

It has been suggested that females are more fearful of using computers than males (Igbaria et al. 1995). In the studies on gender differences on Internet usage, (Jackson et al. 2001) observed that females retain higher levels of computer anxiety and lower levels of self-efficacy than males. Perceived ease of use is suggested to be more salient for individuals espousing feminine rather than masculine values (Srite and Karahanna 2006). Furthermore, perceived ease of use has been found to be more salient for females than for males on the adoption of information technology (e.g. Venkatesh and Morris 2000). This leads to the following hypothesis:

H6a: The relationship between PEOU and intention to use home 3D printing systems is moderated by gender, such that the relationship is stronger for females.

Venkatesh el al. (2003) confirmed the moderating role of gender in the influence of performance expectancy (usefulness) on the adoption of new technology. As perceived usefulness is closely related to one's performance, its values are highly regarded as masculine values (Venkatesh and Morris 2000; Venkatesh et al. 2004). Research on gender difference on using e-learning (Ong and Lai 2006) and on using new technology (Venkatesh and Morris 2000) found that levels of acceptance towards a new technology were more influenced for men by their assessment of usefulness than they were for women. Thus:

H6b: The relationship between PU and intention to use home 3D printing systems is moderated by gender, such that the relationship is stronger for males.

Perceived enjoyment has significantly influenced the intention to adopt the Internet for learning in higher education, for both males and females (Macharia and Nyakwende 2011). However, this is inconsistent with the findings of Hwang (2010), who reported that perceived

enjoyment exerts a stronger effect on intention to use e-commerce for males than for females.

This study will test the following hypothesis:

H6c. The relationship between perceived enjoyment and intention to use home 3D printing systems is moderated by gender, such that the relationship is stronger for males.

Egan and Perry's (2001) work on the multidimensional nature of gender identity provides some initial insights into the possible relationship between genders and compatibility. They link perceived compatibility with self-perceived competency with activities that were either stereotypical of males or females, however, it is not clear whether the moderation effect of gender on perceived compatibility is stronger for males or females. Therefore, we posit:

H6d. The relationship between perceived compatibility and intention to use home 3D printing systems is moderated by gender.

3.4.3 Educational level

Adoption of new technology is inter-related to the extent of knowledge one has acquired in order to use such technology (Rogers 1995). A higher educational level may give rise to a greater level of knowledge in new technologies, thereby accelerating the early adoption of a new technology. People educated to a higher level were found to be more likely to use the Internet (Rhee and Kim 2004) and to be early adopters of spreadsheet software (Brancheau and Wetherbe 1990). Individuals who are less well educated testify that insufficient knowledge about the Internet is one of the main reasons for not using the same (NTIA 2002). Educational level has also been found to have a significantly positive relationship with perceived ease of use in the study of acceptance of new information technology (Agarwal and Prasad 1999) and a moderating effect on the relationship between perceived ease of use and intention to use the Internet (Kripanont 2006). Therefore, we posit:

H7a: The relationship between PEOU and intention to use home 3D printing systems is moderated by educational level, such that the relationship is stronger for people with a higher level of education.

In a study of online music system acceptance, Suki (2011) found that the acceptance level for people with a higher educational level was more influenced by perceived usefulness and perceived ease of use than was the case for people with a lower level of education. Therefore, we propose the following hypothesis:

H7b: The relationship between PU and intention to use home 3D printing systems is moderated by educational level, such that the relationship is stronger for people with a higher level of education.

Perceived enjoyment has not been reported to have a direct relationship with education level. However it is evident that education level is positively related to usage of computers (Igbaria et al. 1995) and perceived enjoyment is one of the main reasons why consumers use the Internet in terms of activities such as messaging, browsing, downloading and purchasing (Teo 2001). Therefore, we hypothesise:

H7c: Educational level has a moderation effect on the relationship between PE and intention to use home 3D printing systems, such that the relationship is stronger for users with a higher level of education.

