Interdisciplinarity between design and engineering

Case study: the development of a classroom chair for children ages 6 - 10

Abstract— *The level of efficiency required nowadays for products to enter the competitive market, led to changes in the methodologies applied by the different actors involved in project development in particular in the area of Design.*

Today's approach to designing a product is not centred mainly on its creative/ aesthetic elements , but rather more and more on its functional purpose in order to adequately respond to the users 'needs and to comply with a wide range of standards, rules and regulations imposed by the market. To satisfy all these requirements, any industrial design project needs to integrate Engineering, Ergonomics or other areas as from its early stages of conception.

The area of Design depends on this interdisciplinary approach. For instance, to produce a sculpture, the artist only needs to choose the technology and the raw material. However, to produce a plastic bottle to contain water, specific chemical and mechanical strength testing is needed before selecting the most appropriate materials. This complexity in the field of Design led to innovative methodologies based on an interdisciplinary approach, in particular with the area of Engineering.

This methodology is currently applied for projects of Industrial Design by the students of the Master Course in Product and Industrial Design hosted by the Department of Mechanical Engineering FEUP. The integration of the industrial design course in this Faculty allows to develop projects with the contribution of the various fields of Engineering and to benefit from existing partnerships with the industrial sector.

The aim of this article is to demonstrate how this methodology was developed. It describes the working methods and processes of Engineering used by Designer as starting point for the development of new products.

Keywords—* *Interdisciplinarity; Design; Engineering; Similarities; classroom chair; school chair; Design methodology; Development of product; Interaction between concepts; Interaction between methodologies.

I. INTRODUCTION

Initially, the area of Design was simply considered the formalization of the product [1, 2]. The constant evolution of the market requirements led the designer to consider not only the appearance of the product, but also its features, thus leading to a new concept of Design as a discipline [3, 4].

Currently, the Design is increasingly seen as a sector that deals mainly with creating products for functional purposes but integrating also aesthetic features, in order to attract and, at the same time, to respond to the user needs [3, 5, 6].

In order to achieve this objective, the area of Industrial Design needs to draw on other complementary disciplines, such as Engineering, Ergonomics, Material Science, inter alia, as it would not be impossible to build or conceive this type of products in isolation [5, 7].

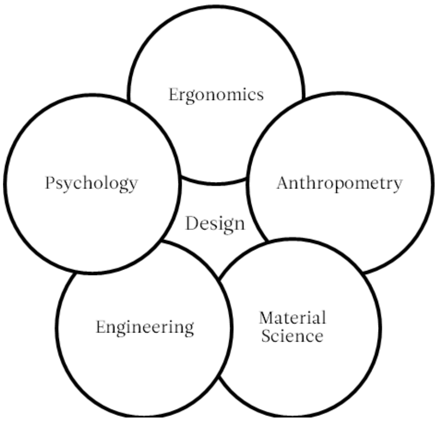

Fig. 1. *Areas contributing to the development of products*

This allows to acquire and to apply the theoretical knowledge in practice or real life situation by designing the products and simultaneously interacting with other areas that are useful to ensure the development of the product [3, 5, 6].

This approach reflects therefore the concept of interdisciplinarity in the area of Design defined by Fontoura [8], as consisting of exchanges between disciplines when there is an interaction between the methodologies and the concepts of the various areas concerned.

The purpose of this article is to describe the different approaches or concepts of interdisciplinarity of some areas, such as Ergonomics, Engineering and Material Science, and their links with the area of Design, thus highlighting its importance nowadays.

Two main assumptions will be addressed as proposed by Fontoura [8], namely, the interaction of concepts and of methodologies. In these sub-chapters a few examples of the interaction between the area of Design and some other areas, will be given.

Concerning the interaction between concepts, it was observed that for this project (designing a chair) the contribution of Engineering was key to finding the solution to design a chair that would be adjustable in height and at the same time stackable. In this case, the knowledge of Engineering on adjustment mechanisms was taken into account and used by further detailed analysis and research, taking into account the methodology used by Engineers.

In this paper, the methodology based on the interdisciplinarity approach will be described and illustrated by the case study of the design of an evolutive classroom chair.

This project of Design was based on a methodology of engineering. The analysis of the mechanisms was the foundation to finding a solution for the most appropriate design.

II. INTERDISCIPLINARITY AS METHODOLOGY

Interdisciplinarity is defined as a methodology of integration of knowledge from two or more disciplines, and depending on the capacity for dialogue and exchange between different teams, so that the work of each one is mutually enriched by the other [8, 9].

