Application of Generative Design in Social Manufacturing

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Abstract. The aim of this research paper is to introduce generative design in social manufacturing, describe the core features of our Generative Design Platform, and demonstrate different types of human-machine interaction with the robotic arm use case supported by this tool. This report describes work in progress.

Keywords: Social Manufacturing, Generative Design, Parametric Modelling, Rapid Prototyping, User Experience, Physical Prototype, Virtual Prototype, User Interaction

1 Introduction

The Generative Design Platform (GDP), developed within the iPRODUCE project funded by the European Union's Horizon 2020 research and innovation program under Grant Agreement no. 870037, promotes generative design techniques through the implementation of parametric modelling and application of genetic algorithms for both "makers" (engineers, designers, manufacturers) and consumers.

The Generative Design Platform consists of three major components: 3D Configurator allows an end customer to select a basic 3D design of a product type depending on a use case and configure it corresponding to individual wishes; 2D Layout Planner decides on the best physical arrangement of all items within a defined facility layout; Spatial Instructor provides an intuitive interface in form of a chatbot, that interprets natural language and generates desired spatial layouts.

In this paper we show the usage of the GDP, in particular 3D Configurator, with a robot arm use case for the evaluation of multiple human-machine interactions and different aspects of the design and product functionality at a very early concept phase. The digital representation of the prototype is developed with visual scripting technology, the core technology of the 3D configurator, where both design and functionality are defined in a visual way. The approach described in this paper has a significant contribution into the existing studies, while it involves following innovative aspects:

1. Combination of several technologies within one engineering process (visual scripting, parametric modelling, generative design, digital twin, rapid prototyping) for improved user experience

2. User friendly techniques for generative design for creating novel designs based on parametric modeling, which helps provisioning of typical engineering techniques with easy interfaces for a better accessibility by non-tech users to allow involvement of more stakeholders into the design process
3. Combination of multiple end-user interfaces of different types: visualization with digital twin, graphical user interfaces on top of digital twin, MIDI control for a haptic access, a remote (Wi-Fi) control via an OSC-application on mobile devices, automatic control with sensorics

2 Background: The Emergence of Social Manufacturing

2.1 Collaborative Aspects of Social manufacturing

The iPRODUCE project is devoted to a novel social manufacturing platform with multi-stakeholder interactions and collaborations to support user-driven open innovation and co-creation [1]. The major objectives are represented by bringing closer manufacturers, makers, and consumer communities; engaging them into the joint co-creation process; and sharing common practices, methods, and tools.

Collective manufacturing represents a novel manufacturing model, where public and private sectors cooperate to enfold great economic and social potential [2]. Collaborative manufacturing allows effective usage of shared resources, enables access to the direct user feedback from social networks and coordinates centrally the usage of devices by means of cloud services.

Digital manufacturing involves many activities such as 3D printing, e-manufacturing or constructive manufacturing, and advances production systems by means of digital technologies [3]. Currently fab labs and makerspaces enable low-cost prototyping, offer access for makers, entrepreneurs, and small-medium enterprises (SMEs) companies to digital manufacturing and networking.

The emergence of social manufacturing created welcoming conditions for the maker movement within civil society and increased the number of people willing to join this initiative.

2.2 Maker movement and citizens engagement

The maker movement emerged as a sub-type of digital manufacturing, enabled by the rapid spread of complimentary digital tools within society, and supported by access to hardware devices in makerspaces and fab labs. These individuals, who support maker movement are often called ‘makers’, while they create new things by their own initiative. The development of additive manufacturing and computation power offered new opportunities for mass customization, reduced cost, and contributed to novel forms of e-engineering such as generative design, parametric modelling, and visual scripting.
Many makers strive for cooperation, knowledge sharing, exploration of open-source applications with an aim to make, create, design, and innovate things [3]. Based on the high interest to Do-It-Yourself (DIY) techniques within civil society, many maker communities emerged.

