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Proposing Digital Design Methodology for Furniture Products by Integrating Generative Design Approach to Conventional Process

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Abstract

Purpose: Considering the growing digital transformations in design field, this research aims to explore the advance language of design - generative design. The study focuses on integration of generative design and parametric modeling techniques with conventional furniture design process to develop a digital design and development methodology for furniture products by doing practical work in Rhino and Grasshopper.

Methodology: For this purpose, a comparative analysis is drawn and three practicals performed in Rhino Grasshopper.

Results: The author learned one of the design tool (Grasshopper) and investigate the possible ways to integrate this digital design process with the conventional process. These examples illustrate the liberty to design and explore any form that is imaginable and offers flexibility in the development process to make multiple design options. This digital way of designing leads to better accuracy, quicker adaptation to the initial concepts, ability to produce new alternatives, ease of revision, quality and realistic results and most importantly ready to manufacture products. This research was carried out, specifically, keeping the industrial environment of Pakistan Furniture Industry in reference.

Unique Contribution to Theory, Policy and Practice: This research proposal helped the author to create an awareness at a very initial level in the targeted scope with the hope to encourage authorities to take some serious steps towards the institutionalization of technological advancement in the design education sector. This research not only honed the author's knowledge in the state of the art but also enabled him to share more advance knowledge about CAD tools with his students. By following and integrating advance design tools to the design process, developments in furniture industry in Pakistan can be made possible in a short time.

Keywords: *Digital Design Methodology, Furniture Design, Digital Design Tools, Generative Design, Parametric Design*

1 | INTRODUCTION – THE INDUSTRY 4.0

Technological transformations have changed the entire product design and development process in the past years in terms of 3d design, modeling, conceptualization and visualization [1]. Raymond (2019) defines digital transformation as, "the integration of digital technologies into a business resulting in the reshaping of an organization that reorients it around the customer experience, business value and constant change [2]." This definition identifies that digital transformation is much more than just a revolution in IT industry such as hardware, software, or a digital platform. More recently, a new trend, often termed as 'The Industry 4.0', has emerged, gaining attention through a notion called the Industrial 4.0 transformation. The industry 4.0 term has emerged, evolved and there is an increasing attention towards this industrial 4.0 transformation all over the globe, in every industry.

The fourth industrial revolution can generally be described as a complex technological system that embraces digital manufacturing, network communication, computer and automation technologies, as well as many other relevant areas [3]. Technologies of the Fourth Industrial Revolution are blurring the lines between the physical, digital and biological world, impacting all business, economies and industries. The current flow of technological development is employing deep changes on the way people work and live. It is influencing all disciplines of daily life, economies and industries, perhaps none more so than design and production sector, including what, why, where and how personalities produce and deliver products and services [4].

In the contemporary era of rapid technological innovations, customers demand products and integrated solutions that are innovative, new and packaged with the modern design and technologies [5]. In addition, customers are increasingly demanding personalized products and services that are tailored to meet their specific requirement(s). This creates challenges for producers and manufacturers who need to establish a strategy that can be individually tailored (customized) to the specific features [6]. This demand of customization creates a gap (fast design with customization and rapid production), therefore; innovative solutions are required to fulfill these demands generated by customers.

The industry 4.0 has opened new dialogues between designers and computers. With the advancement in technology, computer assisted tools are transformed from 2d drafting to 3d modeling in a few years. They have shifted from pixels to vector and basic geometry modeling to direct and parametric modeling techniques. Recently, these tools have been upgraded and have made it possible to model 3d objects and products based on basic geometrical shape and calculations. Today, these tools are more advanced. Today, computer-assisted tools are working on the principles of parametric modeling. Although parametric design is generally linked to today's technological world, it has existed much longer than before its involvement in design tools. Parametric design is defined as "an arithmetic process of design that generate digital concepts to provide multiple options for decision making" [7]. Parametric design can be reflected as a new language of design in architecture [8]. This new language of design increases its impact in design world day by day. In the future, this will be replaced by generative

design and modeling, the language of design based on code and scripts. It means the designer can visualize design outputs on computer screen by writing codes. These scripts help the designer to model 3d CAD design.

1.1 | CONVENTIONAL FURNITURE DESIGN PROCESS

"A design process is a creative attitude that breaks down a big problem into smaller and solvable steps to achieve a solution" [9]. Designers, engineers, architects and design community use this approach to solve a variety of problems and find practical and feasible solutions. They use design processes to tackle problems and translate their ideas into reality.

Nutassey et al., define design process as "a system that is created by human and non-human actions to solve a problem or advancements in existing systems or products [10]. Design solutions do not come into reality without a process. In fact, these solutions are the result of combine effort and actions, human and non-human. A furniture product or accessory can be designed in multiple processes that are different in actions but result would be same. Furniture products and accessories are essential components of a space. According to Khandani (2005), through design, ideas and skills, we mould a space according to its surrounding materials tangible and non-tangible to make in look beautiful and functional. Without furniture pieces, houses are uninhabitable, offices become purposeless and spaces around us are meaningless [11].

