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ROLE OF DESIGN FOR ERGONOMICS AND ADDITIVE MANUFACTURING IN SIMULTANEOUS ENGINEERING

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Abstract This paper aims to emphasize the role of advanced methods, tools and technologies in simultaneous engineering. Design for Ergonomics (DFE) and Additive Manufacturing (AM) play an important role in Simultaneous Engineering (SE) by improving product development through customer-centered design as well as advanced design and manufacturing techniques. Generative Design (GD) has a significant role in product design and in the implementation of ergonomics by leveraging Artificial Intelligence (AI) to create optimized user-centered product models.

Keywords: Simultaneous engineering; design for ergonomics; additive manufacturing; generative design, safety.

1. INTRODUCTION

Report R-338 of Institute for Defense Analyses (IDA) [1], coined the term concurrent/simultaneous engineering to explain the systematic method of simultaneous design of both the product and associated processes. The IDA report, thus, launched the first definition of simultaneous/concurrent engineering, namely [1]: „Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.”

Simultaneous engineering is characterized by its focus on customer requirements and priorities, on the belief that quality is the result of process improvement and, IDA [1] emphasizes, simultaneous engineering is a philosophy according to which the improvement of design, production and support processes are permanent responsibilities of the entire organization. However, the key, the essence of simultaneous engineering is the integrated and simultaneous design of the product and its associated processes which is a totally different approach from sequential engineering [1-3].

In sequential engineering, information flows in one direction (Figure 1). Errors identified in the downstream stages and the changes required by them are fed back to the upstream stages, which leads to wasted time, resources and high costs. In simultaneous approach, information flows are bidirectional and decisions are based on the consideration of both downstream and upstream data (Figure 1).

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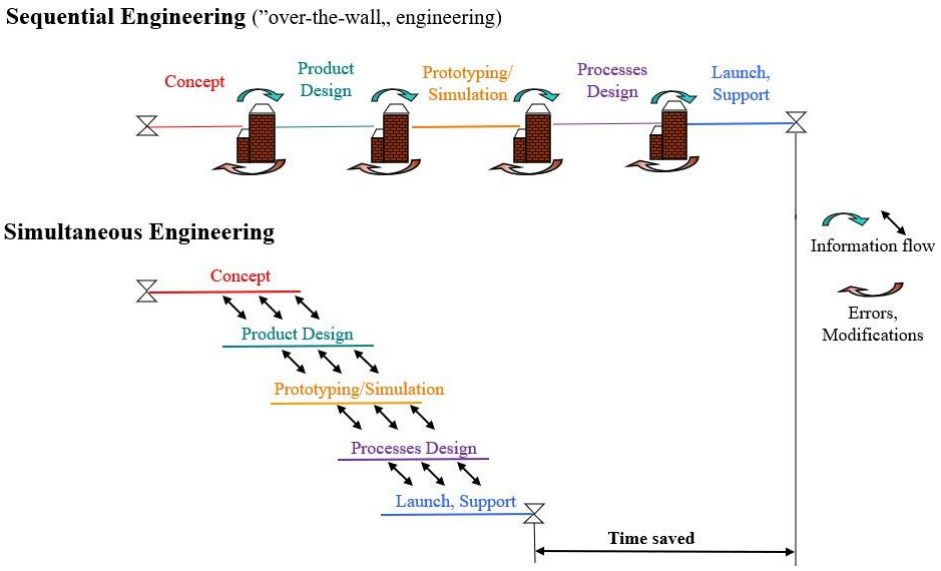

Figure 1. Secvential engineering vs Simultaneous engineering.

Most traditional systems require the part geometry to be complete or nearly complete before a technology design iteration begins. The SE intends to work with approximate models involving certain parameters common to multiple disciplines/stages involved in the product life cycle. Thus, when an activity has sufficient information available, it can start before the previous activity is completed (Figure 1).

