ADDITIVE MANUFACTURING – ENABLING DIGITAL ARTISANS

Rautray, Priyabrata (1);
Eisenbart, Boris (2)

1: IIT Hyderabad;
2: Swinburne University of Technology

ABSTRACT

New technologies have always been disruptive for established systems and processes. Additive Manufacturing (AM) is proving to be one such process which has the potential to disrupt handicraft and its manufacturing processes. AM is customisable, adopt multiple materials and is not restricted by the manufacturing process. Our research discusses this global phenomenon with case studies to highlights the growth of a new kind of professionals known as 'Digital Artisans'. These artisans will assimilate the latest technologies with the cultural practices of the societies to create a new genre of products. The evolution of such artisans will be majorly led by people who have an equal inclination towards art and science and can act as the bridge between the handicrafts and technology. The development of such artisans will be supported by academics that will serve as a cradle and expose them to AM, design and handicraft. Its will also help in paving the growth of contemporary artisans who will utilise the strength of algorithms, artificial intelligence, CAD software and traditional aesthetics to create handicrafts of the future.

Keywords: Additive Manufacturing, 3D printing, Case study, Computer Aided Design (CAD), Industry 4.0

Contact:
Rautray, Priyabrata
IIT Hyderabad
Design
India
md17resch11001@iith.ac.in

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1 INTRODUCTION

In the world of technology, these are exciting times. We are presented with a scenario where multiple technological innovations are ushering the Fourth Industrial Revolution or Industry 4.0 (Abramovici et al. 2015). The first Industrial Revolution was steam engine development, the second one being industrial mass production, and the third one was the digital revolution and electronics. The fourth industrial revolution will blur the lines between the digital, biological and physical world by introducing technologies to manipulate physical and biological materials (Skilton and Hovsepian 2017). It will enable designers as well as engineers to create forms and shapes that are not possible in the previous generation. I will also lead to a change in the production methodologies and management systems. It will not be a linear transition, like what we saw between the second and third Industrial revolution-based processes. Such a disruptive technology is being brought not by just one technique but several interlinked technologies. With the dawn of the Internet, the seeds of this revolution were sowed. It is propelled by technologies like Cloud Computing, Big Data, IoT (Internet of Things), Cybernetics, Smart Factories, Machine to Machine Learning and Additive Technologies. Industrial 4.0 is the first time an industrial revolution has been predicted as an initiative by the German Federal Government (Hermann et al. 2016). It defines six principles as the guiding factors as follow: Interoperability, Virtual Reality, Decentralise, Real-time solution, Service inclined and Modularity.

Throughout history, technological advancement has continuously renewed methodologies and practices established up to this point (Kostoff et al. 2004). It takes a certain amount of time for the new processes to be absorbed by people and into societal cultures and traditions and become prevalent until discovering novel technology. Whether it was the discovery of fire by the Stone Age man or the Additive Manufacturing (AM) in the present-day scenario, all these are tools for future generations to use as a thing of everyday utility. AM technologies have grown immensely in the last decade, making them accessible to a larger population. Handicrafts are based on two central pillars: first human skill and its association with society's local culture. Any form of craftsmanship is highly localised and has always been customised to its community, a trait very similar to the one possessed by the AM technologies (Li 2017). So, there is a strong possibility that these two processes will either fuse or challenge each other in the future. Assimilation of these two methodologies to create a new artisans genre, whom we call Digital Artisans, will be one of the most favourable outcomes of this development. We are trying to explore the process through which AM, rather than becoming a disruptive technology (Kietzmann et al. 2015), paves the way to create this new kind of artisan. With its strong foundation in Information and Technology, India is becoming more and more globalised every day. The government's Make-In-India initiative is also encouraging more technological exchange with other countries (Soundhariya 2016). Thus, with the resource of the new technologies and traditional sensibilities of handicrafts, it can quickly become the melting pot of both, resulting in products of utility and art. Education also plays an essential role in propagating and imparting new knowledge, and AM technology allows students to give tangible form to their vivid imaginations. Even though this technology is still relatively new, more and more schools and colleges can provide infrastructure for AM to students (Ford and Minshall 2019). This has led to a change in the mindset of students where their hand-on skills do not limit them in conceptualising solutions for the future.