On this basis, the decision process is constantly fed by the validation of other areas, thus allowing to deepen the level of detail of the project within each area. Contrary to usual project methodologies , multidisciplinarity would rule out the idea of a fragmented knowledge, scattered into diverse areas, which often prevents a link between parts and the whole [8, 10]. To achieve that complicity in different fields of study, the decisions are complemented not only by the identification of knowledge from other disciplines but also through ownership of such knowledge, i.e. through mutual combination of such knowledge thereby taking joint decisions that are built on sound technological basis [8, 10].

As Couto cited in Fontoura [8] asserts, interdisciplinary implies "... a change of attitude, which allows the individual to understand the limits of own knowledge in order to be receptive to contributions from other disciplines. Interdisciplinarity must therefore be understood primarily as an attitude, driven by a rupture with the positivistic fragmentation-based approach, with a view to ensure a broader understanding of reality. This approach only facilitates an effective interaction that is considered a synonyme of interdisciplinarity."

Reginaldo and Baldessar [11], consider Design as a field of study "without specific boundaries or defined area" and "build-up of knowledge and skills borrowed from different fields, and using a series of flexible and adjustable models that are applicable to any time and circumstances', thus in need to constantly seek innovative design methodologies. Due to the fact that it produces and applies knowledge [8], the field of Design is bound to acquire knowledge specific to other areas. Engineering, Ergonomics, Anthropometry and Material Science altogether [8, 11, 12] contribute to solving a problem, provide the answer to a specific question or contribute to generating new ideas [9]. Nowadays, designers try to integrate the scientific methods of those areas into the Design development process [1].

Globalization of markets intensifies competition and puts pressure on designers to adhere to interdisciplinarity methods as, in such a competitive context, it is no longer possible to use solely the traditional subjective and emotional methods of Design [1, 5].

Currently it is impossible to design in isolation, as no individual knows enough about the relevant disciplines that make a project in a success [5, 7]. According to Bürdek [1], referring Lutz Göbel (1992) "…companies increasingly need neither specialists (people who know a lot about a little), nor generalists (people who know a little about a lot) but rather integralists (people who have a good overview of various disciplines with deeper knowledge in at least one area). These people must be especially capable of thinking about and acting on issues in their entirety.".

According to Fontoura [8] this implies an interaction between concepts and methodologies:

The interaction of concepts or the reciprocal exchange of practical and theoretical knowledge between a range of disciplines is the basis for the area of Design. The Design process may be influenced by several external factors, such as the market, technologies, investment, environment, etc. thus resulting in interventions from different fields in the development process of the project, as explained by Ashby and Johnson [13]. Ulrich (2010) referred by [14] defines, "…the architecture of an artifact more precisely as (1) the arrangement of functional elements; (2) the mapping from functional elements to components; and (3) the specification of the interfaces among interacting components.".

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In order to create a product, appropriate choice of materials is to be made, hence knowledge in the area of Material Sciences is required [13].

The development of a product may benefit from different areas of Engineering, such as chemical, electrical, production, food or mechanical. This interaction between Engineering and Design will allow for better results in terms of mechanical and operational performance, costs and durability of products [6, 12, 13].

The methodological interaction combines approaches of diverse disciplines thus creating a common strategy to achieve more comprehensive and rigorous final results.

However, to ensure the methodological or conceptual interaction, all actors in the process shall articulate their own work processes [12, 13, 16-19].

Any project development process, in whatever area, includes three main stages:

Definition of the problem — describes the purpose and the main objectives to be achieved [13], by creating a new product that matches the specific needs of the users and brings advantages as compared to existing competing products [18].

Definition of concepts — ideas are proposed to meet the objectives taking into account the technical and aesthetic requirements [13].

Development — at this stage the project is developed, from its initiation [18] and design of specifications for each component, to testing of the various components in order to optimise the product as a whole, increasing their performance and analysing the underlying costs [13].

Cross [12] also defines this method as heuristic process, since designers use previous experience, general guidelines and golden rules, to define the most appropriate direction, but without guaranteeing its success..

