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TRANSDISCIPLINARITY AND DESIGN: COMPARATIVE REVIEW AND SYNTHESIS FOR THE DESIGN PROCESS

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ABSTRACT

Transdisciplinarity gained importance in the 1970s, with the initial signs of weakness of both multi- and interdisciplinary approaches. This weakness was felt due to the increased complexity in the social and technological landscapes. Generally, discussion over the transdisciplinary topic is centred in social and health sciences. Therefore, the major challenge in this research is to adapt design research to the emerging transdisciplinary discussion.

Based on a comparative and critical review of several engineering and design models for the design process, we advocate the importance of collaboration and conceptualisation for these disciplines. Therefore, a transdisciplinary and conceptual cooperation between engineering and industrial design disciplines is considered as decisive to create breakthroughs. Furthermore, a synthesis is proposed, in order to foster the cooperation between engineering and industrial design.

Keywords: design process; transdisciplinarity; industrial design; engineering

INTRODUCTION

A positive energy in fostering cross-functional collaborations characterises the current design landscape[1]. Therefore, literature considers design as a total phenomenon, as it normally operates in relation to a wider range of other disciplines and knowledge[2]. This diversified knowledge increases the current complexity of the design problems, and the social and scientific knowledge required to address them increases accordingly[3]. Therefore, this amplified complexity, in both the social and the scientific landscapes, placed the ground for a cross-functional approach as a recognised key to solve this intricacy[4]. However, the referred collaboration between different design disciplines has different tactics, and these distinctive strategies are, sometimes, wrongly considered as having the same philosophy.

Notwithstanding the relevance of other disciplines for new product development (NPD), such as economics, sociology or marketing, the conceptual relationship between mechanical engineering and industrial design grounds this paper. To create new products, or to improve the existing ones, the design process should be then improved accordingly[5]**.** However, and despite the importance of the overall design process, the early and conceptual stage is currently the object of the main action. This early phase was denominated as the Fuzzy Front-End (FFE) in the 1990s[6] and its actual significance is the result of an increased preoccupation with innovation. Also, the diversified array of practitioners waiting to have a voice in design process attributed the current significance for the FFE[7]. Notwithstanding the vastness of design models, literature is inconclusive with an optimal solution; the existing consensus is that there is no set best practice. Other existing consensus is that different design problems necessarily admit different design methods and tools[8]. Hence, we present in this paper a comparative and critical analysis to some design models, spanned throughout engineering and industrial design. Thereby, the general motivation for this study lies in the conceptual and collaborative relationship between engineering and industrial design, inside a NPD context.

This paper starts with a discussion over the transdisciplinary relevance in the current social and technological context. Then, we present a critical analysis of eight design models, with three having an engineering approach, other three having a designerly perspective, and the last two having alternative structures. After that, we will present our brief and synthesising proposal for the conceptual phase of the design process. Finally, we advance with our concise conclusions on this study.

TRANSDISCIPLINARITY

The need for collaboration is now firmly established in many disciplines. However, some people wrongly consider interdisciplinary, multidisciplinary and transdisciplinary, the three forms of collaboration most frequently mentioned, as essentially synonymous terms[9]. As the last two decades of designing large-scale complex systems have demonstrated the inefficiency of either the inter- or the multidisciplinary approaches[10], transdisciplinarity gained importance. It is presently understood as a process or an activity that produces, integrates and manages knowledge in the scientific, social and technological areas. Transdisciplinarity has evolved from special types of problems, which ask for the integration of both scientific and social knowledge[11].

On the one hand, Sanders[12] argues that the boundaries between the design disciplines are now blurring, as many more want to be involved early in the design process[13]. On the other hand, Ertas[14] advocates the elimination of disciplinary boundaries with the aim of stronger collaborations, to be one of the fundamental characteristics for transdisciplinarity. Therein, research from different disciplines work together to develop and use a shared conceptual framework to solve common problems [15]. The overall objective for this paper is to study the collaboration between engineering and industrial design in the conceptual stages of the NPD. Therefore, a parallel between these two project disciplines and the integrative referred characteristics of the transdisciplinary approach might be traced. Correspondingly, an emerging topic that may explain the benefits of a transdisciplinary approach between both disciplines is the Technology-Epiphanies trend. This trend results in the identification of the more powerful and successful new meanings in products enabled by new technologies[16]. In this new paradigm, the designer could potentiate and exploit the use of the new technologies, with his user approach. Conversely, the engineer may foster new meanings and needs to society, with his scientific and technological perspective and knowledge. Nevertheless, only few companies, such as *Apple*, *Philips*, or *Nintendo* have already mastered the technological innovation together with the socio-cultural impact 17. This transdisciplinary epiphany subject is being analysed in parallel.

