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An Integrated Framework to Support Design & Engineering Education*

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The current particular critical moment for the Western industry, and the introduction of information technologies have profoundly changed the product development process. One of the most important modifications occurred is the integration of the two traditional fields of product design and product engineering into the new concept of industrial Design & Engineering. The consequent shift and the extension of the designer's area of expertise concerning the product development process have led to amplify his typical knowledge: both more and more technical knowledge, and also knowledge more focused on conceptual issues and creativity. This trend is fostered by the intensive use of computer systems and also by various Design & Engineering courses, where it has been possible to experimentally observe the difficulty for students to learn the necessary body of knowledge and to manage a wider product development process. However, the multidisciplinary approach to the product development process and to the related education issues are still based on tools and methods developed for a specific kind of user, or usually used in an unarranged way. The research presented in this paper aims at defining the guidelines for developing an integrated framework to support the Design & Engineering education and the multidisciplinary design process based on a structured integration of knowledge and tools currently used by the two main areas of reference. The paper presents the guidelines for the integrated framework and the experimental activities used for the framework validation. These activities have allowed the authors to check the framework usability during team design activities and also to verify its effectiveness in improving students' learning capabilities. Some elements derived from the analysis of the experimental data demonstrate that both students and professional designers can use the framework to assist them throughout the design process and that the knowledge learning related to the project is fostered.

Keywords: multidisciplinary design; design & engineering; design process; design education

1. Introduction

During the last years, Western industry is facing a particularly critical moment in its evolution, due to the market globalization and the subsequently arising of new competitive challenges. In this situation companies need to remain competitive by introducing more design, technology and sustainability in traditional products and in production processes. This is of particular importance for developed economies that need to distinguish themselves from those that are situated in low labour cost countries.

From this situation every company's area has to be improved, and "there is a need to improve on traditional ways of working in design" [1]. Also educational institutions have to cope with new challenges due to the globalization of the markets, as growing competitiveness of emerging markets, rapid technological evolution and consequent rapid product obsolescence, environmental emergency and growing need for solutions in terms of sustainable development.

Similarly, the introduction of information technologies has profoundly changed the structure and the practice of the product development process and, in a more general perspective, the area of ideas representation.

In fact, the representation has always played a fundamental role within design disciplines, constituting the key element to process management and idea communication [2]. The need to communicate the project is so strong that Tomás Maldonado (the famous Argentine designer, who is considered as one of the main theorists of the Ulm Model) says that the need to communicate the project, to satisfy customer's desires to see in advance is at the origin of the architect professional role. In short, he says, the architect was born as a "display" [3].

The use of the computer in the last three decades has dramatically changed the way people relate to each other. The deriving spread of knowledge, and the new, and still in evolution, digital representation tools have become compulsory elements of use by designers (meant as product designers and engineers), with important consequences on the product development process, making the process phases more integrated and extending the designer' area of expertise toward both conceptual and industrialization steps.

Consequently, both the figure and the role of product designers and engineers have deeply chan-

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ged. In the more traditional and still common perception, product designers design consumer products whilst engineers design machinery and equipments. Again, product designers tend to focus more on shape, styling and consumer attributes whilst engineering designers tend to focus more on parameterizing the resulting conceptual design along technological lines taking into consideration manufacturing and cost implications. Nevertheless, among the important modifications, which are taking place in the design area, two of the most relevant concern:

- the need to develop teamwork, related with the complexity of modern design, with many specialists collaborating in and contributing to the design;
- the new concept of industrial Design & Engineering, which combines the two more traditional fields of product design and product engineering [1].

If the first modification is by now well-defined, expressing the need to have flexible resources organized every time in different layouts, the second one is relatively recent and expresses the need to change and improve the figure of the designer. He is no longer simply the "owner" of a limited part of the concept generation process (the conceptual or the engineering ones), but he is becoming a professional figure capable of managing every phase of the product development process from concept to recycling, combining design and product engineering with the needs, potential and constraints of the economic, social and market situation. The shift and the extension of the designer's area of expertise have led to modify and amplify his typical knowledge: on one side he requires to have more and more technical knowledge, which results to be necessary for the development process and the engineering phases, and on the opposite side he focuses his knowledge more on conceptual issues and creativity.