Currently, the process of Design follows sequential tasks carried out with various tools [16, 17, 19] and allows the designer to pose questions and to seek the solutions to the problems encountered [6, 16, 20]. At it is a linear process that allows to proceed into next step only when the previous one is concluded, it is often necessary to go back one step to solve problems not initially detected. For this reason, some authors define the process of product development not just as a linear method but as a straight line method with iterative cycles [6, 16, 17]. The effectiveness of these iterative cycles is reinforced by common methodologies adopted by actors from the different disciplines. For instance, SolidWorks is used by designers but also by mechanical engineers, who use this programme for numerical modelling of shapes. Also, designers use CES EduPack to select the most appropriate materials in a sustained, technical and scientific manner.

Engineering defines the concepts by analogy to previous cases, since it concentrates mainly on the functioning of products, by giving emphasis to the effectiveness of the mechanism adopted [5, 21-24].

The principle adopted is based on the use of a tool of creativity, usually designed as approach called by analogy or "design fixation", and often used intuitively by engineers and by designers [24, 25].

The analogies approach is based on the parallelism established between two products from different domains [22, 23, 26], in an be explicit or implicit manner that may facilitate the adaptation or creation of new products [24, 25]. As stated by Evans [27] "… design, a human activity, is discovery; it is discovery of existing but as yet undiscovered ideas…".

The analogies approach allows to apply existing knowledge in a different context, thus improving the quality of the proposed solutions [22, 23, 28]. This approach is consistently based on the relational and functional similarities between the product source and the objective [16], and may take various forms.

Also, analogies may be observed directly when looking into comparable situations, when the person integrates the problem when looking for the solution, when using natural elements that are similar to the problem to solve, and finally using fantasy or imagination to solve the problem as a fairy tale.

Designers and engineers make use of analogies when creating new products. To invent the concept of desktop, Steve Jobs made a direct analogy with his desk where he had access to the bin, the folders and documents. For instance, Word is similar to handwriting in a blank page where words are added in order to produc e a text [26].

Ligne Roset makes also use of analogies and takes inspiration on the handle of drawers in the form of a ring to facilitate the height adjustment of the Bureau Lunattique [17](Fig. 2).

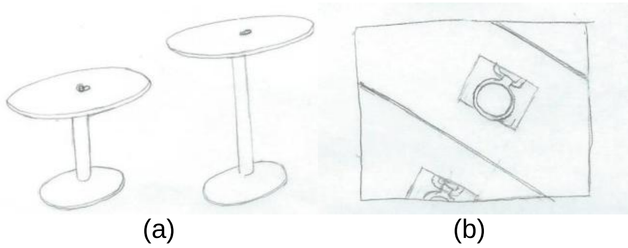


Fig. 2. *a) Bureau Lunattique Ligne Roset; b) Handle, ring shape*

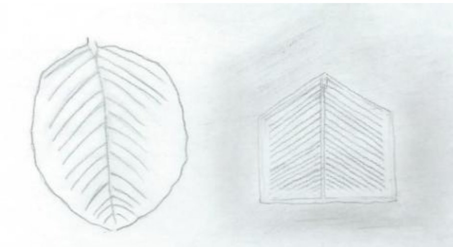


Fig. 3. *Analogy between leaves and bipolar fuel cells*

In Engineering very often inspiration is taken from the Nature to find a system to solve technical problems. For instance, the bipolar cells for fuel were designed by analogy with the system of water dispersion in the ramifications of leaves. This analogy was used to tackle the problem of distribution, guidance and dispersion of the fluid from the surface. When making an analogy between the functional characteristics of the leave and the fuel cell, the engineers could quickly solve the problem by adding to the cells small grooved rainures similar to the lines of leaves [29] (Fig. 3).

III. CASE STUDY

The case of study presented in this paper is a project of Design where a direct analogy was used to solve the problem.

In the context of the Master Studies of Product and Industrial Design, students develop products to propose solutions to problems identified by the industrial partners. Nautilus, a company producing furniture for schools, requested the Faculty to design a chair that would be used by children for the whole duration of their basic education. Also, the chair should be easily stackable, to facilitate the cleaning of the classroom, and height-adjustable to accompany growth of children aged 6-10.

A. Methodology

First step was to define which operational and technical requirements were applicable to the product. Secondly the problems and sub-problems were classified within each field of knowledge. Finally, the main concepts that would usefully contribute to the solution to the problem (Fig. 4.).

In order to tackle the requirement that the chair would be simultaneously height-adjustable and stackable, data was gathered related to the existing mechanisms of height-adjustment and the diverse stacking systems. An analysis of products for a similar purpose or products with a different purpose but similar mechanisms, offered by the main competitors in the market, was made.