Bruce Archer

Bruce Archer, one of the organisers of the Design Methods Conference in 1962 18, published in 1963 his first design model. It was the first attempt to break the design process into linear stages 19. A representation of this model is illustrated in Figure 1.

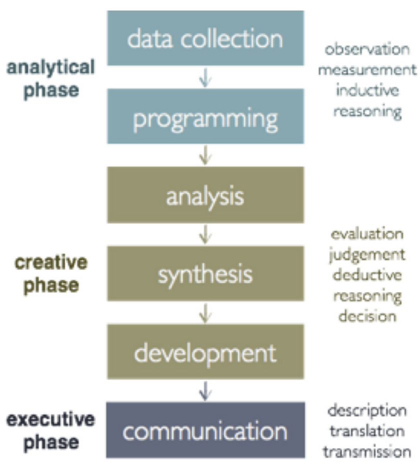

Figure 1 | Bruce Archer's Design Model [adapted from (Council, 2007)]

Three main stages are clearly highlighted: the analytical, the creative and the executive. The generative phase in this model ends in the synthesis step, comprising more than half of the entire model. Interestingly, communication is considered to be the final step, due to the general idea that the project must pass to an internal and executive decision. Yet, Nigel Cross[20] considers this model to be swamped in the fine detail of numerous tasks and activities that are necessary in all practical design work. As referred, a SWOT analysis is conducted to all the presented models and the SWOT to Archer model is represented below (Table 1).

Table 1 | SWOT analysis to Archer's model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
The first model	Numerous tasks and activities	Three clear main stages	No iterations are considered
It tends to suggest a common structure	Linear process	Generalizable and highly influential	

From Table 1, a common structure might be generalizable. However, it is a linear model and presents no iterations.

Bruno Munari

The linear model from Archer, and some of his 1960s peers, was widely accepted. However, in the 1970s Bruno Munari sustained that no model must be considered as absolute or definite. Contrariwise, any model should be considered to be a changeable and iterative tool[21]. Furthermore, Bruno Munari[22] considers industrial design as a clear problem-solving discipline, as illustrated below (Figure 2).

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Figure 2 | Bruno Munari's Design Model [adapted from (Munari, 2006)]

Considering more recent literature, Munari's approach is, in somehow, obsolete, as both linearity and problem-solving approaches are being questioned in their innovativeness. In this model the process is triggered by a problem or a need and it is composed of nine steps. It is relevant to notice that the conceptual phase comprises approximately six steps, ending with the *experimentation* step.

Table 2 | SWOT analysis to Munari's model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Focus in the problem-solving	Numerous tasks and activities	Its creator considered it an incomplete contribution	Highly focused in the problem-solving approach
Individual contributions are accepted	Despite admitting iterations, linearity is advised	Improvements are accepted	

From Table 2, the problem-solving approach might be very restrictive according to the current perspective. Nevertheless, the ability to accept individual contributions is a positive attitude for continuous improvement.

Nigel Cross

Nigel Cross divided descriptive models from the prescriptive ones. The first ones usually identify the significance of generating a solution early in the process, and the later ones aim to persuade designers to adopt improved ways of learning. Accordingly, the first attempt from Archer (Figure 1) is considered as prescriptive[23]. Conversely, Cross[24] developed a simple descriptive model for the design process (Figure 3), based on the essential activities performed by the designer[25].

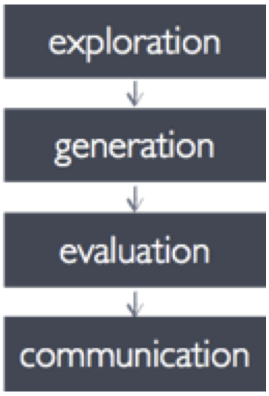

Figure 3 | descriptive model for the design process [adapted from (Cross, 2008)]

In a descriptive approach, Cross[26] considers the solution-focused nature of the design to be clear, as a simple solution is early developed. After some initial context *exploration*, the project arises from the *generation* of an initial idea or concept. Then, the design proposal is subjected to *evaluation* against the criteria of the design brief. It ends with *communication* of the concept ready to development[27]. Also, Cross[28] wanted to reduce the number steps, as he believed that a larger number and their corresponding activities might be hazardous for the smooth running of the process.