Creativity is one of the most important skills linked with the product designers and engineers' activity. We define creativity as the ability to conceive and bring into being something that does not exist [4]; moreover, creativity is the intersection of expertise, thinking skills and motivation and determines how flexibly and imaginatively people approach problems [5]. Inside the design process, creativity is used to resolve problems and to generate solutions: we can say, then, that this kind of creativity is a productive thinking, where "designers must consciously direct their thought processes toward a particular specific end, although they may deliberately use undirected thought at times. Artists, however, are quite at liberty to follow the natural direction of their minds or to control and change the direction of their thinking as they see fit" [6].

If the use of creativity is limited and focussed to obtain a specific goal, then the use of creativity in decreasing the wideness of a topic and getting nearer problem solutions is more limited. This observation leads to the link between design freedom and knowledge during the design process (Fig. 1), and highlights the fact that the traditional roles of product designers and engineers are considered different, and specifically those of the first category of designer as more creative than the others.

This process of knowledge acquisition, besides, is

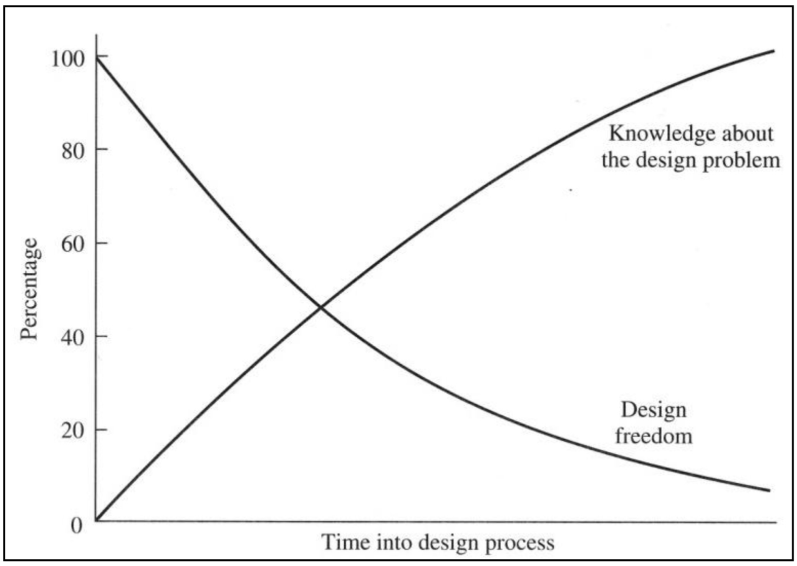

Fig. 1. From Ulman, D.G., The mechanical design process, McGraw-Hill, New York, 2003 [7].

strictly linked with the progression from the initial need (the design problem) to the final product that is made in increments punctuated by design decisions. Each design decision changes the design state, which is like a snapshot of all the information known about the product being designed at any given time during the process [6].

These decisions limit the designer's area with constraints (defined a priori or during the design process as a result of previous design decisions) [7] and, consequently, limit the designer's possibility to carry out important changes in the structure. This is one of the main reasons why the industrial designer and engineer's approaches to the design process are usually considered different, and consequently influence their educations, professional roles and thinking process.

This trend is fostered by the intensive use of computer systems (hardware and software), which act as supporters both of the creative process and of the engineering one, also for those designers who are not skilled in specific disciplines and activities. In this direction, it is possible to affirm that the computer systems have pulled down the boundaries among the disciplines related to the product development process, merging and amalgamating designers' typical knowledge, practices and skills.