Study on the relationship between educational level and technology acceptance is limited (Chong 2013). Rhee and Kim (2004) found that those with a higher level of education will, in fact, be more likely to use the Internet. Liebermann and Stashevsky (2002) found that users with a lower educational level will perceive Internet use to be more risky than users with a higher educational level. Najmul (2006) suggests that perceived compatibility will have an impact on the relationship between learning and technology usage. Users with a higher level of education find e-learning systems fit their learning styles better than those users with a

lower education level and are more likely to adopt such systems. Therefore, it is hypothesized that education level moderates the relationship between perceived compatibility and intention to use home 3D printing systems, such that the effect is stronger for higher educated users. Therefore, we hypothesize:

H7d: Educational level has a moderation effect on the relationship between PC and intention to use home 3D printing systems, such that the relationship is stronger for higher educated users.

3.4.4 Design background

Ralph et al. (2009) defined a designer as a person who “specifies the structural properties of a design object.” In this study, we define designers as those who are currently actively involved in design-related activities and those considering design as either their profession or as a ‘serious’ hobby. Hoskins (2013) describes how the creative industries are now directly interfacing with 3D printing technology and how this influences the practices of designers. By using 3D printing technology, designers can create physical objects directly from a digital model, which provides flexibility in geometric shapes and presents an opportunity for designs to be realized in a way that was not previously possible with traditional manufacturing technologies (Hilton and Jacobs 2000). The usefulness of a 3D printing system to designers is becoming prominent as such systems have helped many designers in several fields, including fashion design, architecture design, the automobile industry, and medical equipment. A plausible reason for designers to use a home 3D printing system is both its usefulness in helping their design work, and its perceived ease of use compared with other systems (Ariadi et al. 2012). Compatibility is found to be significantly related to users’ intention to use innovative products (Tornatzky and Klein 1982), and while most of our participants with a design background had some experience with 3D modelling applications, we hypothesize that designers are more likely to possess compatible experience of working with systems similar

to a 3D printing system than would be the case for non-designers. Therefore, we postulate that designers are more likely to use 3D printing systems than non-designers, especially those who perceive such systems to be useful, easy and fun to use, and compatible with their working experience and needs from their work. This leads to the following hypotheses:

H8a: The relationship between PEOU and intention to use home 3D printing systems is moderated by a designer variable, such that the relationship is stronger for designers.

H8b: The relationship between PU and intention to use home 3D printing systems is moderated by a designer variable, such that the relationship is stronger for designers.

H8c: The relationship between PE and intention to use home 3D printing systems is moderated by a designer variable, such that the relationship is stronger for designers.

H8d: The relationship between PC and intention to use home 3D printing systems is moderated by a designer variable, such that the relationship is stronger for designers.

Drawing upon existing literature and prior empirical findings, the TAM and IDT were integrated to construct the research model for our research (see Fig. 1).