All design processes [12], and problem-solving tasks [13] start with a need, a design brief. Furniture design process begins with a brief, understanding user needs and wants. It starts with the collection of information and gathering and identifying possible problems (Pre-define phase). Every process model starts from idea generation or market analyses followed by concept proposals, developments, model making, prototyping and testing, analysis and refining stages. The following figure 1 shows a conventional process of designing a furniture piece.

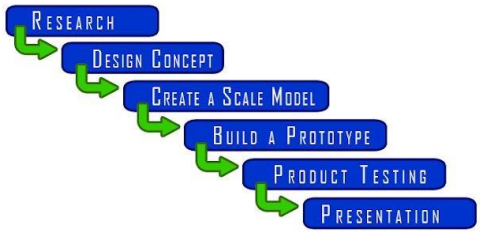

Figure 1 Furniture design process by OPUS Web Design

During the stage of idea generation, the designer starts brainstorming and translating ideas into realities. The designer starts conceptualizing and visualizing ideas using human and non-human efforts. Human efforts means using intellectual and physical abilities to produce results. Whereas, non-human efforts means using external tools and actions for example, getting help from software or machines to translate ideas. At this stage, some individuals are more convenient to produce solutions by manual actions as they are good and feel at ease with sketching and paper work. However, others use both efforts. Some visualization tools help them to visualize solutions virtually. With the advancement in technology some digital tools

are being used during this stage, for example, AutoCAD, Sketch up, 3ds Max etc. These digital tools faster the way to create 3d models and conceptualization and make it easy to show solutions to clients.

In conclusion, a furniture design process is typically a hybrid process that involves human manual skills, abilities and expertise along with some digital design software. These computer-assisted tools enhance the designer performances within the context of furniture design. In the domain of furniture design and manufacturing such tools will not only enable designers to think and create innovatively but also help them to hone their skills and expertise. These tools save time, produce results faster and result in effective outputs.

1.2 | NEED OF TRANSITION

Furniture design process starts once a need is created. Research team analyse market and collects information, talks to clients and identifies a problem or a set of problems [14]. In general, furniture design processes involve four phases, 1) the research and analysis phase (pre-design process) 2) positioning phase, 3) conceptualization phase and 4) detailed design phase [15]. Design teams start translating grounded factors highlighted during pre-design phase. Design teams use all their skills to produce some results. Conventional ways to conceptualize and visualize a design include hand sketching and handmade scale models. This way to visualize a design is time taking and human energy consuming. Another drawback of this practice is that design team can only produce limited results.

However, with the advancement of technology, today, design process is very quick and better. Computer-aided design tools have been widely used in furniture design process. Today, it is very easy to visualize a design through a program. These digital tools (software) have made the process so quick that in a short time we can produce multiple iteration base on product color, finish, style and upholstery. Computer-aided technology has not only replaced manual work in design process but also has made it possible to change design values and coordinates in a little time.

One of the industrial goals is to improve and enhance productivity [16] that inspires and forces companies to find practical solutions with the help of non-human efforts (computer-aided design tools). With the advancement in these computer-assisted tools, from 2d drawings to 3d geometry base modeling, new integrated tools and techniques are introduced such as parametric design and modeling. In the domain of furniture design Barros et al. [17] achieved structural analysis and cost efficiency by using computer-assisted tool – parametric design. In 2008, Pan and Wang [18] used mathematical equations in the furniture design process. Qian 2007 [19], defines parametric modeling as flexibility and time reduction to create multiple options. This definition implies in furniture industry in a way when we need different sizes of a same product, so parametric design makes it possible in a very short time and also reduces work time and errors.

With the advancement of technology, such digital tools are being programmed that will help us to generate design concepts by putting some information about customers and market demands. Here, customer information and market demands are those factors which have been

highlighted during pre-design phase by researchers. Artificial intelligence has made it possible to generate outputs based on input data. Philippe Starck creates "world's first chair designed with artificial intelligence" [20]. The A.I chair is the result of Starck's collaboration with Italian contemporary furniture maker Kartell and Autodesk Research. In the future, computer-aided design tools (Rhino, Autodesk Fusion 360, Dreamcatcher) will not only help designers to visualize design in virtual 3d environment but will also help to generate designs based on data. The following schematic diagram (figure 2) shows how a generative design tool works and what is the role of a designer in this process?

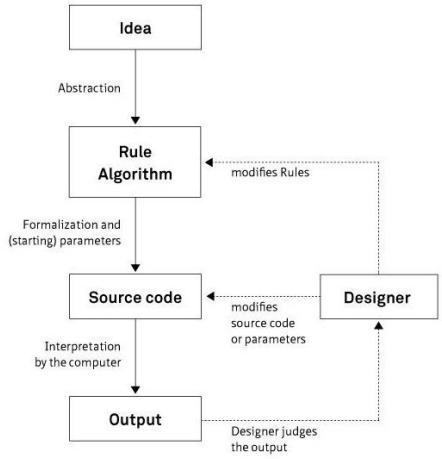

Figure 2 Generative design process by Hartmut et al.

Computer-aided manufacturing revolutionized the product production industry, more particularly, furniture industry [21]. Today, real physical models are created through rapid prototyping based on computer-aided design, as well as design evaluation, reversing, and optimization iterations. Although this revolution was started in 1950 when Alexander Hammer at DeLaval Steam Turbine Company invented a technique to progressively drill turbine blades out of a solid metal block of metal with the drilling controlled by a punch card reader [22]. But, with the advancement in CAM made it possible to print any object at anyplace by pressing a single click. What it is needed only a computer software generated design file and the tools and the media [23].