In order to meet these emergent needs and trends, various Design & Engineering courses, like the M.Sc Degree Course organised at the Politecnico di Milano, have been set up by educational institutions with the objective of training professional figures able to independently manage the industrial product development process, from the concept phase (Design) to the embodiment (Engineering), maintaining the capacity of relating to different experts in diverse areas. The M.Sc Degree Course (Higher Degree Course) in Design & Engineering of the Politecnico di Milano is an example of this multidisciplinary attitude. The M.Sc Degree Course is the result of the synergy between three Departments of the Politecnico di Milano, which represent the subject areas of industrial design, mechanical engineering and materials engineering. It has the objective of integrating different scientific cultures to create forefront profiles in the Western professional scenario. A graduate in Design & Engineering has acquired the skills to combine the design culture with the most advanced technological and production potential, by combining design and product engineering innovation with the needs, potential and constraints of the economic, social and market situation. In this M.Sc Degree Course education is provided through workshops-projects, where the knowledge concerning important technological areas, as manufacturing technologies, materials, virtual representation are put together with creative experimentation and concrete execution of designs. In these lessons, it has been possible to experimentally observe the difficulty, from the students' point of view, to learn the necessary stock of knowledge and then to manage a wider product development process. In particular, some issues arise about the difficulty in learning new technical knowledge, the need to collaborate in multidisciplinary team works, made up of students with different points of view on the design methods, and on the need to use similar tools to develop projects and manage several knowledge typologies.

However, the multidisciplinary approach to the product development process and to the related education issues are still based on tools and methods developed for a specific kind of user (engineer or product designer), or usually used in an unarranged way. These tools do not present a complete platform on which designers can find support for learning (the knowledge essential for the product development process), for managing and for performing the design activities necessary to carry out an exhaustive and complete product development process.

2. The integrated framework

The research presented in this paper aims at defining the guidelines for developing an integrated framework to support the Design & Engineering education and the multidisciplinary design process based on a structured integration of knowledge and tools currently used by the two main areas of reference. Specifically, the framework is structured for supporting students in the management of the design process, the related information and the evaluation of solutions as an organized activity.

This section describes the guidelines of the framework, which define its structure, the current scientific references, the technologies and the tools constituting its basis of reference, as well as its usage modalities. Besides, an analysis of the possible improvements, which could be introduced and applied to the design practice and to the educational activities in the Design & Engineering field, is provided.

Then, the experimental activities carried out for the validation of the integrated framework are described. The experimental activities have been based on the framework structure, asking the Design & Engineering students to retrace a particular design process they had already carried out recently, in order to simulate the selection and the use of the project variables and the possible acquired knowledge.

The integrated framework is structured in order to provide specific support to each phase of the industrial product development process (from the

Concept to the *Approved Design* phases), differently from some current tools that are developed and used within some specific part of the design process, traditionally close to modelling and engineering phases, to foster the reduction of information loss.

Moreover, the framework will support the inductive educational method in the Design & Engineering area, providing knowledge and tools selected both from the product design and the industrial engineering domains.

Specifically, the framework, as a Design Studio, starting from a given problem, pushes and supports a structured (and not random) research towards new information for the project and design solutions: students learn by addressing specific problems, complementing theoretical lectures and improving their learning capabilities.

Finally, the specific field of application of the framework concerns projects of medium-complexity products (as household appliances, medical devices, etc). The definition of "medium-complexity products" derives from the idea that technical artefacts can be represented as systems [8], and the number of their components and the relationship among them determines their level of complexity (low – medium – high).

2.1 Guidelines of the integrated framework

The framework aims at providing designers with a support in some design activities usually carried out separately and through a trial-and-error approach, from which knowledge and methodological principles are drown. From this statement, several goals of the framework have been set up, and correspond to several components of the framework, named *project variables*. These, based on the integration of current tools and classified according to the content, consist in specific areas of knowledge.

Specifically, the framework aims to:

- encourage the generation of innovative ideas;
- support the research for information about the project;
- support information acquisition and creation of a personal database;
- support virtual prototyping;
- support the evaluation of design solutions.

In the following, these items are described in details.

Encourage the generation of innovative ideas, through the integration of methods of design and systematic innovation. This main goal of the framework will be implemented in the project variables category named *Solutions*, and specifically in *Methods of design and systematic innovation*, which foresees the use of some already-known methods of design and systematic innovation and of the software based on these methods [9, 10] and other techniques for finding solutions [8, 11], and in *Patents and technical solutions*, which will be a database of functional principles that could be applied to the framework without identifying a specific technical solution [12, 13].