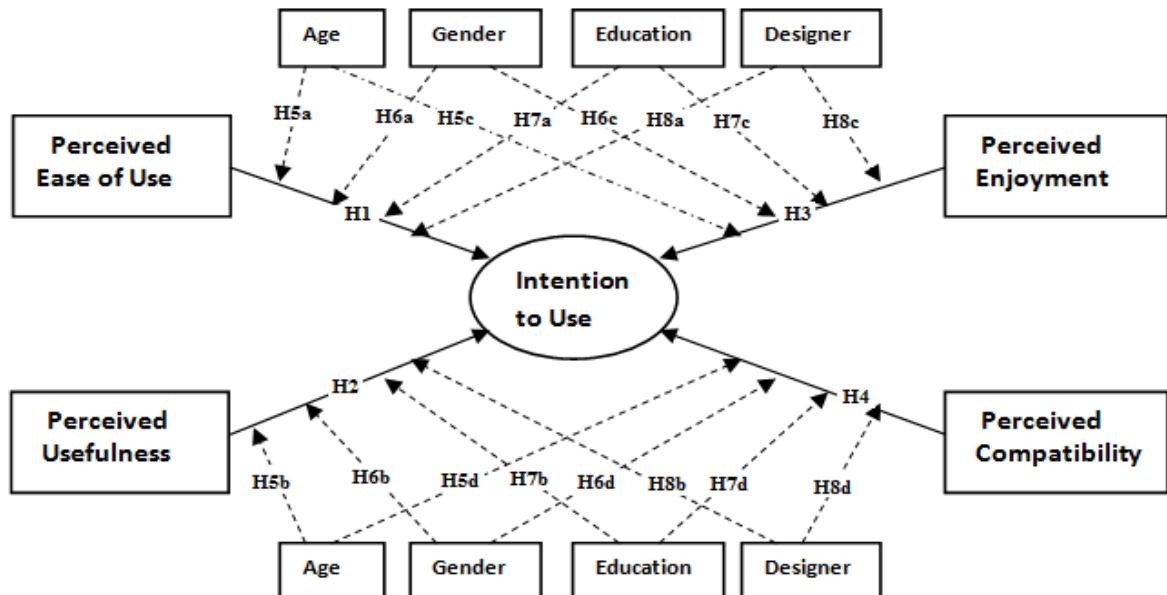


Fig. 1: Research Model based on the TAM and IDT

A Scenario - Using Home 3D printing to print a Vase (Translated from Chinese version)

Step 1: Produce a 3D model of the vase using computer-aided design (CAD) software;

Step 2: Convert the CAD model of the vase to the STL format (a file format developed for 3D printing Systems) by software;

Step 3: Copy the STL file to the computer that controls the 3D printer;

Step 4: Setup the 3D printer, including refilling the plastic material;

Step 5: The printer uses fused-filament fabrication. Molten plastic is extruded from a fine nozzle and laid down on a flat plate. The plate then drops a small distance, and the next layer is added, with each layer adding to build a complete vase;

Step 6: Remove the printed vase from the printer;

Step 7: Post-process the printed vase to remove the supports.

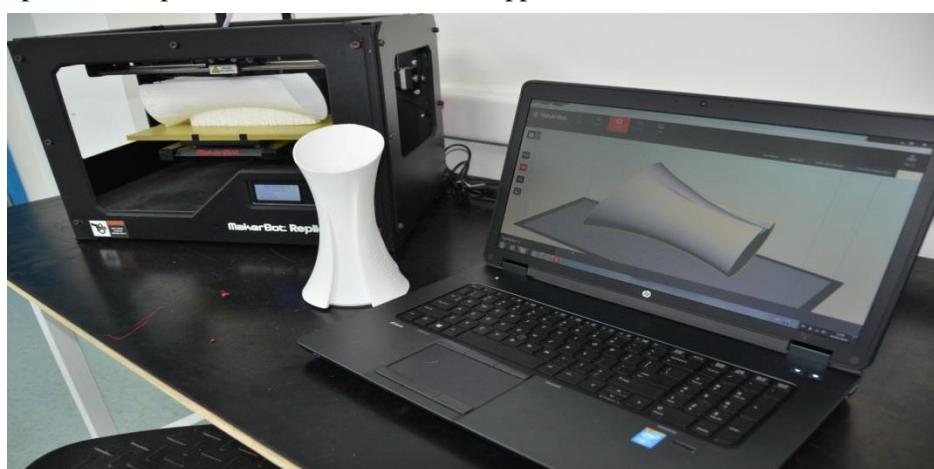


Fig. 2. The white part on the yellow tray is a component of the vase. It was printed from the model depicted on the computer screen.

4. Data collection and Samples

Data for this research was collected in two stages from non-designers and designers from various disciplines including fashion designers, interior designers, advertising designers, graphic designers and design students. A pilot test was conducted with 30 participants with a mixture of university students and designers to validate the survey instruments.

A total of 281 participants took part in the survey (134 males and 122 females). Out of 281 returned surveys, 25 were not usable because of missing data, leaving 256 usable surveys for analysis. Tables 1 and 2 present the demographic profile of the participants of the studies.

Table 1 Demographic Profiles

Demographic profile	Number	Percentage
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Gender		
Male	134	52.34
Female	122	47.66
Age		
20 years and less	39	15.23
21 to 29 years	87	33.98
30 to 39 years	47	18.36
40 to 49 years	41	16.02
50 years and above	42	16.41
Highest educational level		
High school	54	21.1
Diploma/Polytechnic	67	26.2
Bachelor degree	73	28.5
Postgraduate degree or over	62	24.2
Design background		
Designer	112	43.75
Non-designer	144	56.25