The use of digital media in the development process has made it very easy to re-visualize designs after testing and evaluation stages. Computers are no longer used only to provide accurate representation of a design, but also to generate, evaluate and provide information to automatically produce artefacts.

In a broad sense, CAD tools allow designers to generate a design in a virtual 3d environment and designers creatively. Similarly, CAM as a tool used by the furniture designer, may open new opportunities in the creation of customized furniture design that allows a broader control over the process. In conclusion, furniture design processes may take multiple steps, approaches and ways, depending on the situations and experiences. Designers may use manual skills or may get help from available advance digital tools to accelerate the process. Technology is overpassing human skills and in future non-human efforts will be more focused and tailored in

the design process to produce solutions. Now, an integration system or process is needed in which both efforts are combined in a well-balanced way to generate ideas and solutions. This thesis research is about this integration process. The following table 1 shows the comparison between the two processes.

Table 1 Comparison between conventional and digital design processes

Conventional Furniture Design Process	**Digital Furniture Design and Development Process**
research	Information technology (A.I data collection and analysis tools)
Mass production	Mass customization
User – designer- manufacturer relation is not strong	Professional bridge and relation between user – designer - manufacturer
Limited design scope	Designer performs design and production activities
CAD tools	Integration of CAD-CAM tools
Time taking process	Less time, faster and more results
Several steps and errors factor	Real time product testing
Manual drafting and prototyping	Digital modeling and virtual visualization
Pro-long design – prototyping – testing phase	Ready to produce artifacts
Less creative process	Relatively more creative process and enhance designer capabilities
Limited results	Freedom and flexibility of generating results
CAD tools (geometry base modeling)	CAD tools (Parametric modeling)
Less complex solutions are anticipated	More complex and curvy models are possible to draw

2 | STRUCTURE OF THE STUDY

The research is structured in 4 methodological stages.

1) The first stage highlights the need of transition from traditional system to a new digital product design and development process by formulating a comparison between them.

2) The second stage comprises to illustrate the information about the research contents. For this purpose, published literature, case studies and experimental work will be studied and conducted.

3) The next stage highlights the history and influence of artificial intelligence and digital design and development tools in furniture design industry. For this purpose, some cases and experimental work will be presented and discussed.

4) At the end of this research project, a digital methodology is proposed to integrate digital tools in the design and development process. To accomplish this, the author will learn one of the design tool (Grasshopper) and investigate the possible ways to integrate this digital design process with the conventional process (figure 14).

3 | CAD PARADIGMS

CAD can be traced with the development of PRONTO, a numeric value based software, by Patrick in 1957. By the time, drawing boards were replaced by CAD tools, and sketch books were replaced by computer screens. Designers and engineers started to use CAD tools for technical drawings and technical resolution. From 2d vector lines to 3d modeling, this journey increased the productivity of the design and assisted designers to visualize and conceptualize products in a batter and faster way. Over the time, modifications and transformation were made in CAD tools to make them faster, user friendly and more productive. Their languages (the way of operation and communication with them) were modified from 2d vector lines to direct modeling, from geometry modeling to parametric modeling and from parametric to generative. In this section, these three paradigms are discussed in details and following figure 3 shows the timeline of transformation in CAD languages.

Figure 3 Transformation in CAD tools

3.1 | FURNITURE DESIGN AND DEVELOPMENT PROCESS

“Design is the half of the job and everybody knows it” [24]. The role of designer during the whole process is not stand-alone. Designers work in a team composed of production, sales and marketing as well top management. The people concerned in design are researchers, designers, production engineers, producers, salesmen and users [25].

Design of a furniture product does not exist in a vacuum. A typical furniture design and development process involves a series of steps to be followed. This process adds values to the design and brings valuable meanings to the products. Furniture design is a critical process, during the development process certain points needs to be consider and implement such as wood type, style, finish, size, intended market price, manufacturing capabilities and resources.

Furniture is a complicated product with many possible feature combinations, serving both functional and aesthetic considerations.

There are many product design and development process models available (Magrab et al. 2009; Buck 1963; Design Council London 2007 & Ulrich, Eppinger 2007) [26] [27] [28] [29] for example 4 ds (design model, design a furniture based on materials or starting a design project by prototyping etc., particularly related to furniture design. They are similar in terms of steps, practice and implementation. In the furniture-designing phase, design and development processes are integrated so that the outcome is a furniture product with optimum qualities that fulfills desire requirements.

Every design process generally begins with idea generation or researching market analysis followed by concept proposals, prototyping and testing, analysis and refining stages. In this thesis, product development process means the stages come after first concept proposal and lasts until design is finalized and ready for manufacturing. The product development process can vary among industries and individual companies in terms of the stages involved, time length of each stage, stage sequencing, and the total time span involved [30].

After studying and consulting different available process models, the following model (figure 4) is prepared and proposed by the author for this research project. This model will be in discussion throughout the whole study.