Such integration is fundamental for Design & Engineering students: in fact, while in the industrial engineering domains these methods and tools are already frequently used to solve problems, product design students are often unfamiliar with such methods or look at them with caution. In the proposed scenario, the integration of these methods and techniques could improve the quantity and quality of generated design solutions, allowing the students to use the most suitable technique, more or less structured, for each given problem.

Support the research for information about the design problem, by means of the integration (or with external links) of databases of classified information. The phase of consciousness-raising of the design process [14], in which the collection of information and data about the design problem is carried out, is one of the most important moments in structuring the project. New information is often particularly important to make choices regarding the ergonomics issues, the materials, the manufacturing technologies, and all the other possible project variables. Yet, several references about project variables have been developed during the last century [8, 15, 16, 17]. These pieces of information are usually consulted, collected and applied during project development, more or less randomly especially in the field of product design.

On the contrary, in the integrated framework this information will be collected and arranged in some specific project variables. Particularly, in the *Technical Components category* we have *Technical systems and components_standard* that foresees the integration of some databases of mechanical components already present in some software provided by companies or groups of companies [18], and *Materials*, which foresees the use and integration of databases of materials classified according to their main physical and chemical properties, aesthetic features, and manufacturing technologies required to produce them [16, 19]. In the *Industrial Aspects/Industrialization category* we have *Manufacturing technologies*, *Assembling* and *Regulations* about technologies required to manufacture components in development, about solutions for assembling products components and regulations of reference related to electrical and electronic appliances, about safety during the use, and safety in respect to certain user categories [20, 21]. Moreover, in the *Design Components category* we have *Ergonomics*, which concerns the relationship between the product to-be and the human body, and in which way this relationship influences the products use [18] and *Aesthetics and Shape*, which concerns the comparison between forms in development and a database of forms classified by distinctive features (e.g. proportions, relations, degrees of continuity) [22].

The proposed approach aims at searching for information and data for supporting Design & Engineering students not only to think about the design problem as a whole, but also to conduct more specific and exhaustive researches on project issues in advance in the design process, bringing important improvements in design activities as time reduction, costs saving, and diminishing the number of trial-and-error processes.

Support information acquisition and the creation of a personal database.

The last project variable category is *Acquired variables/solutions*. This variable foresees the use and the integration of some already-known methods to support the management of information [23, 24] derived from past design processes carried out by using the integrated framework, collected and arranged in a customized database. This project variable is based on the fact that the information acquired during a design process becomes part of the personal knowledge [25], and is re-used during subsequent processes [26]. This phenomenon presents two important issues, related to the modalities of archiving the acquired information, more or less structured, and the amount of information to store. The improvement of the personal ability to archive information, solutions, etc. that have been searched, used or developed during past design processes can lead to a more efficient re-use of information, supporting inductive learning activity during the design process.

Support virtual prototyping through the use of the three-dimensional modelling and simulation of the product components, by means of the integration of acquired information into the three-dimensional model.

This features of the framework could allow the virtual simulation of the whole product characteristics (such as the dimensions of standard components and how these components work, the properties of materials, the behaviour of mechanical parts, ergonomic dimensions of parts and so on), how its components work and interact and, consequently, could support project development and verification [27]. This integration could improve the whole product development process, and in particular the evaluation phase, where it must be verified whether the selected solutions respond to given problems and requirements.

Support the evaluation of design solutions, through the definition of evaluation criteria (scale of values) [8, 28]. Within the product design area the traditional approach to project evaluation tends not to be structured. Even if it is based on certain objective factors of reference (e.g. industrial manufacturability, the satisfaction of specific ergonomic requirements, etc.), it is often done on the basis of subjective choices with high possibilities to make mistakes, as the exclusion of interesting and potentially innovative design solutions due to partial and biased evaluations. This is particularly important for Design & Engineering students, for which the personal knowledge is still in an evolving phase and they still do not have an adequate background on which the evaluation of developed design solutions can be based. On the other side, in the industrial engineering domain, to support the evaluation process, a number of researchers [29, 30] have developed some comparison and evaluation methods that help to judge each solution in relation to the characteristics defined in the Brief and in the Concept phases.