Table 3 | SWOT analysis to Cross's descriptive model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Focus in the problem-solving	Iterations only between the evaluation and the generation stages	An easily generalizable model	Solutions might be developed too early
Iteration loops are considered		Highly focused in the conceptual phase	

From Table 3, we might advance that *communication* is a transition step between the conceptual stage and the development one. With a descriptive approach, Cross[29] advises the early development of new concepts.

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Gavin Ambrose and Paul Harris

These two authors clearly reinforce the iterative characteristics of the design process. However, it is argued that the design process is linear in nature, as proposed in Figure 4 (Ambrose & Harris, 2009).

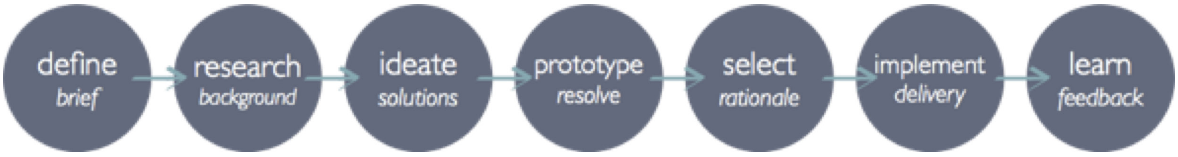

Figure 4 | Design Thinking process [adapted from (Ambrose & Harris, 2009)]

Ambrose and Harris (2009) are aligned with Munari[30], who has advised a certain order to coordinate the process, despite the considered iterative and creative character for the design process. Revisit earlier segments of the process, rework and iterate on them are considered as essential. Besides, it is considered that design thinking should be present in each step composing the design process (Ambrose & Harris, 2009).

Table 4 | SWOT analysis to the Design Thinking model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Creativity is inherently considered	Some conservatism for a model considered as iterative	Revisiting, iterating and reworking are advised	Despite the iterative character, linearity is advised
	A strict path is implied		

From Table 4, it is possible to highlight the inherent creative and iterative character for the design process, despite its linear and sequential shape.

Pahl, Wallace and Blessing

Phal, Wallace and Blessing (2007) consider a problem-solving approach for the design process as well. Accordingly, these authors believe that the process is triggered by a problem and the outcome is expected to be a solution for this same problem, as illustrated in Figure 5.

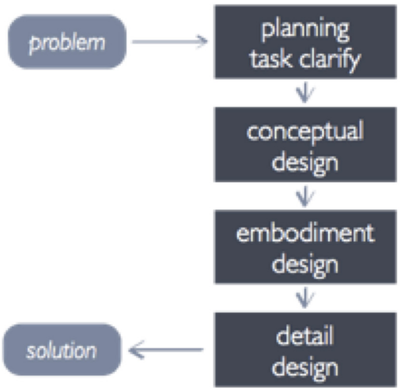

Figure 5 | Pahl, Wallace and Blessing's Design Model [adapted from (Pahl, Wallace, & Blessing, 2007)]

Regardless its structure, the challenge in defining a clear borderline between the four identified stages is underlined. Besides, their systematic approach aims to keep the iteration loops as small as possible in order to make design work effective and efficient (Pahl et al., 2007). The conceptual phase represents half of the entire process, and the importance of abstraction is emphasised over the early stages.

Table 5 | SWOT analysis to Pahl, Wallace and Blessing model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Stages are very clear	No iterations are admitted	The difficulties in create boundaries between the different steps	Mainly problem-solving
A solution concludes the process (problem-solving)	Linearity is advised		

From Table 5, it is possible to highlight the strict and linear approach proposed for the efficiency and effectiveness of the process. Also, the challenge in clearly borderline each step that composes the process is underlined.

Borja de Mozota

Borja de Mozota (2003) identified three types of design processes: the analytical, the iterative and the visionary. However, whether analytical, iterative or visionary, design process follows similar, yet different, stages (Figure 6).