Implementing such an organization requires that each subsequent activity knows the status of the previous activity. This implies collaboration between product life cycle activities, overlapping and interdependence of tasks. Moreover, such an approach, and the companies studied in the IDA report found that achieving this information exchange requires changes both at the organizational and technological level. Several companies that have implemented simultaneous engineering have presented evidence of how the application of one or more of the elements associated with simultaneous engineering has helped them achieve the goals of lower cost, higher quality, and shorter development times [1, 2, 4] which also became the objectives of simultaneous engineering.

It can be stated that the main objective of concurrent engineering is to reduce the time of development and launch on the market (time-to-market) of the product. For this, it aims to parallel the activity of the different fields that intervene on the product. It is very obvious that simultaneous engineering is not a product, i.e. it cannot be bought off the shelf. It is neither a strict process nor certain predetermined steps. Simultaneous engineering can best be described as a management philosophy - a way of thinking, of approaching a situation. It is very important to understand the concept and the effective use of methods, tools, more specifically the essential elements (Figure 2) of simultaneous engineering [1-3] through which parallelism can be achieved in the design and development of new products. Simultaneous engineering ensures an environment in which the collaboration of different specializations and departments is encouraged, supported and improved towards the same goal of creating a product according to engineering requirements.

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People, processes and technology are essential to any organization and are essential in implementing simultaneous engineering to obtain shorter development time, lower cost, improved product quality and meet customer requirements (Figure 2). But people need appropriate methods, technology and also tools to carry out the processes.

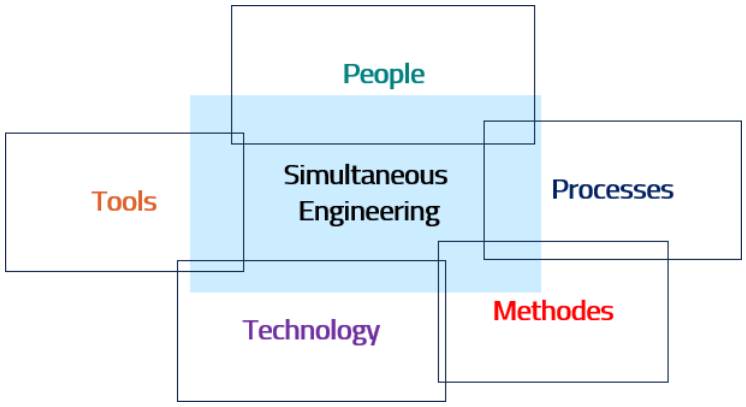

Figure 2. Key elements of simultaneou engineering.

People are the backbone of any organization. Simultaneous product development is a multidisciplinary team task. SE requires multidisciplinary teamwork. The multidisciplinary team brings together different specialists involved in the product life cycle activities. Each member brings his/her contribution and competence to the realization of the tasks so that the common objective can be achieved: a quality product that meets the customer's requirements, easy to manufacture, inexpensive and above all, designed and made faster than the competition. Team members are selected for their ability to contribute to the design process by identifying potential problems early and initiating timely action to avoid bottlenecks.

In order to achieve the objectives, SE and hence the organizations that have implemented SE use a number of methods (for designing and supporting processes) to help understand the behavior of processes, products, mechanisms and lead to significant reduction of life cycle cost, shortened design cycles and improved quality.

In the results of the published studies [1, 2, 5-7] it is mentioned that organizations use both "formal" methods such as: Quality Function Deployment (QFD), Design of Experiments (DoE), Failure Modes and Effect Analysis (FMEA), as well as recent, newer methods such as: Design For Assembly (DFA), Design For Manufacturing (DFM), Design For Manufacturing and Assembly (DFMA), Design For Excellence (DFX), where "X" can mean: cost (Design For Cost - DFC), additive manufacturing (Design For Additive Manufacturing - DFAM), sustainability (Design For Sustainability - DFS), ergonomics (Design For Ergonomics-DFE) etc. An advanced and powerful method is Generative Design. Not all of these methods must be implemented by organizations, but a combination of some of them can be used in specific cases. Some of the mentioned methods are already included in software systems used in simultaneous engineering and not only [8-10]. Combining these methods can have an even greater positive effect on the final product.