The maker communities offer great opportunities for networking, sharing, and knowledge exchange. For example, Thingeverse [4], MyMiniFactory [5], YouMagine [6] are dedicated to the sharing of user-created digital design files suitable for different manufacturing technologies, including user specific customization. The leading companies such as Arduino [7] and Ultimaker [8] offer complimentary software and platforms for the non-makers and young people to foster their interest to the existing technologies, therefore, increase usage and engagement rates within civil society.

2.3 Engineering with generative design, parametric modelling, and visual scripting

The generative design is a form of solution engineering based on a problem specification, rules, constraints, and optimization goals. The process withing generative design involves automated generation of optimized models, supported by pre-defined rules and constrains. Fusion 360 [9], Siemens NX [10], and SolidEdge [11] apply generative design practices in design, engineering, electronics, and manufacturing. Nevertheless, the functionality of the given tools is limited to the automated generation by means of predefined algorithms and require engineering skills.

The parametric modeling plays a significant role for the application of generative design in 3D/2D construction and optimization, because the parametric models have an ability to define the way object is created and the way it can be modified. Rhinoceros 6 and 7 [12] together with Grasshopper [13] enable creation of parametric 2D & 3D models, Galapagos Plugin [14] performs generative studies.

The visual scripting is a programming paradigm based on the graphical elements in the form of visual expressions, spatial arrangements of text, and graphic symbols. Grasshopper and Bolt by Unity [16] offer solutions for programming without a line of code, nevertheless, these tools stay dependent on the programming logic. The combination of visual scripting for parametric modelling and generative design in our Generative Design Platform enables effective modelling and model optimization.

3 The Generative Design Platform

3.1 Core functionality and User Interfaces

The GDP applies different generative design techniques through the integration of genetic algorithms within different user interfaces. The GDP consists of three major sections shown on Fig. 1 – 3D Configurator, 2D Layout Planner, Spatial Instructor – and one supportive component for management purpose. Each of these components represents a special graphical user interface (GUI) serving different usage scenarios.

The 3D Configurator tool enables a real-time visualization of the introduced parametric models for a 3D product design. Users have a possibility to change parameters, set up constraints, get a real-time visualization of changed parametric model, and download the final model. The parametric modelling in 3D configurator plays a significant role in the generation process, while it enables customization of chosen parameters. The search for an optimal model can be automated by a genetic algorithm that generates multiple models according to the optimization goals defined by the user

Fig. 1. The user interfaces for 3D configurator, 2D layout planner, and Spatial instructor.

The 2D Layout Planner offers advanced opportunities for space definition and asset allocation by means of genetic algorithm. This tool is predominately assumed to place objects on a 2D surface of an office environment or conference facilities, and offers many predefined office assets (tables, chairs, desks). A user can create a new layout from scratch by placing assets and applying genetic algorithms according to the requirements. The resulting optimal layout can be pre-viewed as a 2D or 3D visualization and shared as a JSON format with other participants.

The Spatial Instructor tool offers an opportunity to generate 3D or 2D objects and locate them in the 3D/2D space through a natural language communication. The interface in form of chat-bot processes textual inputs, recognizes objects and their location, and visualizes the generated results in the pre-view window. The major commands are represented by object creation and relocation, color and form restrictions, rule applications related to multiple objects processing within one layout. During the dialog with the bot, a user can request a generation of an optimal object allocation.

The last section, product management, carries out a supportive function with an aim to collect, manage, and share results from the main functional components. A typical example process for the usage of the GDP for the social manufacturing is shown on Fig. 2. Here users with different roles participates at different stages, use different GDP components, and exchange their results, requirements, and constraints over the GDP.

