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Generative design and insights in strategies for the development of innovative products with tailored mechanical and/or functional properties

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ABSTRACT
Creative design methods should allow the extraction of novel wisdoms and favour their integration into many technological domains, thus leading to an innovative product. The current research reports some technical considerations on the role of generative design as a "collaborative partner" in supporting the ideation process through the development of design alternatives in agreement with the designer's criteria.
A specific case study was considered and the role of the generative design method was stressed, also focusing on technical features and differences in terms of solutions for the given design problem. The possibility of selecting well defined manufacturing methods (e.g., traditional or advanced – additive manufacturing) was highlighted.

Section: RESEARCH PAPER

Keywords: Generative design; design methods; additive manufacturing; mechanical measurements; product design and development

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1. INTRODUCTION

The advances in design strategies, materials science and technologies have pushed the research towards the development of innovative methodologies and products with improved properties for both industrial [1]-[4] and biomedical [5]-[16] applications, as well as in cultural heritage [17], [18].

Today, an engineer may employ a great number of tools for supporting the early phases of the design process. Over the past years, a suitable set of computer-aided design (CAD) tools has been developed for providing a support to the ideation process of several design alternatives, in agreement with the designer's criteria.

In this scenario, generative design tools are usually considered.

The potential of these tools and the related differences have been frequently analysed in the early design phases, also taking into account industrial cases.

Conceptual design can be considered a fuzzy front-end phase in the product development process. It may be considered as a fundamental step in the process of product development, where a designer may generate and evaluate several design alternatives in order to find the optimal solutions.

It is well known how at this step the technical decisions can strongly affect the successive phases of the product development, also including several areas (e.g., testing, manufacturing) [19], [20].

The possibility of determining up to 80% of the product costs within the end of the design phase was already reported [19], [21].

Consequently, different requirements should be considered in the design phase, the aim being to prevent the accumulation of additional costs in the successive process steps.

Designers and engineers have developed a wide range of design tools for supporting creativity, thus promoting a faster generation of concepts and testing phase. This should clearly accelerate the design process [19], [22].

Unlike the past years, complex numerical operations, continuous iterations and optimizations may be possible in a short time, due to the current availability of high-performance computing power via cloud.

Multiphasic and complex simulations can be run for analysing different configurations of a product in several conditions.

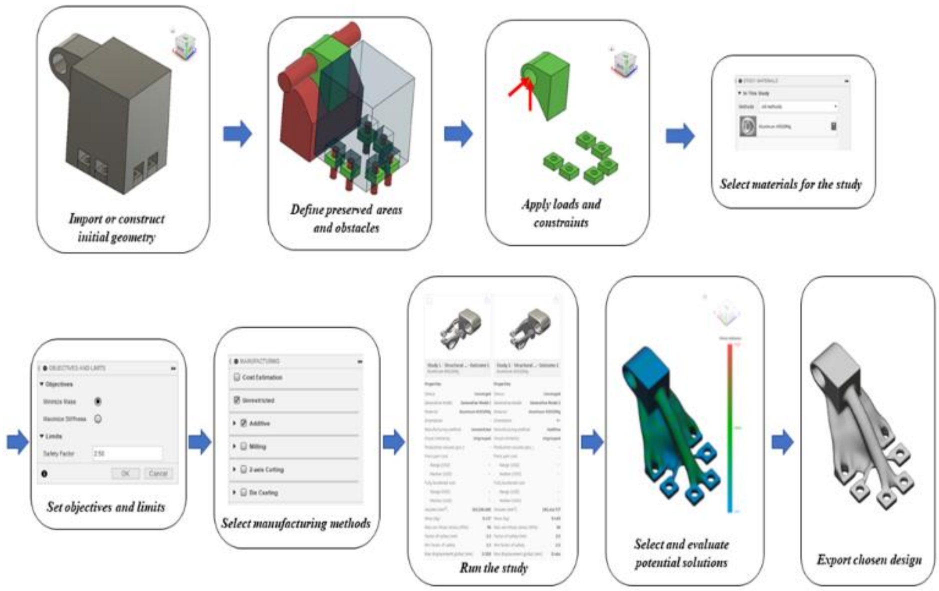

Figure 1. Workflow adopted in the case study.

With regard to the technologies, the increasing development of additive manufacturing has led to great changes in the design and fabrication processes of the products.

It has been currently stressed the possibility of developing components with very complex geometries suitably satisfying the design requirements, also overcoming the drawbacks related to the traditional manufacturing processes [19], [22], [23].

The engineering of innovative structures with enhanced functionalities may be obtained by novel design processes, where the use of suitable CAD tools can provide a shift of the support systems for the design to the conceptual design [19], [22], [24].

In the past years, CAD tools were not generally employed by the designers for the development of ideas, but only for their implementation [19].