This research paper consists of five sections; the first sections are the general introduction followed by a discussion on AM and its influence on handicraft and Digital Artisans' growth in section two. It is followed by three case studies on the global pioneers of digital craftsmanship in section three. Section four elaborates on the importance and relation between academics and AM technologies, and it ends with the conclusion in section five.

2 ADDITIVE MANUFACTURING AND HANDICRAFT

AM is a part of rapid prototyping, where virtual 3D models are drawn using CAD software act as the source file. This is usually done by laying down multiple thin layers of materials like plastic, metal powder, ceramic, resin, wax, food materials, and even living tissues. Thus, through layer-by-layer printing, the 3D CAD model is transformed into the product without the need for the die or other manufacturing process (Kumar et al. 2019). With improved technologies and base materials, 3D printed parts can be widely used in industries, automobiles, aerospace, medical, construction, lifestyle accessories etc. Depending on the printing processes and the materials, AM can be categorised into SLA (Stereolithography), FDM (Fused Deposition Modelling), SLS (Selective laser sintering), 3DP

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(Three-Dimensional Printing), LOM (Laminated Object Manufacturing) (Jasveer and Jianbin 2018). Whereas handicrafts are predominantly based on traditional methods and time-consuming processes, making them expensive and reducing their economic viability. Still, many artisans are unwilling to shift from the conventional form of work, which is more due to the availability of resources and adaptation of the technologies to suit their needs. As shown in Figure 1 below, AM is hardly used in handicraft or artefact industries (Wu 2016).

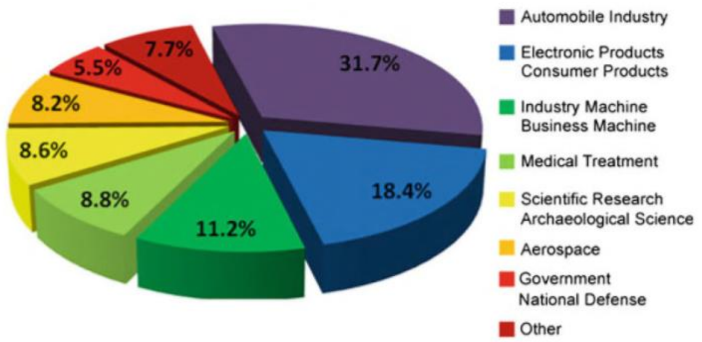

Figure 1. Distribution mapping of 3D printing in different industries

In the future, there will be a fundamental change in the manufacturing of traditional handicrafts due to the rapid growth of CAD software and AM technologies. This growth will open up a new window of opportunity for the future generation of designers to participate in the design process with significantly less or no hand skills. Integration of culture and tradition with modern technologies will lead to the development of both new crafts that address contemporary issues (Gulati and Mathur 2017). This kind of amalgamation of tradition and technology will pave the path for Digital Artisans of the future. Thus, there is a considerable scope of improvement in the adaptation and development to nurture these new-age Digital Artisans. They will be equipped with the necessary designing software, AM technologies, and the culture and the sensibility of traditional cultural belief systems.

2.1 Growth of Digital Artisans

Designers are a group of intellectuals who are exposed to both technology and the field of art. They are believed to keep a balance between functionality and aesthetics (Press and Cooper 2017). There is a high degree of sensitivity among the designers about their country's cultural and handicraft heritage. Many designers are incorporating or getting inspired by the craft methodologies for their products. The designers will arm themselves with these new AM technologies and are expected to create their products (Lawson 2006). They will be independent of the industry-based manufacturing systems and can integrate crafts sensibility in a localised manner without developing requisite hand skills. Thus, the designer will be the forbearers of this new genre of Digital Artisans. Digital Artisans will be the designers, craftsman and enthusiasts who will bridge the demands and supply gap. They will likely act as an interface between the artisans and the contemporary world. With the demand for personalised or customised designs increasing, these Digital Artisans can produce artistic products in larger quantities and, at the same time, leads to the development of contemporary art forms.