In this paper, the role in Simultaneous Engineering of Design for Ergonomics and one of the most

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advanced design methods, Generative Design, is emphasized. Also, the role of the emerging technology of Additive Manufacturing in SE is highlighted, the connection with the Design for Ergonomics method as well as with the advanced design method, Generative Design.

2. DESIGN FOR ERGONOMICS IN SIMULTANEOUS ENGINEERING

Ergonomic design aims to design products and environments that are efficient, safe and easy for people to use. It can help improve productivity, reduce employee and customer injuries and increase their satisfaction [11, 12].

Design for Ergonomics refers to the design method that ensures certain characteristics, functions, principles or quality criteria related to ergonomics are reflected in the final product design. So that ergonomic problems can be identified and eliminated from the stage of product conception [11-13]. In the multidisciplinary SE team, the ergonomist will collaborate with the designer, the manufacturing engineer, and can make recommendations regarding the assembly process, the equipment and tools that will be used or the layout of the work area [13].

DFE plays a crucial role in SE, ensuring that products are designed with user comfort, safety and efficiency in mind from the very beginning of the development process [14, 15]. Some of the key aspects of the role of DFE in SE are summarized below.

Integrated design process

In Simultaneous Engineering, different aspects of product development are addressed simultaneously rather than sequentially [1, 2, 13]. This integration allows ergonomic considerations to be incorporated early in the design process, ensuring that the final product meets ergonomic standards without the need for costly redesigns.

User-centered design

Ergonomics concentrates on designing products that fit the needs and abilities of users. By integrating ergonomic principles into SE, designers can create products that are more intuitive, more comfortable, and safer to use. This approach helps to identify and solve potential ergonomic problems early [14, 15].

Improved collaboration

Concurrent Engineering promotes collaboration between different disciplines, including ergonomics, design and manufacturing. This collaborative approach ensures that ergonomic considerations are balanced with other design, manufacturing (such as manufacturability) and profitability requirements.

Increased productivity and quality

By addressing ergonomic factors early in the design process, SE helps create products that lead to increased productivity and reduce the risk of user injury. This leads to higher quality products that are more likely to meet user expectations and required standards [16].

Rapid prototyping and testing

SE often involves rapid prototyping and iterative testing. Ergonomic designs can be quickly prototyped

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and tested with real users, allowing for immediate feedback and adjustments. This iterative process helps refine the design to better meet ergonomic criteria [17].

Cost and time savings

Incorporating ergonomics into SE can lead to significant cost and time savings. By identifying and addressing ergonomic issues early, companies can avoid costly redesigns and modifications later in the development process. This efficiency contributes to faster time-to-market and reduced development costs.

By integrating DFE into SE, companies can create products that are not only functional and efficient, but also comfortable and safe for users. While digital tools and simulations are an integral part of SE, integrating ergonomic assessments into these tools can be challenging as well as beneficial. Ensuring that ergonomic considerations are accurately represented in digital models and simulations requires specialized software but also expertise [18].

Advanced, emerging technologies are already having a significant impact on manufacturing, influencing how products are designed, developed and brought to market. Emerging technologies also rise to today's ergonomic challenges [19-21]. From AI integration in CAD/CAM systems, cloud computing and Digital Twins to Extended Reality (with Virtual Reality, Augmented Reality), these trends of transformation are shaping the future of manufacturing and prefigure a new era of optimized design, improved and efficient production and sustainability [21-23].

2.1. Generative Design in Ergonomics

Generative Design is an advanced design method that uses AI to generate multiple and diverse design solutions. The generation of multiple design options is based on design criteria and constraints imposed by the designer and takes place in the early stages of product development (concept, design) (Figure 3). GD allows designers to quickly evaluate and filter the generated options based on the imposed requirements, such as functionality, ergonomics, and performance [23-27].