Then, the assumption is that the integration of these methods and derived tools could support progresses in the Evaluation phase, helping the Design & Engineering students in carrying out a more objective and rational choice, naturally without excluding their personal ability and experience, which are nonetheless fundamental.

Not each of the above-presented *project variables* is equally important and can be applied in the same way. The *Solutions* variable category concerns methods and tools to support the idea generation process, and it is at the highest theoretical level. On the opposite side, the *Technical Components*, *Industrial Aspects/Industrialization* and *Design Components* variable categories are on a lower theoretical level. Finally, the *Acquired Variables/Solutions* variable derives from the others and can be considered as standing on an intermediate level. This organization is more easily understood if graphically represented, as shown in Fig. 2.

Moreover, not every project variables can be applied during the whole design process, because some of them are specifically designed for one or more phases of it. In particular, during the concept and provisional design phases, all project variables can be considered as the starting points of the product development process, even if the *Solutions* variables are theoretically predominant. On the opposite side, the *Solutions* variable category have not been designed in order to be extensively applied in the subsequent phases of the process, and the design solutions generated in the first phases of the

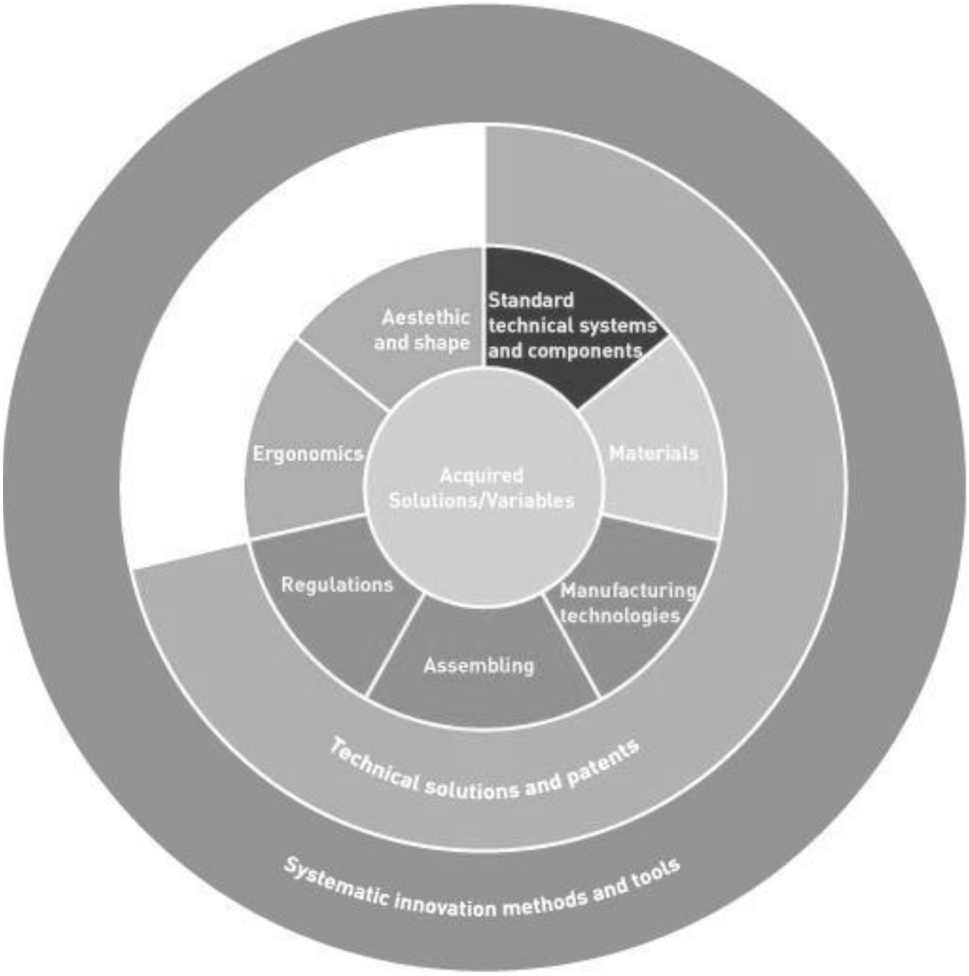

Fig. 2. The project variables arrangement [31].

product development process need to be validated by using the other project variables. Table 1 shows which project variables have to be considered as fundamental and necessary (black points) or optional (white points) during the product development process phases (from the *Concept* to the *Approved Design* ones).