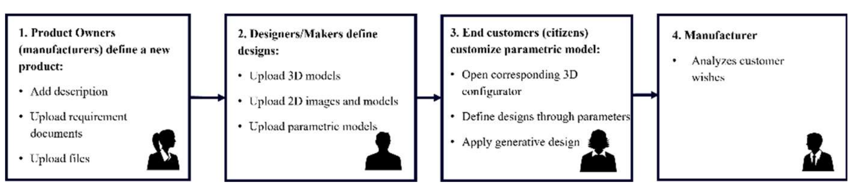

Fig. 2. Design process lifecycle within generative design platform

3.2 Technologies used in the GDP

The implementation of the GDP is mainly based on an open-source, cross-platform, back-end JavaScript runtime environment, such as node.js [17], a JavaScript runtime built, such as .NET Core [18], and an end-to-end development platform, such as Docker [19]. Node.js enables data collection from users and communicates with the GDP server by means of RESTful API. .NET Core is used for the GDP server and for the 2D Layout backend (BE) to process API calls in the separated applications. Docker application supports the GDP implementation by encapsulating each component with different development environment into one container. For example, we use a React-based application for the 2D Layout Planner frontend (FE) and encapsulate this into one container, which is accessed via an internal URL path from the GDP frontend. In this way, we can easily integrate different technologies into one GDP application as illustrated in Fig. 3.

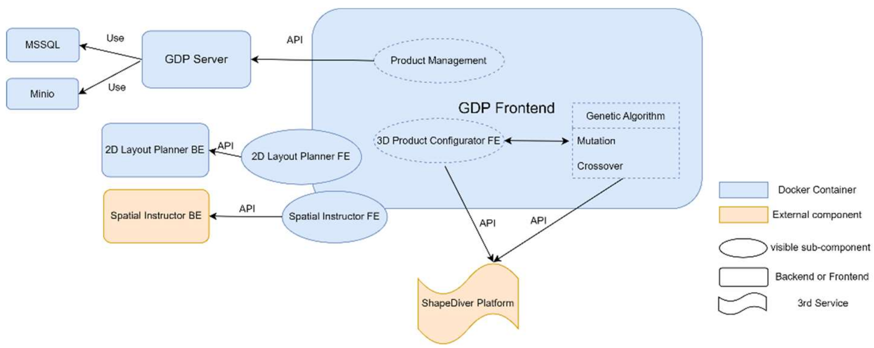

Fig. 3. Overview of GDP components

The GDP also communicates with external components, such as Spatial Instructor BE and ShapeDiver Platform [15]. Spatial Instructor BE is hosted on a different cloud resource exploiting the GPT-3 engine for the natural language processing. Spatial Instructor FE sends API calls via external URL path. ShapeDiver is a 3rd party platform with a cloud service for web-based 3D model visualization and is heavily used by the 3D Configurator component. We developed several examples of parametric models within Rhinoceros/Grasshopper [13] for 3D design generation and transformation – robot arm, back brace, headboard, chairs, and others – which were uploaded to the ShapeDiver platform for the remote usage. 3D Configurator FE sends API calls with the required parameters to ShapeDiver, and it replies back with the rendered geometry and its data which are visualized on the 3D Configurator page.

For the generative design approach, we are developing a genetic algorithm (GA) to find the optimal geometry model for 3D configurator. Our genetic algorithm creates a pool of individual designs for different parameter values and select the best out of them corresponding to the target criteria defined by the user. GA extends the pool applying crossover and mutation operations and reduce it by selecting designs with the best values of the optimization target.

4 Use Case from the Social Manufacturing

4.1 Rapid Prototyping of Assistive Robotics

Originally, a virtual representation and a physical prototype have been developed from scratch to show design possibilities and movement simulations of the future digital twin. The initial virtual design was developed as one of the use cases in the GDP, a parametric model within the 3D Configurator component, created with the help of visual scripting in Grasshopper [13]. Firstly, the virtual simulation was applied to evaluate the design decisions. Secondly, simple physical prototype, based on a selected virtual design, was developed by means of the rapid prototyping techniques such as 3D printing and usage of basic electronics.