Variable measurement

The questionnaire was designed with items validated from previous technology adoption studies adapted from previous research (Igbaria et al. 1995; Venkatesh and Davis 2000; Wei et al. 2009). The construct - perceived compatibility taken from IDT to be used in our study measured (i) users' assessments on how the system fits their work and lifestyle; (ii) users' self-rated level of how the system fits their working experience and design interests; and (iii) their assessment on the needs of using the 3D printing system for their work. The scales used to measure the TAM constructs, the IDT constructs and the additional construct of perceived enjoyment were set on a 5 point Likert Scale ranging from 1 (strongly disagree) to 5 (strongly agree). Gender was coded as a dummy variable, which is in line with prior studies (Venkatesh et al. 2003), while age was considered as a continuous variable (Morris and Venkatesh 2000) and educational level was recorded as the highest educational qualification attained, coded from 1 to 4 (i.e. 1 for high school and 4 for postgraduate degree or higher). Design background was coded as 1 for a non-designer and 2 for a designer. Participants in this study who were regarded as designers included those who claimed to work as a designer

or who have actively (measured by frequency and within one standard deviation of lowest frequencies of professional designers) engaged in design related activities, such as DIY, personalization of mobile or digital applications, painting or drawing.

5 Results and Discussion

5.1 Reliability tests

The reliability of this questionnaire was tested by Cronbach's alpha. Nunnally (1978) stipulated that if the constructs are generally above or close to 0.70, then it can be confirmed that the item measurements of the constructs are reliable. In Table 2, Cronbach's alpha for the four constructs range from 0.794 to 0.909, thus confirming the reliability of the item measurements of the constructs.

Similar to methods used in e.g. Teo (2001), factor analysis with varimax rotation was performed to ascertain whether Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Perceived Compatibility (PC), Perceived Enjoyment (PE) and Intention to Use (ItU) are distinct constructs. Following Igbaria et al. (1995), an eigenvalue of 1.0 and a factor loading of 0.50 were used as the cut-off points. For these constructs, the corresponding eigenvalues are greater than 1 and their associated factor loadings are larger than 0.50, therefore, they are confirmed to be distinct from each other (see Table 2).

Table 2 Factor analysis

	No. of items	Factor loadings	Cronbach's Alpha	Eigenvalue	AVE
PEOU	4	0.656-0.845	0.807	2.368	0.6367
PU	3	0.779-0.817	0.768	2.059	0.7006
PE	3	0.779-0.824	0.873	1.343	0.8256
PC	3	0.632-0.758	0.704	1.032	0.6165
ItU	3	0.697-0.798	0.786	1.078	0.7436

5.2 Validation tests

The average variance extracted (AVE) of each construct was used to confirm the measurement model. Fornell and Larcker (1981) proposed that convergent validity is achieved if the AVE for each construct is greater than 0.50. Table 2 shows that the AVE for

each of the constructs is well above 0.50 and, therefore, convergent validity is evident. To confirm discriminant validity, the square root of the AVE for each construct should be larger than the correlations of the inter-constructs in the measurement model (Hair Jr et al. 2009). The results are shown in Table 3 and it can be seen that the discriminant validity of each construct is clearly supported.

Table 3 Correlation and squared root of the AVE

	PEOU	PU	PE	Comp	ITU
PEOU	0.798				
PU	0.617	0.837			
PE	0.507	0.687	0.908		
PC	0.468	0.559	0.548	0.785	
ITU	0.576	0.767	0.629	0.736	0.862

5.3 Hierarchical regression analysis

Table 4 presents the results from a regression analysis. The combined model using constructs from both the TAM and IDT could explain 57% of the variation (adjusted R²) in intention to use, which significantly improved what the TAM has achieved. All motivational variables are confirmed to have a significant positive relationship with intention to use at different significant levels. This finding is consistent with previous findings from technological adoption studies in computers, the Internet, E-commerce, online games, Internet shopping, and mobile commerce (Basyir 2009; Chang and Cheung, 2001; Chong, 2013; Hsu et al., 2007; Igbaria et al., 1996; Wei et al., 2009).