In this context, the introduction of generative design tools has supported the designers' creativity as they can generate multiple design alternatives.

A novel design approach is now feasible through the possibility of selecting a wide range of materials and manufacturing techniques in a single study [19].

In this context, the aim of the current research was to focus on a specific case study, reporting technical considerations on the role of generative design as a fundamental support to the ideation process through the development of design alternatives in agreement with the designer's criteria.

In particular, technical features and differences concerning design solutions were reported.

2. CASE STUDY

A model of the door support fitting was considered as a case study and designed. The model was imported into the generative design workspace (Fusion 360, Autodesk), and AlSi10Mg was selected as material.

The definition of loads and structural constraints was an important step in the process. A simplified model was applied to the device. It had to be as light as possible and the displacement of the loaded point lower than a fixed value in both loading conditions

Briefly, with regard to the boundary conditions, all the translations were fixed at the fasteners hole centre. Two loading cases were analysed to simulate two different conditions i) vertical loading – the door is opened with its weight inducing a vertical load on each support; ii) lateral loading – the door is closed with the locking system inducing a lateral load on each support.

Figure 1 reports a typical workflow for the study.

If compared to the topology optimization process, generative design method does not consider the concept of the maximum volume as a limitation of the design space [19].

In particular, this approach is not based on the removal of the unnecessary material, but it builds up the geometry through the connection of the preserved design areas, while avoiding prohibited areas (i.e., "obstacles") [19].

The design space was defined by bodies taking part in the definition of the design problem. Specifically, it included parts of the following types of geometry: preserved geometry and obstacle geometry.

The preserved geometries were assigned to the parts that had to be incorporated in the final design shape; such parts are displayed in green in Figure 1.

The obstacle geometries were assigned to the parts representing empty spaces where the material was not placed during the outcome generation; such parts are displayed in red in Figure 1.

The possibility of taking into account multiple different materials and manufacturing techniques at the same time reduces the number of analyses which are normally required.

In addition, stiffness maximization or mass reduction can be generally defined as design objective.

As a result of a generative design study, several solutions are usually available. They satisfy the input data and the design objectives in different manners.

This clearly suggests that different combinations of structures and materials can be feasible.

In general, the manufacturing limitations can be also considered in the generative design study, and some of the generated solutions should not need a further redesign [19], [22].

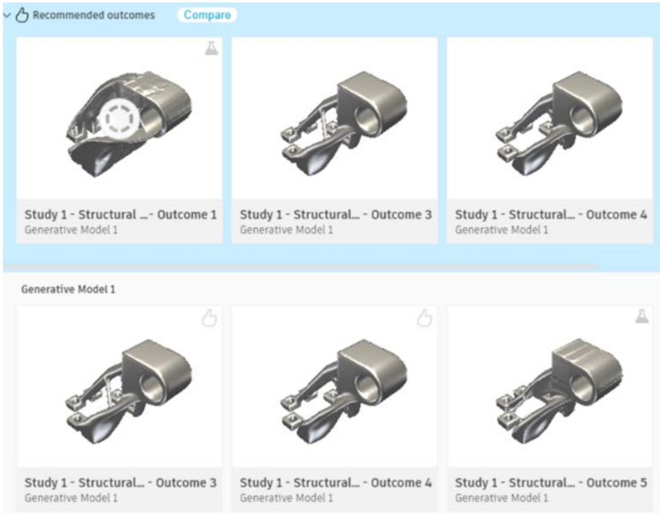

Figure 2. Examples of several outcomes to create a specific design.

In the reported case study, the objective was to minimise mass, and 2.5 was the safety factor limit.

With regard to the manufacturing methods, traditional (i.e., die casting, 3-axis milling) and advanced (i.e., additive manufacturing) technologies were considered in terms of options.

The obtained outcomes were explored in terms of manufacturing features ad methods, using the suite of the exploration tools (Figure 2).

The outcomes were properly sorted satisfying the design criteria.

Figure 3 to Figure 6 report some examples of the generated results (i.e., mass decreasing from 0.9 to 0.5 kg), also providing a suitable combination of the geometry and manufacturing option.

In particular, these examples are related to the converged and completed outcome status, where the safety factor limit was met.

3. TO FURTHER IMPLEMENT THE DESIGNER'S GUIDELINES

The employed algorithms also considered the manufacturing limitations.

Accordingly, some of the obtained results did not need further redesign.

This means that the objectives were reached during the generation of the several outcomes and the minimum factor of safety was equal or greater than the safety factor limit.

However, it is also worth noting that many outcomes were not considered as the minimum factor of safety was lower than the defined limit for the safety factor (2.5); the iteration limit was met before achieving the safety factor limit (Figure 7).

Anyway, this outcome was also considered as a starting shape in a successive process of concept generation to obtain further alternative solutions.