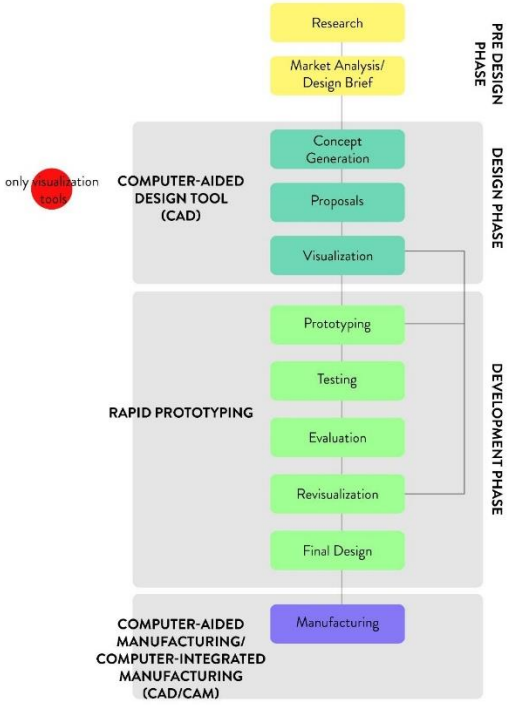

Figure 4 Furniture Design and Development Process Model

Furniture design companies, studios, or individual designer analyze market needs or listen to the client. This market analysis or dialogue with customer creates a need for the new design or

a starting point for design. This research phase provides a ground for new design. Design team follows these grounded factors and translate them into visual language of design.

In general, furniture designing involves four phases, the research and analysis phase (pre-design phase) positioning phase, conceptualization phase and detailed design phase (development phase). Design teams start translating grounded factors highlighted during pre-design phase. Design team uses all their skills to produce some results. Conventional ways to conceptualize and visualize a design include hand sketching and handmade scale models. This way to visualize a design is time taking and human energy consuming. Another drawback of this practice is that design team can only produce limited results.

Dirk Vander Kooij [31] crafted his endless chair designed by using one plastic string with the assistance of a robot (additive manufacturing). This chair is an example of making furniture products by using non-human ways and digital media. A computer generated design file was translated into execution command. By analysing the whole process, the author has concluded that this case illustrates the importance of CAM tool/s during the furniture development process. However, this case indirectly relates to the generative design process.

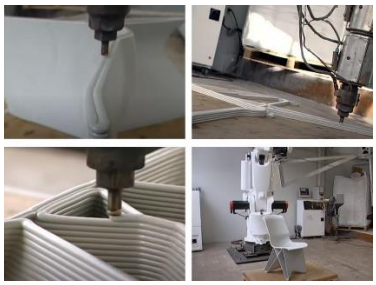

Figure 5 Endless chair additive manufacturing process

After studying and analysing this example, it can be stated that technology has changed the way we approach design and manufacturing techniques. In comparison to conventional furniture design and make process where the design process starts from a sketch on a paper and then following the sequence of steps in ends with a 3d model that is just a visual representation of final furniture product. Today, furniture design process is more digital and innovative, where it starts on a computer screen and ends on a 3d model that is more than a virtual representation of the final product. This computer generated 3d model is ready for production using CAM tools (Additive manufacturing). Therefore, the above figure 4 can be amended and represented as the following figure 6.

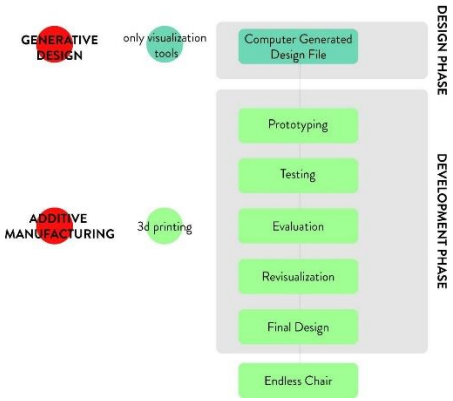

Figure 6 Digital design and development process for endless chair

3.2 | PARAMETRIC MODELING VS DIRECT MODELING TECHNIQUE

How about starting a design process on computer screen rather than on a piece of paper and through a rough sketch? Technology has changed the way we approach towards an idea or a concept. The process of interviewing and surveys to collect information or data about users or a problem has been changed by internet of things (IoT). Today, we get data from interactive tools and analyze it in minutes to find a problem. Similarly, today, we do not need a paper to make a sketch as technology has made it possible to start ideation and conceptualizing a product directly on a computer screen using computer aided design tools.

Computer-aided design tools enhance the creativity of designers. Today designers can design and conceptualize innovative products in relatively less time than by hand drawings. These tools (such as Rhino, Autodesk Fusion 360, 3ds max, Dreamcatcher and many more) play a significant role in increasing the quality and aesthetic of design. These computer –aided design tools consist of two modeling standards: direct or geometry modeling and parametric modeling.