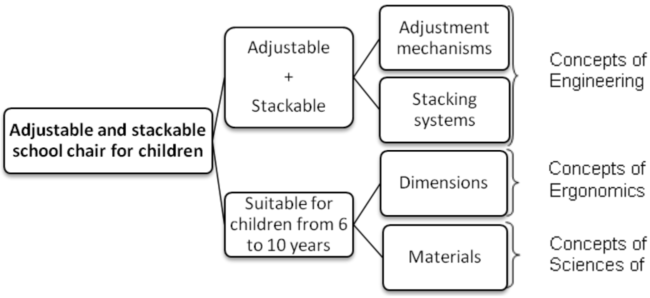


Fig. 4. *Subdivision of the problem*

As the product targets the specific market-niche of schools, the solution to propose should be produced and offered in the market at low costs and prices. It was therefore decided to analyse manual mechanisms of simple operation, as the use of more sophisticated technologies would increase the production costs.

The detailed analysis of existing manual mechanisms reveals that height-adjustment is mostly made with cranks, fast grips and screw mechanisms. When examining the screw mechanisms, it was observed that the use of this system, with time, resulted in the loosening of the screw mechanism, thus putting at risk the safety of children. It was also observed that the belt mechanism was safer. However, the fact that it incorporated a larger number of components and materials, would significantly increase the production costs. Other mechanisms, such as "position system", screw or pipes, were not suitable as its many components would not allow for easy stacking.

The analysis of the crutch mechanism used by the client company led to the conclusion that this mechanism was not user friendly and did not offer a sufficient resistance level. In fact, to adjust the chair, the child needed to simultaneously press on two springs, which should be sufficiently resistant for the chair to offer the required safety level and for the child to sit on it without lowering under the seated body pressure.

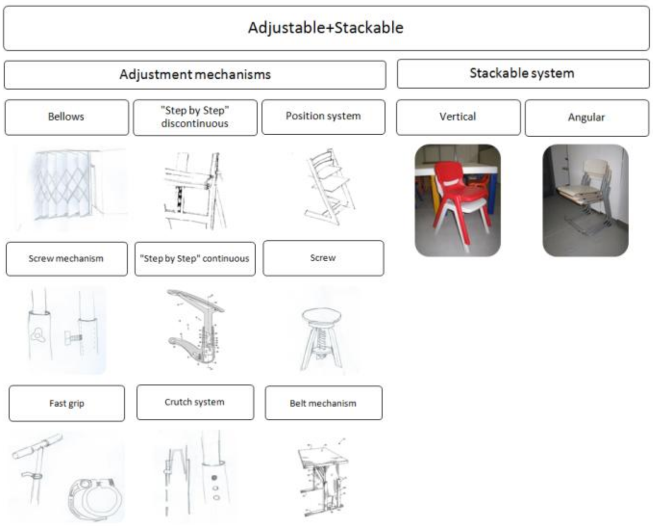


Fig. 5. *Summary of analysis of height-adjustment mechanisms and diverse stacking systems*

Finally, the observation and analysis of mechanisms led to exclusion of all but the 'step by step' system, continuous or discontinuous, as it proved easier to regulate.

When analysing the different methods of stacking, it was observed that it could be done vertically or transversally in order to satisfy the purposes of organisation, tidying and cleaning of the classrooms as well easy transport of the chairs. These needs could be complicated by the mechanism of height-adjustment of the chair. Therefore it was first decided to choose the height-adjustment mechanism whilst keeping in mind the possible stacking methods.

After analysis, it was concluded that a manual height-adjustment mechanism would be the most appropriate to serve also the stacking purpose.

The thorough analysis and observation of each mechanism led to a better understanding, not only of their functioning, components and materials they were made of, but also of their advantages and disadvantages or even potential future problems. The knowledge thus acquired led to refining an height-adjustment mechanism, usually inserted in diverse other objects, to be adapted to the chair. This methodology allowed also to easily decide which mechanisms would be suitable for children to manipulate and which should be definitely excluded.

After an in-depth analysis of all sub-elements of the problem, the full elements of the development programme were identified in order to structure and identify the key points to consider when designing the chair.

B. *Exploring the concept design*

The design concept of the product was the articulation of the height-adjustment mechanism of the chair with the possibility to stacking it.

The manual mechanism chosen was not normally applied to build chairs. To understand its functioning, the mechanism was dismounted and each of its parts and its interaction was observed.