2.2 Benefits of Additive Manufacturing in handicraft

Before the industrial revolution and factory drove mass production, most of the world's products were created by artisans in the existing craft production paradigm. These products were personalised, unique and were regarded more as an art than a product. With the growth of new tools and technology, there is a shift from mass manufacturing to mass personalisation (Hu 2013; Castro E Costa et al. 2017). Some of the critical benefits of AM technologies are as follow:

- AM produces fewer wastages than subtractive manufacturing and does not depend on traditional raw material availability (Diegel et al. 2010).
- There no added cost due to the complexity of the design or the unique form of the product. This will act as a great enabler in form exploration and creating new handicrafts (Hague et al. 2003).

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- AM give the freedom to personalise, and there is no added cost involved if we have mixed designs in the production line. The cost solely depends on the material used and not the designs' variation (Dillenburger and Hansmeyer 2013).

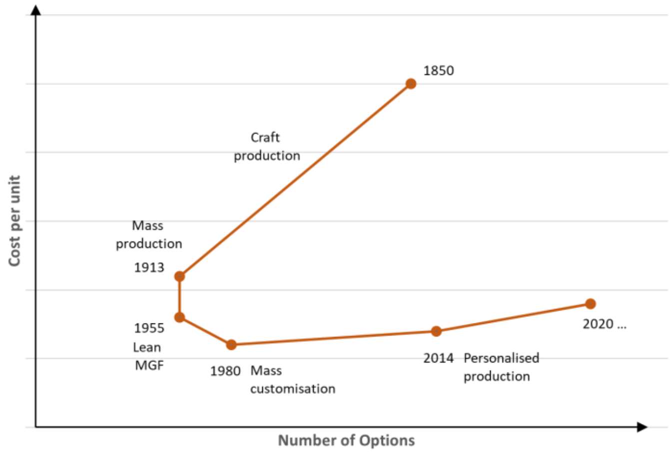

Figure 2. Relation between cost per unit and number of options (Castro E Costa et al. 2017)

Figure 3 highlights how AM can improve personalised or custom-made products while reducing production cost compared to traditional craft production. AM has come a long way from just a new technology used in the experimentation and academic setting to become a tool for customised production. Thus we can safely predict that AM can become a Digital Artisans' tool to create or assist in developing future products. Therefore, AM will act as an enabler for digital artisanship and part of what is established practice now, but not the whole picture. Still, we focus on the contributions it can make to facilitate the digital design process and its translation into reality without expensive tooling or acquiring desired hand skillsets.

3 CASE STUDY ON PIONEERS OF DIGITAL ARTISANS

To understand indigenous digital artisans' growth in the Indian sub-continent, we selected three prominent contemporary designers from different areas from a selected digital artisans list. For this selection, we followed a two-step protocol: first, we studied various sources like established database, web portals, journals, articles, reports such as - Rapid Prototyping journal (Emerald), Virtual and physical prototyping (Taylor and Francis), Progress in additive manufacturing (Springer), Additive Manufacturing (Elsevier), 3dprint.com, engineering.com, 3dprintingindustry.com, 3ders.org, etc. to gather the list of prominent digital artisans. We selected the potential archetypes such as product design, architecture, and art to choose artisans in specific fields relevant to our study. Second, we followed a thematic clustering and factor analysis method to reduce the designers' list. In the thematic clustering, the designers were grouped into corresponding domains. And a factor or cluster analysis was conducted to find the most suitable designer to represent the group. Through our research, we will try to elaborate on how they have used 3D printing (the selected archetypical artisans predominantly use the term 3D printing in terms of AM technologies) to overcome the boundaries between traditional crafts and modern technologies to become the pioneers of digital craftsmanship.