CAD tools generate outcomes which are directly dependent on the ability to use them. Direct modeling process helps designers to make quick ideas and proposals. It empowers designers to capture and define geometry quickly without worrying about product features and constraints. This type of modeling process is feasible for straightforward objects and geometry. These programs are relatively easy to interact and operate (for example, AutoCAD, Solidworks & Inventor) but, they are very restricted to model complex and curvy design. On the other hand, some of CAD tools (Fusion 360, Rhino, 3ds Max, CATIA) are integrated with parametric modeling technique that has made it possible to model impossible designs. Designers feel more flexible and relax when they draw. Although, this modeling technique is not easy to learn but it offers liberty to make changes to the model anytime. Parametric modeling is a mathematical and systematic approach to 3d design. By changing variable, resulted outcomes can be visualized in seconds. Today, designers use parametric modeling technique to design 3d models and prefer it over direct modeling process because of its multiple advantages. The following table 2 shows the comparison between these two modeling techniques.

Table 2 Comparison between modeling techniques

Direct Modeling Technique	Parametric Modeling technique
Quick ideas/modeling	Everything is possible to model
Easy to learn	Flexibility to make amendments during and after
Limited modeling and editing tools	Post modeling editing is possible
Complex modeling is not possible	Multiple design iterations
Hard to model curves	Variable based modeling
Post modeling editing is not possible	Better understanding and analysis of geometry using tools
No link with CAM tools	Linked with CAM tools
No iterations are possible	Iterations are possible

3.3 | GENERATIVE DESIGN – AN ADVANCE LANGUAGE OF DESIGN

The followers of direct modeling technique could find creative and new ideas during the process but this technique is not good for complex objects and cannot generate iterations. Moreover, direct modeling technique requires more time to model an object and after modeling amendments are not possible. Also direct modeling approach offers limited options of a designed object [32]. Parametric tools are now integrating with new options that will not only increase the creativity of designers but will also allow them to choose the best model among infinite options. CAD tools now enhancing the decision making power of designers along with creativity. Combination of Rhino and Grasshopper can enable designers to create innovative and new design forms and lead them to decide the best solution among computer generated unlimited opportunities. This advance process to CAD tools is called generative design.

Generative modeling (3rd paradigm) technique is an iterative 3d design process that creates an infinite number of 3d design outputs and these computer generated outputs meet certain design features and constraints set by the designer. In this process, the designer can fine tune the best feasible solution by choosing specific outputs or by changing input variables and constraints.

The computer generated outputs could be 3d models, sounds, images, animations and much more. Therefore, it is a fast method to explore design possibilities in contrast to conventional direct modeling techniques (1st paradigm of modeling techniques).

In the light of the reviewed literature and the above comparison, table 2, made between modeling techniques, it is concluded that generative design and parametric modeling technique

can be applied to advance the furniture design and make process. With the implementation of this advance language of design, new developments can be made in furniture design.

3.4 | METHODOLOGY OF GENERATIVE DESIGN PROCESS

In generative design, instead of drawing the products manually, the designer starts working on computer screen using digital tool (Rhino, Fusion 360, SolidWorks, etc.) and creates multiple options based on required parameters. After the modeling process, he visualizes and analyses the solutions to select final output. The Following figure 7 shows this methodology.

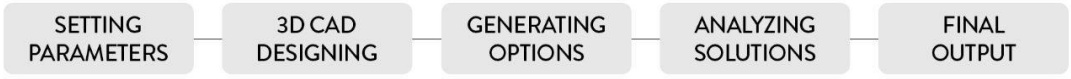

Figure 7 Methodology of generative design process

To explain this, take in consideration the following two examples:

3.4.1 | EXAMPLE-1

The designer wants to design a chair. Instead of start working and drawing on paper to explore possible forms and developments, he sets some parameters like thickness, length, width, seat height, back rest angle, material type, manufacturing process, cost etc. and designs a 3d model in software. Depending on the set parameters and variables, computer generates iterations and then designer makes decisions to get final output. The following sample work (Figures 8 and 9) is done to explain this methodology in Rhino 7 and grasshopper. The author has got some expertise in this generative design tool during his research project to illustrate some practical work. In this example 5, parameters were finalized 1) thickness, 2) seat height, 3) seat width, 4) seat depth and 5) backrest height. Then using modeling and editing tools (Box domain, move tool, addition tool) he modelled the block. Once the 3d CAD model was ready by changing the parameters iterations were produced.

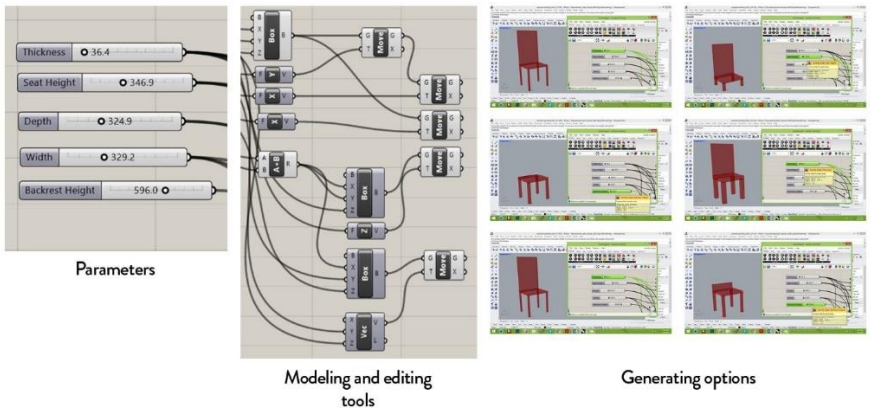

Figure 8 Example 1 How generative process works in Rhino

3.4.2 | EXAMPLE-2

To explain this process a practical is done in Rhino 7 to model a chair based on multiple parameters, such as, thickness, height, back rest height and angle, seat width, accuracy and

smoothness of curves, back rest curvature, base curvature, seat contour, steepness of curves and color swatches. This chair has been modeled in total 9 steps and above mentioned parameters can be seen in the following figure 9.