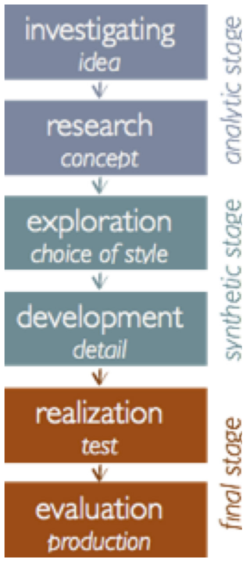

Figure 6 | Borja de Mozota's model for the design process [adapted from (Borja de Mozota, 2003)]

Generally, the iterative design processes are considered as the ones that produce the radical innovations (Borja de Mozota, 2003). It is assumed that the analytic stage comprises steps one and two, the synthetic stage comprises steps three and four and the final stage comprises steps five and six. Notwithstanding the perceived creative character for this design model, the more creative and conceptual stages end with step three, with the tasks of choice of ideas, selection of concepts and styling.

Table 6 | SWOT analysis to Borja de Mozota's model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Iterative processes are considered essential for radical innovations	Concepts to be found early in the process	Three main stages can be translated from this model	Iteration loops are not represented
		Easy to generalise a common structure	

From Table 6, and despite the advised iterative character for the design process, no iteration loops are represented, which assumes a threatening character. Nevertheless, the three and clear generic phases in this design model are well sustained and are very promising for generalisations.

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Vijay Kumar

According to Kumar (2013), the design process moves iteratively through different modes of activity to deliver real breakthroughs (Kumar, 2013). Therefore, this author proposed a non-linear and iterative model for the design process (Figure 7).

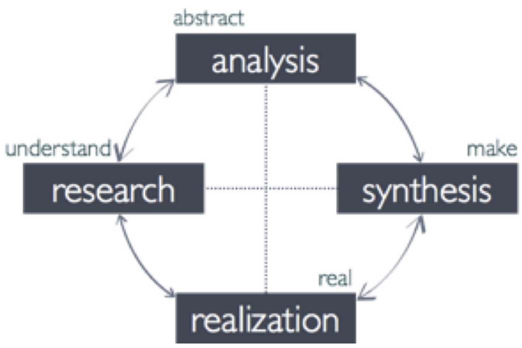

Figure 7 | Kumar's iterative model for the design process [adapted from (Kumar, 2013)]

Detailing each step, research is about knowing the reality. Analysis is about trying to come up with good mental models. Synthesis is about generating new concepts with previous abstract models. Lastly, realisation is about implementing tangible offerings. Besides, Kumar (2013) considers the design process as non-linear and iterative, advocating that more iterations might generally lead to more successful innovations (Kumar, 2013).

Table 7 | SWOT analysis to Kumar's model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
Highly iterative	Highly subjective	Focused in the conceptual phase	Difficulties is closing the loop
Design and technology-driven		More iterations to more successful innovations	The proposed iteration between the final and the initial stages

From Table 7, it is possible to notice the highly iterative character of a model, and the difficulties in closing the loop. However, Kumar considers the amount of iterations as decisive for successful innovation, and emphasises the importance of both design and technology for the conceptual phase.

Elizabeth Sanders

Elizabeth Sanders[31] developed a non-linear model for the design process as well. The initially referred Fuzzy Front-End (FFE) is clearly marked in this model, as illustrated below (Figure 8).

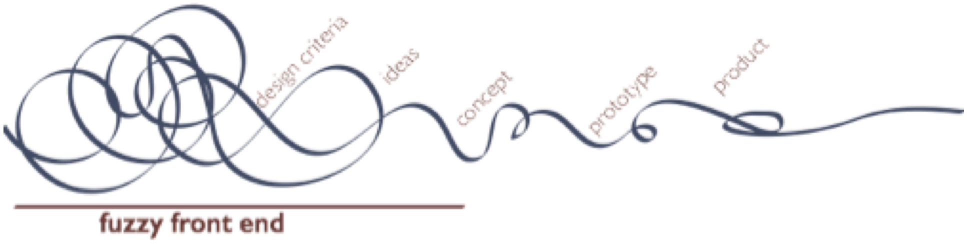

Figure 8 | generative model for the design process [adapted from (Sanders, 2010)

Presently, the FFE suffers from an increased interest over the design community. Its main focus in new ways of understanding and emphasising the wills and dreams of society are behind this interest[32]. Accordingly, the amount of time, resources and iterations applied at the early stages increased. Different areas of expertise, including engineering and design, should be assigned early to the process[33].