The physical prototype was interconnected with an Arduino microcontroller and the virtual representation from Grasshopper, this enabled continuous input and output exchange between both prototypes. This connection was also used to calibrate the functionality of both virtual and physical worlds to make them consistent to each other (see Fig. 4). During the functionality evaluation, the physical prototype interacted with the environment by means of temperature, light, magnet, voice, and obstacle detection sensors. Depending on the combination of sensors values, the behavior of the physical arm prototype and its digital twin changes.

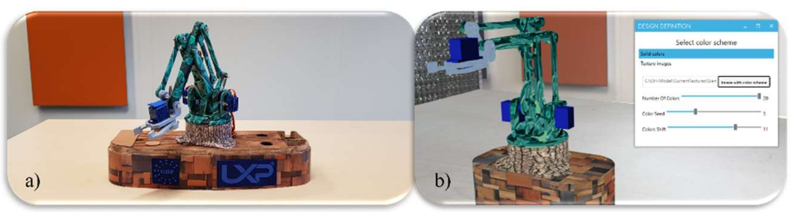

Fig. 4. Digital Twin: a) the physical prototype; b) the virtual prototype.

The parametric nature of the Grasshopper' models allows to define multiple design parameters easily as inputs and to calculate diverse outputs for the model generated for those parameters. This implies that a user can easily define his/her own generative design settings by selecting design parameters as genes and an output value as the optimization target to steer the genetic algorithm.

In this use case the generative design was used for multiple optimizations related to the packaging, transportation, and movement. Thanks to the successful optimizations and rapid prototyping techniques, the cost for the physical prototype and the construction time were minimized. Moreover, the robotic arm use case contributed to the effective evaluation of suitable design and proper functionality in the early stages by means of visual scripting, electronic prototype, 3D printing prototyping, and generative design. The physical prototype was tested for the following application domains: kitchen aid, tinker assistance, and care service.

4.2 Evaluation of the Human-Machine Interaction

This research project involved the application of multiple human-machine-interactions prototypically and evaluated the following types of interfaces: GUI to allow user's inputs within the virtual prototype; Musical Instrument Digital Interface (MIDI) controller as a haptic interface in a physical world connected to the digital twin; diverse sensorics linked to the physical prototype; mobile device with a special application for wireless connection as a remote control (Fig. 5.).

Fig. 5. Different types of interfaces (GUI, MIDI, sensorics, mobile device).

The listed user interactions were designed with visual scripting in Grasshopper, where each input parameter in the original parametric model was connected to a so called "fusion" function. This function collects the corresponding values from all connected UIs and selects the resulting values for the model generation. When several different input signals for the same parameter arrive simultaneously, the "fusion" function defines the priority of the activated UIs. For example, a human can interact with the robot arm over a set of different sensors. A combination of sensors' values determines the behavior of both prototypes (virtual and physical), e.g., to test collision avoidance.

These user interfaces were prototyped to improve user experience and to evaluate the input fusion during concurrent sessions of co-design. The variety of interfaces aims to engage different customers with different (physical and mental) abilities and different personal preferences, but still produce the same outputs on both virtual representation and physical prototype.

5 Conclusion

We have recognized that the connection from the physical prototype to the digital twin helped to improve the virtual prototype by adding constrains observed in the physical world. This research project demonstrated the value of the rapid prototyping at the early stages of sustainable development and effective tool evaluation.

This research project illustrated multiple opportunities for user interaction based on the robot arm example. A low-cost rapid prototyping technique contributed to successful evaluation of design, functionality, and user experience. The user-friendly interfaces of the GDP have an ability to engage people with different abilities and skills into the design process.

This paper reports about work in progress. The described tool and its application in different domains are still under development. For the next steps we plan to add more UI types – connection to the chat bot from Spatial Instructor, speech recognition, gesture recognition – and extend the current version with remote control over the internet.

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