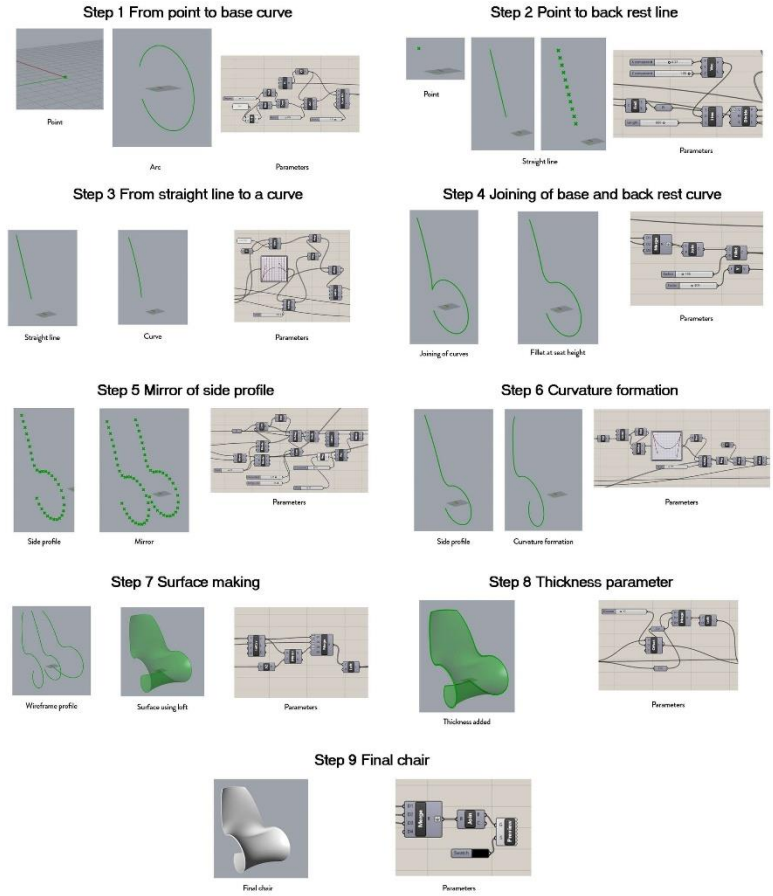

Figure 9 Example-2 Step 9 final chair in Rhino

This chair is an example of digital process to design furniture pieces using digital tool. This process gives the liberty to design and explore any form that is imaginable and offers flexibility in the development process to make multiple design options. Following Figure 10 shows multiple iterations created using Rhino 7 for the above mentioned chair.

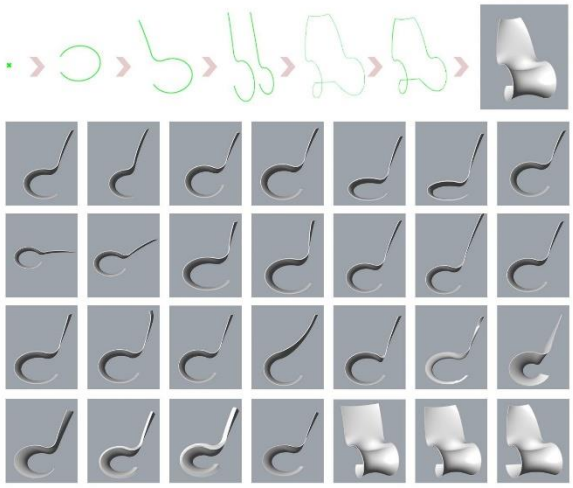

Figure 10 Example-2 Designing a chair in Rhino 7 using generative design process

3.4.3 | EXAMPLE-3

To support the practical work, the following example 3 shows how a table with multiple adjustable parameters can be modelled in Rhino.