Table 4 Regression analysis

Dependent variable: Intention to Use	TAM Only	TAM & IDT
Perceived ease of use	0.128**	0.166**
Perceived usefulness	0.383***	0.465***
Perceived enjoyment	0.174***	0.216***
Perceived compatibility		0.197***
Adjusted R ²	0.456	0.576

Note: *** p<0.01, **p<0.05

5.4 Structural equation model

All hypotheses related to the moderating effects were tested using covariance based structural equation modelling (SEM). SEM has the strength to examine and estimate causal relationships even among latent variables that cannot be measured directly. To test the moderation effects, we followed the procedures outlined in Hair et al. (2009) by testing the imposed equality constraints on the path coefficients in the competing models to confirm the moderation effects of age, gender, education level and design background on the relationship between motivational variables and intention to use. To do so, we divided our sample into subgroups accordingly (e.g., when considering the moderation effect of gender, we divided the sample into a male group and a female group).

Table 5 Moderation effect

		P values			
		Age	Gender	Education Level	Design background
PEOU	→ ITU	0.032	0.072	0.144	***
PU	→ ITU	0.148	0.167	0.715	0.002
PE	→ ITU	0.345	0.050	0.425	0.149
PC	→ ITU	0.276	0.216	0.383	0.016

Note: All the numbers presented in the table are p values, *** indicates that p<0.001.

Age has been found to have a highly significant positive moderating effect between perceived ease of use and intention to use (see Table 5). The moderation effect is stronger for older users (see Table 6). Therefore, H5a is supported. In addition, the degree to which a 3D printing system is perceived to be easy to use is highly influential on aged people's decisions to reject or adopt the technology (Kubeck et al. 1996). However, age was not confirmed to have a significant moderating effect between perceived usefulness and intention to use, between perceived compatibility and intention to use and between perceived enjoyment and intention to use. Therefore, H5b, H5c and H5d are all rejected. These results may indicate that the degree of the effects that perceived usefulness, perceived enjoyment and perceived compatibility have on intention to use are less sensitive to age than perceived ease of use. Previous researchers have also stressed the highly significant importance of ease of use for

older individuals compared to younger users in terms of the acceptance of new technology (Gurtner et al. 2014), which is probably due to older users having less experience with technology as a result of declining absorptive capacity (Sorce 1995). The moderation effect of gender is evident between perceived ease of use and intention to use (see Table 5). The coefficients for both females and males on the path between perceived ease of use and intention to use are found to be significant (see Table 6), however, for females the effect of perceived ease of use on their intention to use is highly significant at a 0.1% significant level, while for males the effect is moderately significant at a 7.1% significant level (see Table 6). This difference is further reinforced by the magnitude of the estimated coefficients reported in Table 6. Gender has also been found to have a significant positive moderation effect between perceived enjoyment and intention to use (see Table 5). For males, their intention to use new technology is found to be more influenced by their perception of enjoyment gained from using such new technology (see Table 6) when compared to females. Hence, H6a and H6c are both supported. Gender is not found to have significant moderation effects on the relationships between perceived usefulness and intention to use. This is contrary to the findings of Ong and Lai (2006) and Kim (2010) which found male users' intentions to use were more influenced by usefulness than was the case for females. Gender is also not found to have significant moderation effects on the relationships between perceived compatibility and intention to use. This is consistent with Hur et al. (2013) who found that gender does not have significant moderating effects on the relationship between perceived compatibility and intention to use a tablet computer. Our findings show that perceived usefulness and perceived compatibility are considered equally important for both males and females on predicting their adoption of 3D printing systems. Hence, both H6b and H6d are rejected.

Table 6 Moderation effect

Moderation effect - Age	Coefficient estimate		
	Age group 2	Age group 3	Age group 4
H5a: PEOU → ITU	0.058 (0.601)	0.211 (0.227)	0.554(***)

Moderation effect - Gender		Coefficient estimate	
H6a: PEOU → ITU	Female 0.797(***)	Male 0.304(0.071)	
H6c: PE → ITU	0.047(0.682)		0.317(0.005)
Moderation effect - Designer		Coefficient estimate	
H8a: PEOU → ITU	Non-designer 0.040(0.498)	Designer 0.177(0.028)	
H8b: PU → ITU	0.336(0.346)		0.532(***)
H8d: PC → ITU	0.158(0.268)		0.316(0.032)

Note: Numbers in brackets are the associated p values, *** indicates that p <0.001; age group 2 is between 21 and 30; age group 3 is between 31 and 40; age group 4 is between 41 and 50; the bold coefficient estimates are significant at certain significance levels (as shown in brackets).