3.1 Neri Oxman

An architect, designer and inventor, she has worked immensely in the field of 3D printing. PhD in Computation from MIT, her work is displayed in some of the world's best art galleries. She leads a team that researches computational design, digital fabrication, materials science and synthetic biology. Her work tries to showcase the relationship between the "built, natural and biological environments". Most of her works are deeply inspired by nature, and she realises them through her research (Oxman 2011). In one of her works named 'Gemini Acoustical Chaise', she has created a piece of furniture that uses 44 digitally produced materials using both additive and subtractive technologies. She uses both natural and synthetic material for the same (Figure 3). The materials have different flexibilities and sound-absorbing properties.

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Figure 3. Gemini, by Neri Oxman, 2014[1]

“Vespers” is a series of death masks designed by Neri Oxman and her team (Figure 4). It comprises of three groups, with five masks each. Traditionally, these were made up of plaster of Paris modelled on the facial features of the deceased. Instead of commemorating the dead, these masks are conceptualised to focus on cultural beliefs, recreating them through modern technologies like modelling with high-resolution and multi-material 3D printing and artificial biology. Her concepts are highly futuristic and challenge the capabilities of 3D printing technology.

Figure 4. Deathmask with internal colour strand and transparent curve volume[2]

In her exploration, named ‘Qamar’, the Arabic terminology for the Goddess Luna is a breathing apparatus, as shown in Figure 5. It is inspired by the Lunar surface, and it is designed to carry oxygen and algae as a biofuel.

Figure 5. Qamar. Luna’s Wanderer by Neri Oxman. 2014[3]

Her work shows that we have not even scratched the surface of possibilities this new technology holds for the human race in the future. She introduced the term “Material Ecology” as a new creative field,

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1 Gemini by Neri Oxman 2014, *Stratasys Connex Technology, CNC milling. Paris, France*

2 Death Masks from MIT Capture Your Dying Breath by Nari Oxman, *Courtesy of MIT Media Lab*

3 Qamar, Luna’s Wander by Nari Oxman 2014 *3D print Euromold, Frankfurt, Germany*

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where computation, manufacturing, and the material are considered one with design. But along with technical innovations, her work also represents digital craftsmanship par excellence.
These examples showcase how new-age AM technologies, combined with other techniques, can create a new art form based on culture and the place's traditional belief systems. This kind of exploration leads to Digital Artisans' development, which blurs the boundaries between traditional handicraft and modern technical manufacturing like AM.

3.2 Michael Hansmeyer

An Architect and programmer by profession used computation to create architectural forms and spaces. His designs concepts are based on the usage of advanced technology, fabrication procedures, and additive manufacturing such as 3D printing. Thus, the form's complexity is no more a hindrance and incorporates function without disregarding form or, as Mr Meyer refers to as 'Visual Reductionism'. This has led to new possibilities instead of following the established norm of "Form follows Function". Armed with these tools, he uses his ideas to create forms and spaces which are highly sculptural. His creations delve into unique 'topographies and perspectives' that were otherwise very difficult to achieve through conventional architectural construction methods (Bushwinkel 2020).

Figure 6. Grotto installed at Centre Pompidou[4]

His projects, such as "Grott", redefine the platonic solids or the Digital Grotesque I & II (Figure 6). Each of the projects has an inherent sculptural appeal but achieves the needed architectural purpose. Even if everything is conceptualised and planned on parametric software, the craftsmanship is undeniable (Dillenburger and Hansmeyer 2019).
From his work, we can deduce that the future artisanship can move beyond hand skills to more conceptual, computational and emotionally evoking in nature. In the future, AM will help in the transition of manual craftsmanship to machine-based craftsmanship, where the uniques designs are conceptualised and developed in a 3D space and manufactured by machines.