Moreover, it is possible to inquire into *project variables* via three different types of research:

- *Quantitative solutions based on defined numerical data*,
- *Solutions for the project based on specific parameters,*
- *Quantitative evaluations via comparisons of data.*

While it is possible to use different approaches for some *project variables*, other *variables* require a particular type of research. For example, *Quantitative solutions based on defined numerical data* should not be used for the *Solutions* variables (*Methods of design and systematic innovation* and *Patents and technical solutions*), because this research implies precise data already defined as input, while *Solu-*

Table 1. The use of project variables during the product development process phases

	Concept	Prov. Design	Modelling	Evaluation	Appr. Design
Project Variables					
Methods of design and systematic innovation	●	●			
Patents and technical solutions	●	●			
Technical systems and components_standard	○	○	●	●	●
Materials	○	○	●	●	●
Manufacturing technologies	○	○	●	●	●
Regulations	○	○	●	●	●
Assembling rules	○	○	●	●	●
Ergonomics	○	○	●	●	●
Aesthetics and shape	○	○	●	●	●

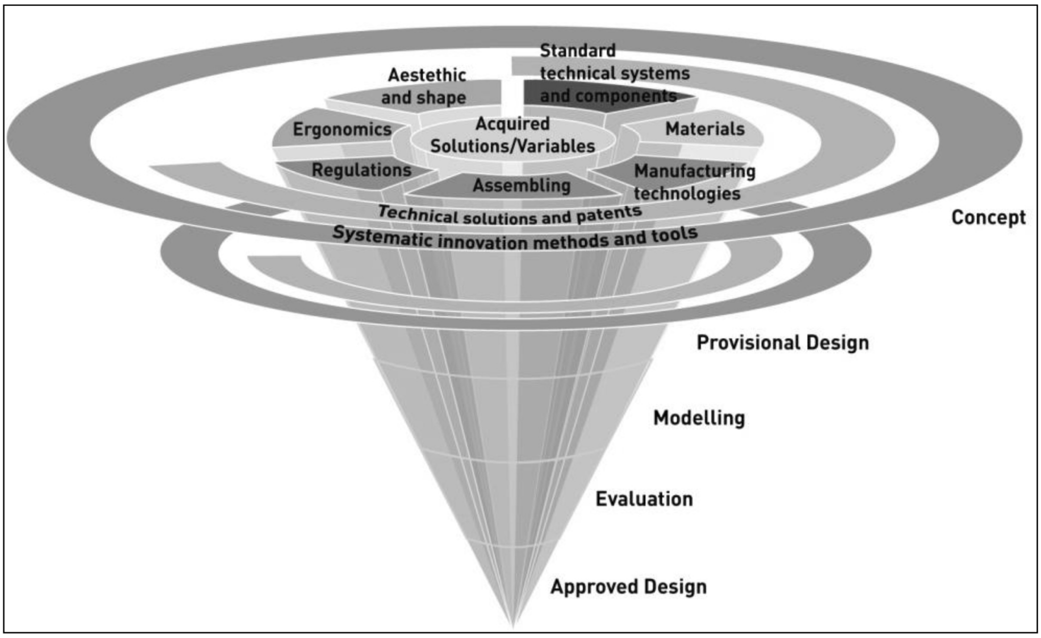

Fig. 3. The structure of the innovative framework integrated with the classical structure of the product development process (from the *Concept* to the *Approved Design* phases) [31]

tions for the project based on specific parameters could be used every time. This is related to the necessary level of specificity of information, and consequently to the way in which designers search for and use this information.

The product development process, carried out with the support of the framework, has been represented with the IDEF0 technique (Figs 4a and 4b).