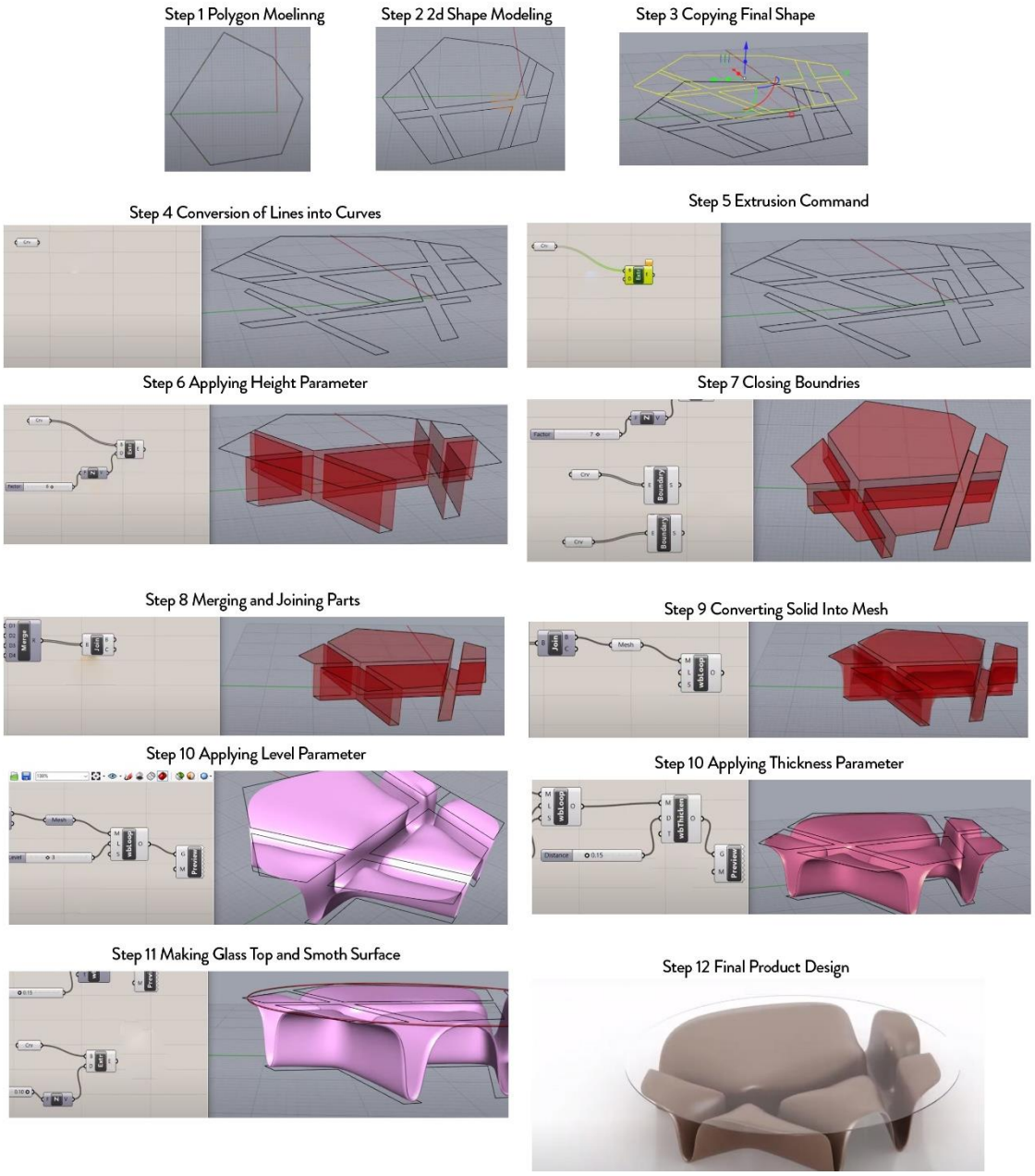

Figure 11 Example-3 Designing a Table in Rhino 7 using generative design process

4 | DIGITAL DESIGN METHODOLOGY FOR FURNITURE DESIGN JOURNAL PAPER PREPARATION

The designer uses CAD tools as a starting point to make ideas and concepts. This way of thinking is called as a digital methodology in this research project. This way of using CAD tools has significant output for design process. This digital way of designing leads to better accuracy, quicker adaptation to the initial concepts, ability to produce new alternatives, ease of revision, quality and realistic results and most importantly ready to manufacture products. By integrating this with the design process, a digital methodology for furniture design can be proposed as:

Figure 12 Digital design methodology for furniture design

4.1 | CHARACTERISTICS AND BENEFITS

The following figure 12 shows the characteristics and benefits of digital methodology in design process.

Figure 13 Benefits and Characteristics of digital methodology

4.1.1 | INNOVATIVE DESIGN

With the help of digital tools, it is now true and possible to create and develop any forms that are imaginable. Generative design tools allow designers to draw complex curves in any dimension and has made possible to fabricate designed objects as well. These tools enable them to think out of the box and ideate innovative concepts without any compromises. With the use of parametric modeling technique it is possible to draw, manipulate and achieve curved structured of furniture pieces on computer screen and later to fabricate those using CAM tools. This characteristic is not directly available in direct modeling tools like AutoCAD.

4.1.2 | READY TO MAKE

Parametric modeling technique based CAD tool such as Rhino, Dreamcatcher, Fusion 360 and Solidworks that are being used in the field of furniture design have the possibility to generate ready to make models. These software support most of the available rapid manufacturing techniques. This computer generated file is used for 3d printing, rapid prototyping and computer aided manufacturing. The best advantage of this linkage between CAD-CAM tools is that the designer is able to see final outputs in minutes and make changes to the design very easily. In this way, design development, prototyping, testing, evaluation and amendments steps (see figure V) squeeze into less steps and divided into CAD-CAM tools.

4.1.3 | PROCESSING TIME

Digital tools have made it possible to draw objects and make technical details in less time as compared to hand drawn technical drawings and models. Digital method has shortened the time of drawing. Visualization, technical resolution, concept forming, 3d modeling and simulation is relatively easy and quicker with the help of CAD tools. These tools fasten the process of design and development. With the help of CAD tools it is easy to go back to initial design and make changes.