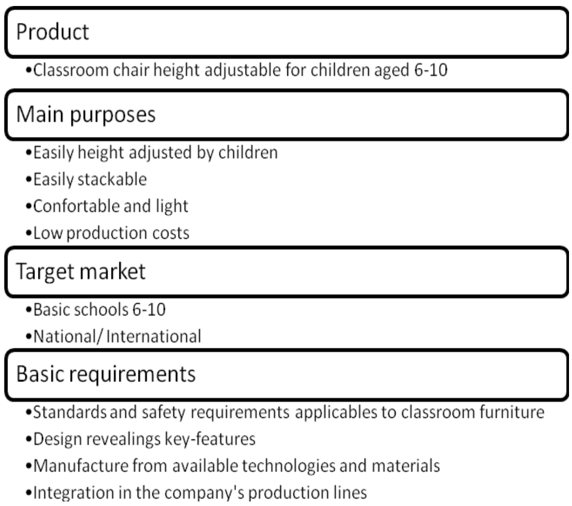


Fig. 6. *Key elements to consider when designing the classroom table and chair for all ages, Seat&Grow*

Fig. 7. *First drawings*

Once the first drawings were finalised, a few modelling tests were applied in order to check the matching of main selected concepts with the required functionalities. To validate this operation and better understand the stress resistance of the chair, the students consulted their mechanical engineering experts.

The first option was to take inspiration on the ZAZZ chair, produced by NUNA. The height-adjustment is done by the lifting of the hull, pulling it out of its supporting structure.

When modelling this system, it was confirmed that it could be stackable but the height-adjustment mechanism presented some problems. The angular motion of the hull that it would imply, would render its seat support fragile, thus easy to break. When modelling this system, it was confirmed that it could be stackable but the height-adjustment mechanism presented some problems. The angular motion of the hull that it would imply, would render its seat support fragile, thus easy to break.

The second option was to take inspiration on a chair reproducing the shape of a doll and, for the height-adjustment, using the mechanisms of the arms of office chairs.

For this second option the adjustment mechanism would be placed on the back of the chair. However, when modelling it, it was found that only 3 chairs could be stacked.

After testing the 2 options, it was decided to apply the height-adjustment mechanism inserted in the frame and similar to option 1.

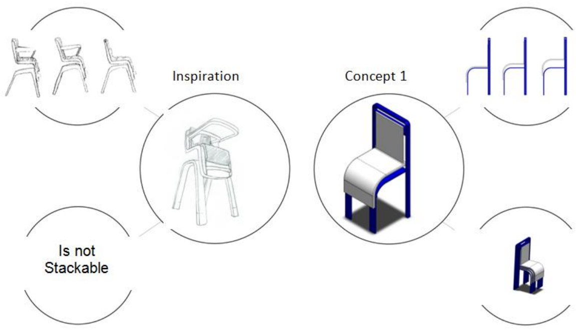


Fig. 8. *Inspiration vs concept 1. Source: http://www.nuna.eu/zaaz*

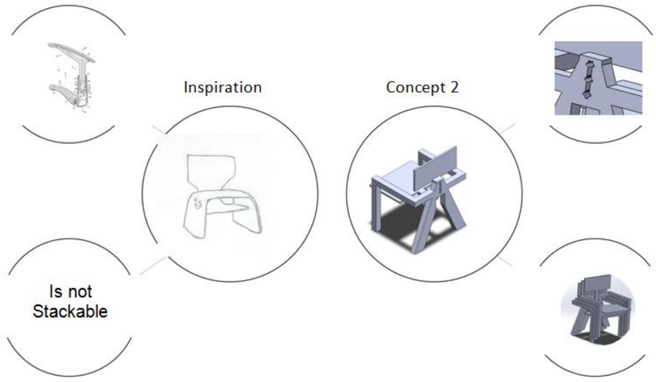


Fig. 9. *Inspiration vs concept 2. Source: https://www.behance.net/gallery/3513747/BITA-CHAIR*