2.2 Experimental activities

Within the context of the research, the validation of the integrated framework has been carried out

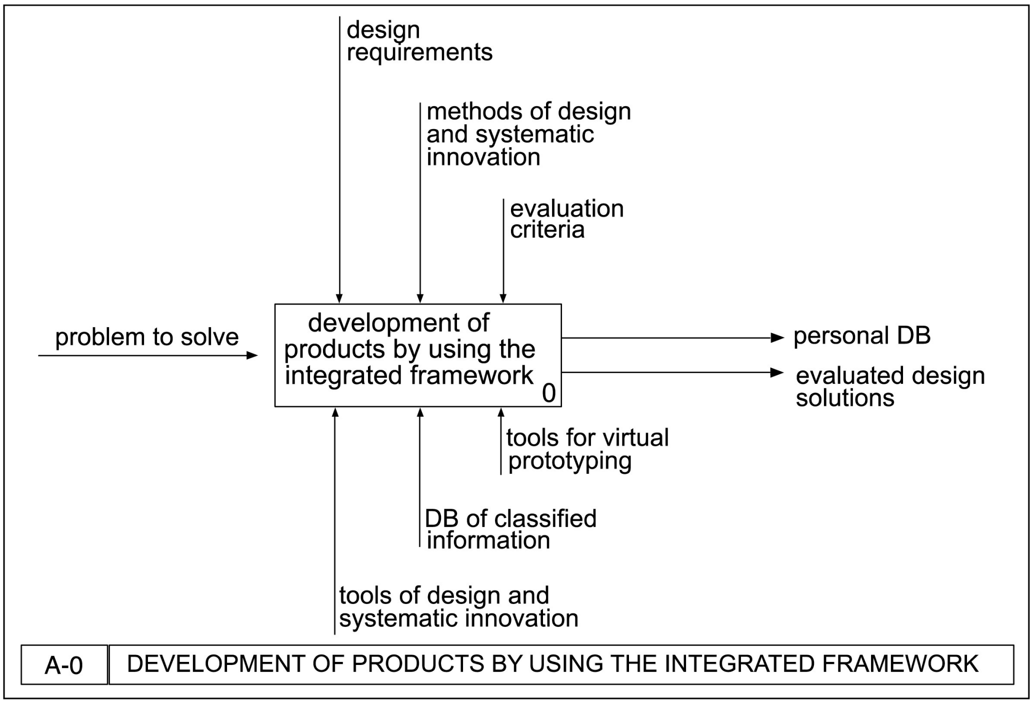

Fig. 4a. Representation, by using the IDEF0 approach, of the development process of industrial products with the support of the integrated framework (level A0).