3.3 Olivier van Herpt

As a design student at Design Academy Eindhoven in the Netherlands, he studied product design and ceramics. As a part of his curriculum, he was introduced to 3D printing. However, he found the process very limiting to his ideas and creativity. He was deeply influenced by the properties and the possibilities that clay offers while creating things. He believed in the idea that this new technology and ceramics can be used together for his creations (Gürsoy 2018). Thus, he experimented and modified the 3D printer machine in a manner that it could use clay as a printable material. With his machine, he could create unenclosed 3D printed vases. He modified the device to allow him to interact with the

4 This Mysterious 3D Printed Grotto Challenges Boundaries of Computational Geometry and Human Perception, © Fabrice Dall'Anese

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clay product while it was being printed. This resulted in a unique interaction between the 3D printing machine and the designer (user) (Çakmakçıoğlu 2017).
In one of his projects, he wanted to create a 3D portrait of the Nobel Prize winner Ben Feringa in clay for casting in bronze, as shown in Figure 7. The sculpting process required him to stop the machine again and again and detail out the different parts of the face, such as nostrils, ear lobes, etc., by hand. This art piece demonstrated the application and amalgamation of the machine and handmade processes. It was nowhere close to the precise outputs of industrial methods. He believes this new process of additive manufacturing has 'democratised the manufacturing processes and paved the way for the designer to be closer to the user in terms of their needs. It removes the industrial chain in-between them a hindrance due to its limitations (Herpt 2012).

Figure 7. Nobel Prize Portrait Bronze head of Ben Feringa and different artefacts[5]

3.4 Inference

The above case studies highlight the versatility of AM technologies and their power to accommodate different creative approaches. People from varied backgrounds can use this technology with their unique way of creating artefacts considering contemporary socio-cultural beliefs. It can develop its unique aesthetic and art style that can become the norm in the future. Thus, AM is a powerful tool that will facilitate the growth of new-age artisans. AM can either be used for purely experimentation purposes or for making utility products, and it has made manufacturing more user-centred than before. In a way, it has democratised the manufacturing process; users have become both the creator and consumer of the product, thereby creating a new paradigm shift in the handicraft.

4 ACADEMICS - CRADLE FOR DIGITAL ARTISANS

The emerging field of AM opens up new frontiers and teaching opportunities in professional courses and even at school levels. It can change our approach to teaching and learning and, in doing so, imparts the basic knowledge of AM technologies and creating a new generation of Digital Artisans. Researchers have highlighted the following six usages of AM in academic institutions (Ford and Minshall 2019).
Teach students about additive printing techniques- The students can use it to generate and iterate their tangible form ideas.
Teach educators about AM techniques - The educators need to get acquainted with the methods to teach their students. They can also use AM as part of their research explorations and test modes.
As a support tool during teaching- Teachers can generate tools to teach the students, such as creating topographies while teaching geography or 3D dimensional objects to teach maths (Ford and Minshall 2019).
To teach design and other creative processes, many creative courses are being made a part of teaching in many schools and universities, including Design, Engineering and Technology subjects (DET) (Hsu et al. 2011). AM can be used for conceptual and detailed model creation.
To create supporting or technologies that assist specially challenged and differently-abled students and improve their learning, such as tactile graphics for the visually impaired (Stangl et al. 2014).

5 Nobel Prize Portrait Bronze head, image by Koos Breukel and Olivier van Herpt

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To create artefacts such as monuments or models that help teach or give demonstrations to the students (Fernandes and Simoes 2016).

Though these utilities have been well defined, the implementation has remained at a novice level. In schools and colleges, these students can create study and test models and share them with standard libraries as 3D printing models and create experiment and share knowledge (Bull et al. 2014). This also opens new horizons and possibilities by making design easily accessible to research or even school children without limiting itself to design courses. Secondly, this can also form a substantial bridge between design and engineering. It presents the opportunity to experiment and iterate the prototype in a physical working format that otherwise is difficult to assess in visualisation or through crude prototyping. However, the biggest challenge is to learn the software, resulting in its limited application. But gradually, the library resources and the know-how about AM is becoming more common day by day. Thus, academic plays a dual role in developing a new generation of digital artisans and spreading AM knowledge to the masses.