4.1.4 | MASS CUSTOMIZATION

Technology has changed the way of manufacturing. 3d digital tools have made complex design easy and quicker. Rapid prototyping has made possible to produce different parts in different materials and in less time. Today in the age of fast fashion, where customers want options and variety and want to customize products according to his taste. They want to be treated as individuals not as a part of the crowd, generative design tools have made such customization real. These tools can generate hundreds of iterations in seconds. Parametric modeling and generative design tools offer the possibilities of exploring new versions of design thus, they are able to produce new alternatives with respect to shape, form, material, size and colors.

4.1.5 | COST

Although digital tools have changed the way of designing and manufacturing and they have made these processes faster and quicker, these tools require time and expertise to learn and operate. In terms of initial time investment and during learning phase, these tools could be expensive but later on, they are very important to reduce product cost. These tools are very helpful to calculate per part cost as well as product cost. In addition, we can also calculate material and manufacturing cost.

5 | DISCUSSIONS

It is clear that technology is influencing the design process and assisting the design community to create solutions in less time. Still, there are some limitations. Computer generated designs are created using algorithms and based on computer suggestions not based on human decisions. However, advancement in software make this possible as well. Now, it is possible to select the best possible solution that best fits the user and manufacturing constraints. The data we input into software is now helping to choose the best design among hundreds of computer-generated options.

Less parameters and variables lead to faster processing time during the design process. But when working with many parameters to generate thousands of design alternatives, understanding each parameter's effect and behavior on the output design is sometimes beyond human comprehension. In the future, it is believed that generative design software will allow and enable designers to apply machine learning to identify and understand parameters during design process.

Generative design processes are best to analyze product parts individually irrespective of their shape, form and complexity. Integration of generative design tools with additive manufacturing machines and printers made possible to produce such complex parts that were hard to

conceptualize. This benefit of generative design on manufacturing is one among many others. Generative design is not particularly beneficial during furniture design and development phases. However, it can be more helpful during post designing phases, like material sampling and handling, production, packaging, marketing and distribution. Now the question is can we produce such designs that are ready to manufacture and sale? Can we incorporate real data (end user needs and wants, trends, running or upcoming style, economy, environmental issues, etc.) as an input to generate design instead of functional and aesthesis parameter inputs?

6 | CONCLUSION

Innovation and creativity are considered to be essential to a successful product. Therefore, digital design processes bring the benefits of parametric and generative design for exploration and conceptualization of products along with production and engineering. The designer can effectively explore vast options and generate ingenious design iterations to make better design decisions. In sums, generative design process empowers design community and enhances their capabilities and skills. Digital methodology for furniture design makes the whole process faster, quicker and better. It makes less imposition on the designer's work process and keeps the flexibility and fluidity of his work constant for creative and innovative design exploration and conceptualization.

Generative design process can be followed separately to initiate a design project or it can be combined with conventional furniture design and development process for faster, quicker, better and innovative results. This hybrid system will be more productive for the designer as he can combine his manual and digital skills to create design solutions. The following figure 13 shows this hybrid furniture design and development process.

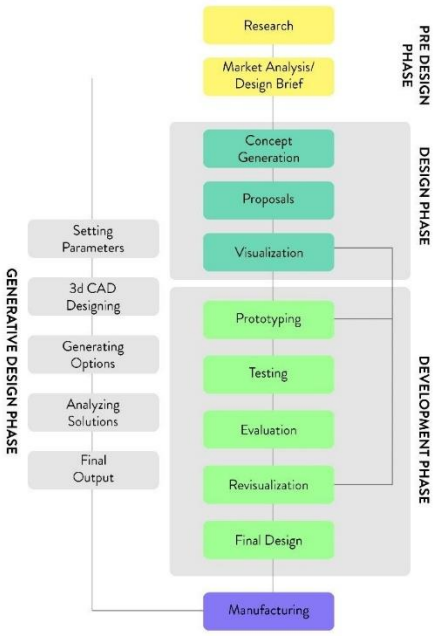

Figure 14 Hybrid design and development process (generative and conventional process)

This research was carried out, specifically, keeping the industrial environment of Pakistan Furniture Industry in reference. Developed countries already have implemented advance digital design and development tools and the outcome is not deniable. Arthur's professional role as a mentor is influencing Pakistan Furniture Industry, directly and indirectly. This research proposal helped the author to create an awareness at a very initial level in the targeted scope with the hope to encourage authorities to take some serious steps towards the institutionalization of technological advancement in the design education sector. In addition, this research also helped the author to explore new opportunities within furniture design and development process. This not only honed the author's knowledge in the state of the art but also enabled him to share more advance knowledge about CAD tools with his students. This research motivated many individuals with technology mind who want to explore digital tools. By following and integrating advance design tools to the design process, developments in furniture industry in Pakistan can be made possible in a short time. Curriculum developments can be made in accordance to the evolving technologies and likewise transformations in industrial production sectors can be made.

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DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

CONFLICT OF INTEREST

The author declares no potential conflict of interest for this article.

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