Thus, if the final outcome does not meet all the criteria defined in the study, it may still be considered to generate valid outcomes, in many cases working better than the previously obtained findings for the design needs.

4. CONCLUSIONS

"Generative design" may be considered as collaborative partner for the designer [19].

In particular, this term is generally used for describing a wide range of methods that are able to support the product

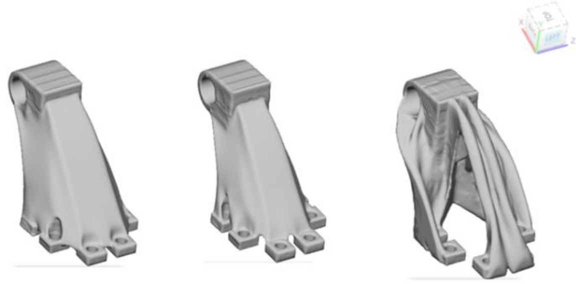

Figure 3. Some examples of the generated results – die casting, orientation Y+Y-.

Figure 4. Some examples of the generated results – die casting, orientation Z+Z-.

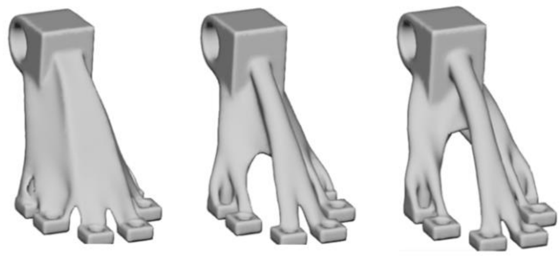

Figure 5. Some examples of the generated results – 3-axis milling, orientation X+,Y+,Z+, X-,Y-,Z-.

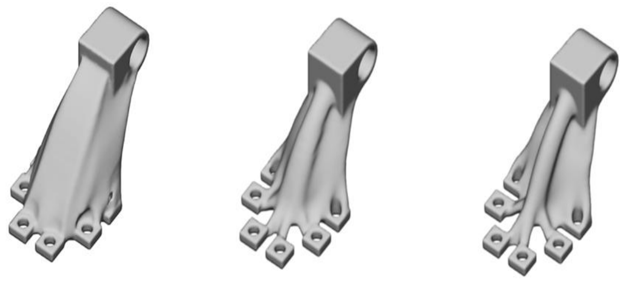

Figure 6. Some examples of the generated results – additive manufacturing, orientation Y+.

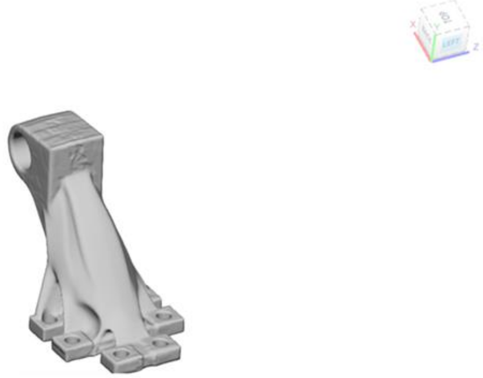

Figure 7. An example related to an outcome where the safety factor limit was not met

development through computational capabilities, thus generating feasible solutions [19].

This design method uses algorithms and artificial intelligence to develop multiple technical solutions according to well-defined design criteria and constraints.

Such approach aims at expanding the designer's reference frames and provides novel findings, without considering already known solutions.

The current research reported an example related to the integration of a structural design with a modelling approach focusing on a performance-driven generative design process, evidencing the possibility of exploring several design alternatives.

In the proposed study, the objective was the mass minimisation, the idea being to minimise the required amount of materials, while satisfying the structural and functional requirements (i.e., strength and maximum displacement).

The obtained findings highlight how generative design represents a powerful tool leading to innovative designs, which are impossible or difficult to obtain by means of conventional design methods.

However, a wide of applications and implementations may be covered, starting from the field of industrial manufacturing to biomedical examples.

Furthermore, differently from conventional manufacturing methods, additive manufacturing allows the fabrication of customised devices with tailored mechanical and functional properties, complex geometries and architectures, also enhancing the performance of critical components in different fields.

Accordingly, in the industrial production, the increasing applications of additive manufacturing technologies have currently led to product reimagination from a new standpoint.

From a technical point of view, the reported considerations may allow the designer to explore other design options and variations, also quickly assessing and refining them based on defined requirements (e.g., performance, functional and structural features).

This clearly provides technical suggestions for re-design guidelines.

For this reason, benefiting from the technical considerations reported in the study, future research steps would lead to the design of advanced and lightweight products, with a focus on the improvement of the quality and the environmental impact together with the time and cost reduction, enhancing the product development efficiency.

A bioinspired generative design for additive manufacturing could also favour the development of innovative products based on the extraction of novel wisdoms.

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