4.1 Indian scenario

In response to the challenges mentioned above, many organisations like Digital fabrication laboratories (FabLabs), Maker's Asylum, TinkerLabs, are working hard to integrate technology, design and craft. Similarly, an online portal like Jaaga (https://jaaga.in/blorecreate/) provides a faster and cheaper way to connect, collaborate and create. These workshops and websites are providing artisans with a platform to practice and realise their unique crafts. More and more Indian institutes and design colleges offer 3D modelling and printing knowledge through workshops and courses. Thus, based on our research, we can postulate that Digital Artisans will act as a catalyst for Indian culture and traditional crafts and emerging technologies like adaptive manufacturing. They will help to bring the best out of these two strikingly vibrant and different mediums of creativity.

Figure 8. First-semester project work of students at IIT Hyderabad

Figure 8 showcases the project works of first semester students of IIT Hyderabad. Through the Digital Fabrication course, they were exposed to the possibilities of 3D design and additive manufacturing. This course helped in the 3D visualisation of products and printing the actual model in tangible form. With the limited exposure but with proper guidance from the faculties, these students exhibited a Digital Artisan's initial characteristics. This knowledge helped them create utility products to solve their academic needs or for aesthetic purposes in future semesters. Thus, this is one example that shows how education can act as a cradle for Digital Artisans.

4.2 Impact of exposure to AM in education

AM as a technology gaining acceptance in mainstream education to engage students with tangible and hands-on interactions. It can offer students a powerful tool for creativity, exploration, and building and make them independent. Students get an opportunity to evolve their uniques style to create artefacts without worrying about hand skills. Early exposure and a strong foundation in AM leads to the creation of a strong sense of research. This, in turn, develops new techniques, material and forms in AM. The above discussion is purely transitional thinking regarding what this technology means for future education, as shown in the three case studies in Section 3. And we predict that education will play an essential role in shaping the future, and it is bound to play a crucial role in developing Digital Artisans.

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5 DISCUSSION AND CONCLUSION

India is very new to AM on a larger scale compared to its counterparts in Europe and the Americas, even though it is growing fast. Computational design is yet to become a mainstream course in our institutes and Universities. However, Indian students are getting exposed to these courses in foreign universities and premier universities of India, and they are bringing back their expertise and gradually creating a knowledge pool. There are a considerable number of Indian Institutes collaborating with institutes in the UK, USA, and the Netherlands, resulting in creating the right kind of atmosphere for this new field of study. Based on our research, we have categorised four main challenges that need to be mitigated to develop a conducive environment for the digital artisans to thrive and generate a new design and craft ideology:

Accessibility to AM technology: India is a vast country divided into the urban and rural population. Indian crafts are practised mainly by this rural society which forms the more significant part of the country's population, and it is devoid of access to modern technologies presently.

3D design software and developing skillsets: India is lagging in developing 3D design software about Indian craft, and internationally available 3D design software are either expensive or out of reach for large sections of the population.

3D printable material in sync with Handicrafts: India is home to thousands of handicrafts that varies in material and technique. Developing similar content for AM is a significant challenge for present technologies.

Growth of AM in academics: a large part of the population goes through one educational process's rigour. With the right kind of encouragement and foundation, academics can set the environment for digital artisans development.

With AM technologies' growth and large scale adoption of AM technologies in education, both secondary and tertiary, we will likely see more AM penetration into daily life activities. This will lead to new aesthetics and form factors, creating contemporary art and handicraft genre. Digital Artisan will be the forebearer of this change, which could, in turn, start a new revolution in the field of handicraft segment. There are a few challenges like establishment cost, material suitable for the indigenous art form, software development, etc. But we believe with time, these issues will be resolved to create a more robust and flexible AM framework suitable for handicrafts. Future research avenues include studying contemporary artisans using AM technologies for handicrafts in India, creating feasibility and economic viability report.

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