Educational level is not found to be an important moderator of the key relationships with intention to use. Hence, H7a, H7b, H7c and H7d are all rejected. These findings contradict previous studies which support the hypothesis that highly educated people tend to adopt new technology more quickly than the less educated (e.g. Weinberg 2004). However, the findings from these studies do not necessarily suggest the true causal effect of education on technology adoption, as highlighted by Riddell and Song (2012). Our study could suggest the potential effects that education has on technology adoption may depend on the kind of technology to be adopted.

Design background is a highly important moderator for three out of four key relationships in our model (see Tables 5 & 6). Hence, H8a, H8b and H8d are supported. Perceived ease of use, perceived usefulness and perceived compatibility are considered far more important for designers than non-designers on their intention to use home 3D printing systems. The significant difference is probably due to the differences between the skills possessed by designers and non-designers, as pointed out by Dunne and Troske (2014) who found that the adoption of technologies associated with design tasks is strongly related to the skills of the workforce. Our results do not support that there is a significant difference between designers and non-designers on the impact of perceived enjoyment on their intention to use a 3D printing system. However, our results (see Table 6) indicate that designers

consider the usability of the 3D printing system (i.e. how easily the 3D printing system can be used), the functionality of the 3D printing system (i.e. how useful it can be for their work) and compatibility with their working experience are far more important than how enjoyable it can be to use the system. Hence, H8c is rejected. We have included summaries of the hypothetical results in Table 7.

Table 7 Summary of Hypotheses Results

Direct Effects (Dependent variable: ITU)			
		Brief Explanation	Decision
H1	PEOU	Perceived Ease of Use is found to have a significant positive effect on ITU. A system which is easy to use enhances users' intentions to use such a system. This confirmed the earlier findings on the importance of systems' usability in influencing users' intentions to use the same (e.g. Pavlou and Fygenson 2006).	Accept **
H2	PU	Perceived Usefulness is found to have a significant positive effect on ITU. A system which is perceived to be useful enhances users' intentions to use such a system.	Accept ***
H3	PE	Perceived Enjoyment is found to have a positive effect on ITU. When users perceived a 3D printing system as enjoyable to use, this enhanced their intentions to use such a system.	Accept ***
H4	PC	Perceived Compatibility is found to have a positive effect on ITU. When users perceived a 3D printing system as compatible with their previous experiences or needs, this enhanced their intentions to use the same.	Accept ***
Moderating effects			
		Brief Explanation	Decision
Age	H5a	PEOU → An improved perception of ease of use can significantly increase older people's intentions to use a 3D printing system.	Accept ***
	H5b	PU → ITU There is no significant difference in the influence of PU on ITU across all age groups. Perceived usefulness enjoys equal importance across different age groups in the adoption of a 3D printing system.	Reject
	H5c	PE → ITU No significant difference was identified in the influence of PE on ITU across all age groups in this study.	Reject
	H5d	PC → ITU There is no significant difference in the influence of PC on ITU across all age groups.	Reject
	H6a	PEOU → ITU PEOU exerts far more influence on females than males on their intention to use a 3D printing system. This is explained by the higher technological anxiety commonly observed among females.	Accept ***

	H6b	PU → ITU	There is no significant difference in the influence of PU on ITU across the genders.	Reject
	H6c	PE → ITU	PE exerts far more influence on males than females on their intention to use a 3D printing system.	Accept ***
	H6d	PC → ITU	There is no significant difference in the influence of PC on ITU across the genders.	Reject
Designer	H7a	PEOU → ITU	We found there is no significant difference in the influence of PEOU, PU, PE and PC on ITU across the educational levels.	Reject
	H7b	PU → ITU		
	H7c	PE → ITU		
	H7d	PC → ITU		
	H8a	PEOU →	Designers value perceived ease of use, usefulness and compatibility more than non-designers, which is probably because designers are more likely to use 3D printing systems if they perceived them to be useful in their design work, easy to use and compatible with their professional experience.	Accept **
	H8b	PU → ITU		Accept ***
	H8d	PC → ITU		
	H8c	PE → ITU	There is no significant difference in the influence of PE on ITU between designers and non-designers.	Reject

Notes: ***p<0.001, ** p<0.01, * p<0.05.