Used in various fields (engineering, robotics, product design, architecture, fashion design), GD helps to obtain optimized design variants that can be more innovative and efficient that would be difficult to achieve through classical design. Also, the involvement of AI leads to the efficiency of the design process, reducing the number of iterations, which results in resource and time savings [25, 26].

Generative Design plays a significant role in SE and the implementation of ergonomics principles in product design by using algorithms and AI to create optimized, user-centered designs. By incorporating generative design into the ergonomic design process, designers can create products that are not only highly functional, but also tailored to the unique needs of individual users, enhancing comfort, safety and utility. The most important aspects covered by Generative Design from an ergonomic point of view are summarized below.

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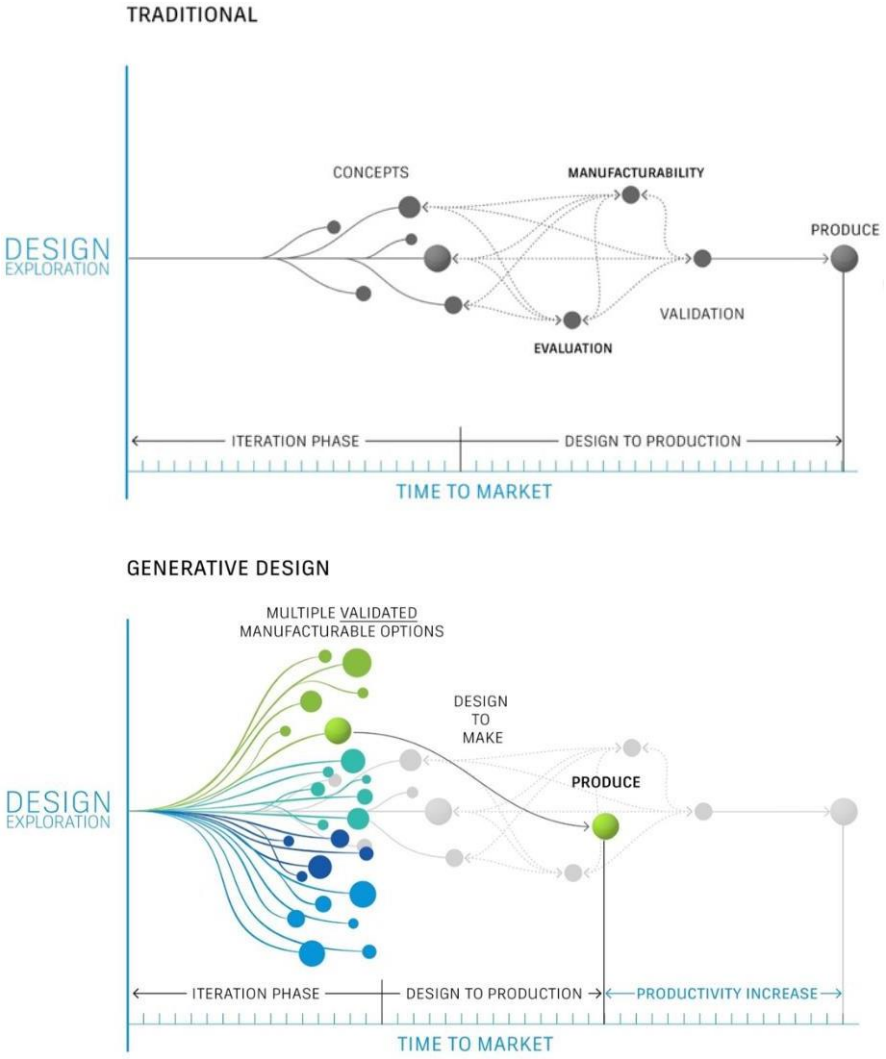

Figure 3. Traditional vs Generative Design [26].