Table 8 | SWOT analysis to Sanders' model

Strengths	**W**eaknesses	**O**pportunities	**T**hreats
The generative space of the early stages is underlined	Highly abstract model	The conceptual stage represents half of the entire process	The amount of loops may swamp the process
Wide space for iterations		An early compromise between engineering and design	

From Table 8, we highlight the abstract character of this model, and the iterations perceived as decisive and positively generative. Also, we emphasise the suggested early and cross-functional compromise among engineering and industrial design.

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PROPOSED SYNTHESIS

As abovementioned, the models previously analysed represent a brief synthesis of the overall study on this topic. From this study, we highlight the general interest and debate over the FFE, as the development steps *per se* are already established and well documented in the literature. Therefore, the proposed synthesis presents four steps and it is mainly focused in the conceptual stage of the design process (Figure 9). This proposal is clearly influenced by the engineering design models from Nigel Cross[34] and Pahl, Wallace and Blessing (2007), despite presenting a non-linear structure as proposed by Sanders[35] and Kumar (2013). The general idea behind this model is to reduce to the minimum number of steps, as many tasks and activities may swamp the process[36].

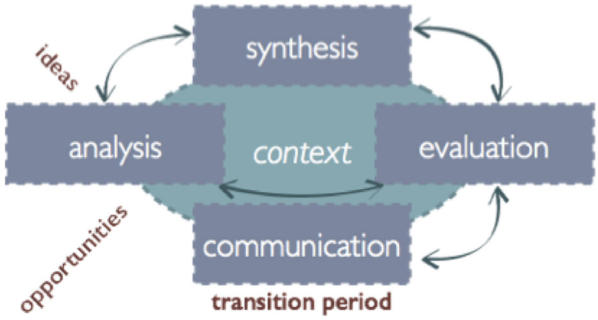

Figure 9 | Proposed synthesis for the conceptual phase of the design process (authors)

As above illustrated, both individual or group ideas and the identified market and technological opportunities may trigger the process. According to Kumar (2013), technological innovations start with the identification of new technology possibilities and opportunities, and design innovations start with the understanding of society and the development of new ideas for it. Thus, understanding where these two processes interact is the key to achieve a holistic and transdisciplinary success. From the wide spectrum of analysed models, a common structure was traced composed by *analysis*, *synthesis*, *evaluation* and *communication*. To foster creativity and innovative outcomes, iteration loops were inserted in-between each step composing this model. An additional loop was inserted between *evaluation* and *analysis* in order to reset the process if needed. The latter step, *communication*, was considered as a transition period, as the final outcomes have to be approved and developed internally or externally, depending on the NPD context.

Iterations should be fostered in-between all the steps and the context or environment in which the project is undergone. Besides, the dashed lines serve to illustrate this interacting purpose, aligned with the referred difficulties in border the steps composing any model (Pahl et al., 2007). This continuous interaction between all the steps and their context fosters transdisciplinarity since the early beginning of the process.

CONCLUSION

In this paper we have highlighted the importance of a transdisciplinary approach to deal with the increased challenges faced by society in general, and the design disciplines in particular. As the social and technological landscapes increased in complexity, companies undergoing NPD projects started to face new challenges. Therefore, several sources of knowledge got needed, and design disciplines became prone to positively cooperate since the early beginning of the design process. Notwithstanding the scarceness of conducted studies over this subject, it is our belief that an early, cross-functional and transdisciplinary approach might be beneficial for design in its broadest sense.

Regardless the variety of design models, we have underlined the importance of the abstract and generative stage. Therein, uncertainty and iterations were considered to face a highpoint when compared to the subsequent stages. The referred variety of design models might be explained by the diversity of design problems, and the extension of the design criteria to be solved early in the process. However, the discussion in the design landscape is now placed in collaborations over its conceptual phase, the FFE, due to its perceived impact in the overall design process. Therefore, a transdisciplinary approach among engineering and industrial design was considered as essential, and the proposed synthesis aimed to foster a holistic cooperation since the conceptual phase. Also, the continuous interaction with the social and technological context, identified in this synthesis, underlines this general idea. Further studies should then test and evaluate the proposed synthesis in academic and/or industrial environments.

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