6 Conclusion and Implications

Studies of the use of 3D printing technology among Chinese users remain sparse. This research investigates Chinese users' intention to use home 3D printing system. Although the TAM and IDT are two well-established theories for explaining the diverse aspects of the adoption of technology and innovation, each individual theory has limitations in terms of explaining adoption decisions that reflect both product and consumer dimensions. Hence, this study has attempted to combine the established theories of the TAM and IDT to gain an understanding of technology acceptance. We have also included an analysis of the moderating effects of user-specific variables (i.e. demographic variables) in our model to better understand people's acceptance and intention to use new technologies (Chen and Chan 2011).

Our integrated model based on the TAM and IDI was found to account for approximately 57% of the variance (adjusted R^2) in intention, which is a considerable improvement over the original TAM model (See Table 4). We proved our proposed direct constructs (i.e. perceived ease of use, perceived usefulness, perceived compatibility and perceived enjoyment) to be the main driving force behind users' intentions to accept 3D printing systems. These results may be shed some theoretical insight on conceptualizing the dual approach (TAM and DIT) to studies of the adoption of innovative technology.

Our results also suggest that younger people are more likely to be early adopters of home 3D printing systems. Age was found to have a moderation effect on the relationship between perceived ease of use and intention to use, while the effects of perceived ease of use on intention to use become more profound as age increases. This may indicate that for older users their intention to use home 3D printing systems could possibly be enhanced if their perceptions of ease of use of such systems can be improved. Furthermore, age is not found to have significant moderation effects on the other key relationships with intention to use.

Gender was found to have significant moderation effects on the relationship between perceived ease of use and intention to use, and between perceived enjoyment and intention to use. This may suggest: 1) the perception of ease of use is more salient for females than males. An improved perception of ease of use of 3D printing systems could help to boost female's adoption of the same as female users tend to have higher levels of fears of using new technology, as identified in earlier studies (e.g., Igbaria and Chakrabarti 1990); 2) males are more influenced by their perception of enjoyment of using home 3D printing systems when compared to their female counterparts, and perceived enjoyment exerts a much stronger influence on men than on women with regard to their intention to use such systems.

Contrary to the findings of previous studies (e.g., Chong 2013), a moderation effect of educational level on the key relationships with intention to use has not been established in

this study. This challenges the perception that only highly educated users will use home 3D printing systems. However, participants' design background was found to have a significant impact on their intentions to adopt home 3D printing systems, and participants with a design background are more likely to adopt such systems than non-designers. Perceived ease of use, perceived compatibility and perceived usefulness are all found to exert more influence on participants with a design background than those without a design background. Drawing from designers' emphasis on a system's ease of use, compatibility with their previous working experience and its usefulness, a 3D printing system should be supported with the most widely used 3D modelling software if 3D manufacturers' main target users are those with a design background. As non-designer users' concerns over using a 3D printing system centre on their lack of technical design skill, an easy to use design tool to accompany the system may foster higher levels of consumer adoption of home 3D printing systems among non-designers. One suggestion is to use software that is already embedded with licensed 3D models for various purposes as a starting point, with which users can continue building their own 3D models. Another alternative is to build a crowd sourcing 3D model library for users to buy, download and modify. A good example is the Thingiverse repository, initiated by Bre Pettis, for individuals to upload and share digital models for 3D printing (Bradshaw et al. 2010). With the input of consumers, an anticipated advantage is an enhancement of motivation for design innovation.

The lower degree of adoption by non-design participants indicates that it is still not feasible for consumers with non-design background to directly manufacture their products at this moment. A new collaborative approach of user participatory design could be a potential solution, in which the artistic elements of the product design is done by designers, while the remaining design decisions would be added by the actual users. This finding is consistent

with Campbell et al. (2011) who highlighted that the replacement of production professionals is not currently possible, and collaborative consumer design is required.

This study of Chinese users' adoption of home 3D printing systems may facilitate new conversations between manufacturers and consumers and thereby introduce new opportunities to design products in new business models for open design platforms in China. Future research work could examine the effectiveness of 3D design tools for creating a mini-revolution in consumer-led design in the ways products and services are designed and consumed in China. We will examine the facilitation process in terms of the home 3D printing technology, design tools and resources that would enable consumers to successfully conceive and produce their own designs.

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