Customization

Generative design allows the creation of highly customized products, adapted to the individual needs of users. By inputting specific ergonomic requirements, such as body measurements or user preferences, the AI algorithm can generate a model that provides optimal comfort and usability [18].

Analysis of design alternatives

Generative design algorithms can quickly generate and analyse a large number of project alternatives from the early stages of development (concept, design) (Figure 3). This capability allows designers to evaluate multiple ergonomic solutions and choose the one that best meets user needs. It helps to identify innovative solutions that might not be discovered through traditional design methods [28].

Optimizing for comfort and efficiency

Generative design can optimize products for ergonomic requirements such as weight distribution, grip comfort, and ease of use. For example, in the design of a tool handle, the AI algorithm can adjust the geometry to minimize strain on the user's hand and wrist, increasing overall comfort and reducing the

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risk of injury [18].

Integration with additive manufacturing

Generative design facilitates rapid prototyping, allowing designers to quickly produce and test multiple variants/iterations of a product. This iterative process is crucial to ergonomic design because it allows for continuous refinement based on user feedback and ergonomic assessments.

AM can produce the complex, organic shapes often generated by AI algorithms, enabling the creation of ergonomic designs that are both functional and aesthetically pleasing. This integration supports the production of customized products such as prostheses or wearable devices [18, 24]. The most well-known advanced software systems that offer generative design capabilities are Fusion 360 (from Autodesk), NX (Siemens), Creo Generative Design (from PTC), MSC Apex Generative Design (MSC Software), nTop Platform (nTopology) [23].

2.2. Additive Manufacturing in Design for Ergonomics

Additive manufacturing plays a significant role in improving design ergonomics by not only enabling new geometries through early revisions, but also influencing the way designers think during product design. Design for Ergonomics and Additive Manufacturing is closely linked and AM contributes to the improvement of DFE.

- AM technology can produce near-net shape parts with complex geometries that are difficult or impossible to achieve by conventional manufacturing methods (Figure 4). This capability enables the design of more innovative ergonomic products that better fit the human body [29, 30].
- Designers can quickly produce and test prototypes, making iterative improvements based on ergonomic assessments. This iterative process, right from the design stage, is essential for DFE to achieve the best fit and function for users and ensures that the final product is ergonomically optimized (Figure 4).
- AM allows the creation of products with a high degree of customization, adapted to individual needs. This is particularly beneficial in DFE, which aims to adapt products to fit the specific needs and physical characteristics of users significantly improving comfort and efficiency [5, 17, 29, 30].
- Both AM and DFE emphasize a human-centered approach. DFE focuses on user needs and limitations, while AM provides the flexibility to create products that meet these needs and enhances the usability and safety of products, making them easier to use [17, 29].
- AM combined with generative design can lead to the creation of ergonomic products that are both functional, safe and comfortable.

The potential of GD is maximized if AM technology is used for fast manufacturing of the product. GD combined with the capabilities of AM technology leads to obtaining an optimized design from the first phases of the product design process. Generative Design makes the convergence of design and manufacturing a reality, and Simultaneous Engineering can truly be implemented as a technology-enhanced automated process. Generative design gives the SE team the power to generate multiple CAD design options, based on additive and subtractive constraints of real manufacturing [25].

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Figure 4. Toyota car seat frame created using GD and 3D printing [30].

3. CONCLUSION

SE involves the parallel development of different stages of the product life cycle. Integrating DFE and AM in the early stages of development ensures that ergonomic and manufacturing considerations are addressed concurrently, resulting in more coherent and efficient product development. Integrating DFE and AM into SE encourages collaboration between multidisciplinary team members as well as with different teams, ensuring that all aspects of the product, from user comfort to manufacturability are considered simultaneously. Also, combining DFE with AM in a SE framework leads to innovative solutions that are both easy to use and easy to manufacture. This approach improves product quality and reduces time-to-market.

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