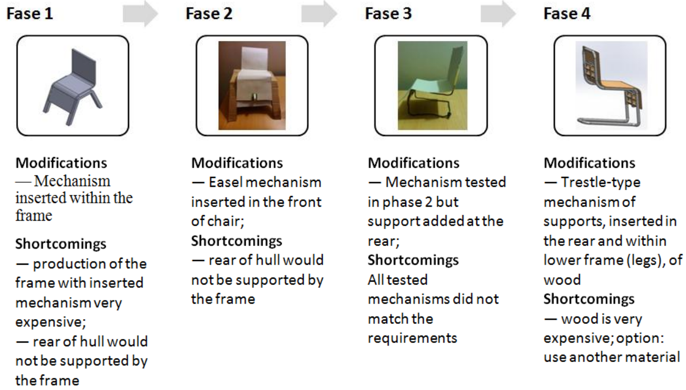


Fig. 10. *Stages of the project*

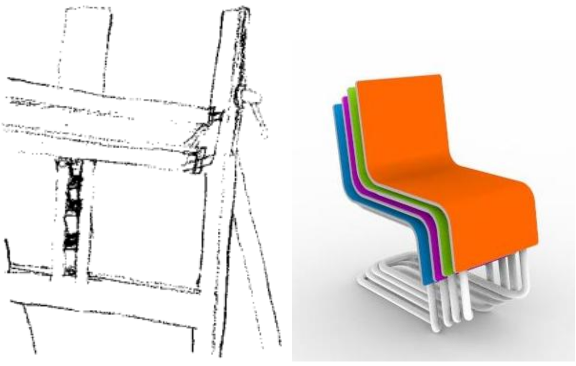
Once the mechanism was selected, the project development entered the next stages of the design of the chair, and in several instances the students consulted experts in the areas of Mechanical Engineering and Design. Several drawings were subject to modelling, technical drawings on a scale of 1: 2 and a few models were built.

Once the different stages described were finalised, it was concluded that, in order to satisfy the technical requirements of the product, the concept should be submitted to additional improvements through a systematic trial and error approach of the solutions to the problems encountered.

On this basis, the iterative process resulted in the final design of the chair.

IV. CHAIR SEAT & GROW

Fig. 11. *Seat & Grow Chair*



(a) (b)

Fig. 12. *a) Adjustment system (inspiration; b) Stacking*

A. Height-Adjustment mechanism

Designed for the child to be able to easily adjust the chair, the height-adjustment mechanism was inspired on the trestle system.

B. Stacking

Stacking is possible from above and up to 5 chairs.

C. Materials

The seat is manufactured from wood and different colours are possible. The figure below shows 4 examples. It is also suggested to apply a different colour to the adjustment mechanism.

The frame is manufactured from steel, for its resistance. This material is also easily available to the client company. The small parts of the adjustment mechanism are manufactured from Nylon, for its resistance and flexibility

D. Manufacturing process

1) Frame

The frame has 3 different components: stretchers, seat and support. All parts may be manufactured from tubes to be cut then bent by a CNC machine and finally assembled by welding.

2) Seat

The seat is made from plywood that is previously moulded to bend according to the technical drawings. The melamine sheets are applied before the moulding process of plywood. The seat is drilled to apply the riveting system needed for the final assembling with the adjustment mechanism.

3) Adjustment mechanism

The parts of the adjustment mechanism are made by injection moulding of plastic. Once moulded, these parts are drilled in order to be assembled in the rear of the seat. It is also possible to use another technology, such as cutting the nylon with CNC turnings.

E. Final design model

Fig. 13. *Model on a 1:2 scale*

As the proposed equipment and materials were not available, the model on a scale of 1:2 was made using iron to build the frame and Bakelite to build the seat and the adjustment mechanism.

The project was selected to be developed by the company. Indeed, this decision was based on its feasibility and on the simplicity of the mechanisms proposed to respond to the needs of the users.

V. CONCLUSION

The design of this classroom chair was developed on the basis of a thorough analysis of mechanisms and project decisions were supported by sound and technologically sustainable criteria. This development process was possible because from its outset, the project was based on Engineering and Design knowledge acquired in an articulated and integrated manner.

This integrated and knowledge sharing approach chosen by the designer facilitates the development of the functionalities of the product, fosters quality and boosts creativity. Indeed, on the basis of all possible information and knowledge available, the designer is well equipped to boost creativity and thus solve the problems by proposing broader and innovative solutions.

The use of tools of creativity by the designer - which in this case study were the analogy or similarities approach - is also an important support to develop new products and to propose solutions. Indeed, the designer takes inspiration by observing other products or solutions having similarities or differences when compared to the issues to be tackled.

In this case study, the analysis of the mechanisms existing on the market and the use of Engineering methodologies and processes resulted in the design of the chair that offered an effective and innovative solution to the existing need, i.e., its stacking and height-adjustment specificities.

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