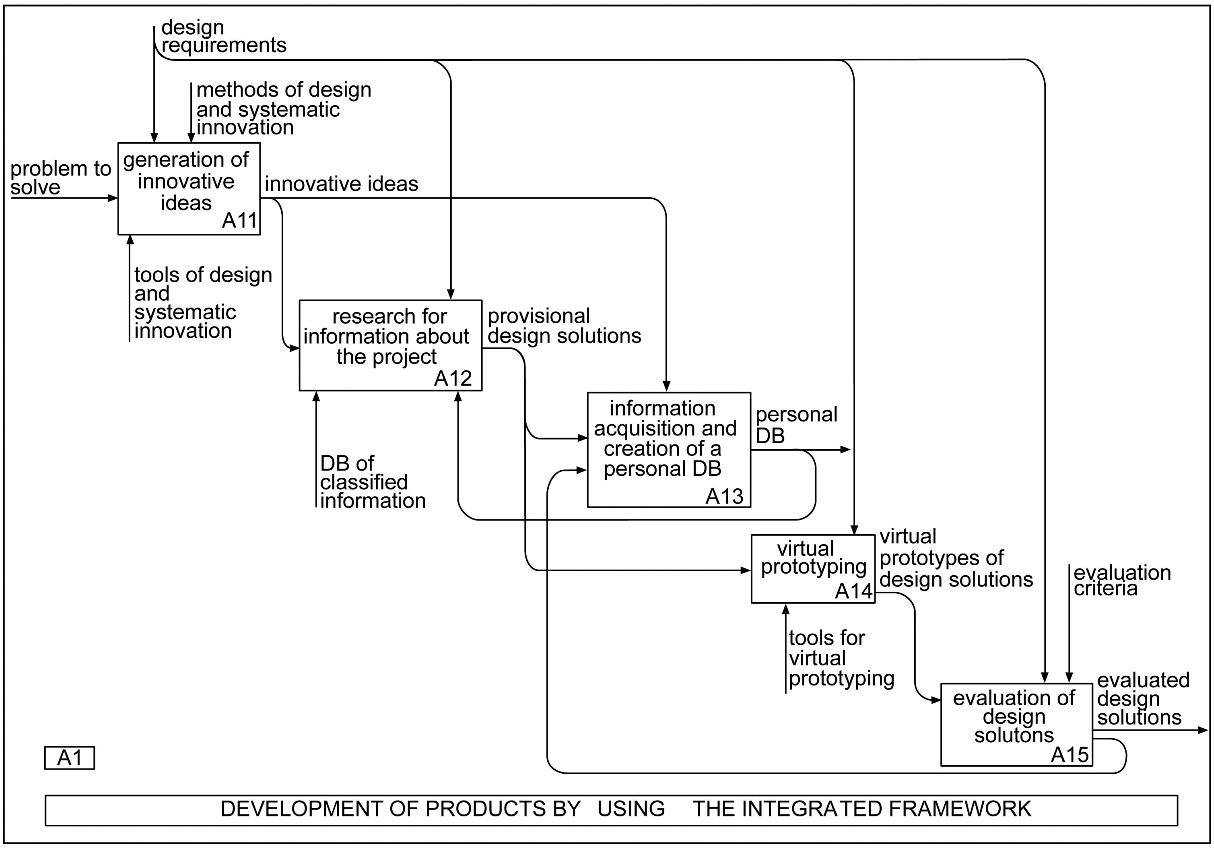

Fig. 4b. Representation, by using the IDEF0 approach, of the development process of industrial products with the support of the integrated framework (level A1)

through experimental activities, in which the framework has been used within a simulation of past design processes. The experimental activities to test the framework have been based on the framework structure, asking the Design & Engineering students to retrace a particular design process they had already carried out recently, and comparing their activities with those carried out by senior designers. The verification of the system guidelines simulates, referring to the product development process phases, which project variables are selected, the modalities of selection of questions and answers, and how search results are integrated within the system.

This simulation was run to demonstrate how responsive the integrated framework is to designers' needs and to determine whether it was necessary to implement changes to the framework. The designers, the subjects of these experimental sessions, were divided into two different groups, Design & Engineering students and senior designers. The decision to differentiate the subjects into these two broad categories arose from the need to see how personal experiences could influence the way in which the system may be used. Consequently, the validation phase was structured in order to highlight different approaches to project management and, above all, in what ways the innovative tool could be useful for product design students.

In particular, as already described, the framework is structured differently according to each of the five main phases of the design process, from conceptualization to the approved design: each phase, in fact, has different project variables that can be used, and the same happens for the above-presented three main different types of research. The relationship between project phases and project variables is illustrated in figure 3, where the design process is represented as a cone divided into horizontal segments (representing phases), while the project variables are arranged around the base circles (cross-sections of the cone).

The structure illustrated in these figures was used as a reference for the experimental activities, both during the experiment and during the analysis of results. The graphic representations of the framework have been used as a reference to explain the system structure to the Design & Engineering students, as principal subjects of the experimental analysis, and to the senior designers.

The experimental activities were partially carried out during the teaching activity within a Design Studio at the Design & Engineering M.Sc degree of the School of Design of Politecnico di Milano, and with senior designers (product designers and mechanical engineers).

The first category, Design & Engineering students, was made up of 10 working groups (35 people in total), including students with a background in product design and mechanical engineering. Consequently, the past design process to be simulated was chosen collectively, in order to compare similar activities and courses: the common project theme was the Ape Piaggio (a small car), which was designed by the students during the Design Studio course.

The second category, senior designers, was composed of 6 individual product designers. They have been chosen for this simulation because they had similar backgrounds and education and also because they used similar design methods. In these study cases, in order to be able to compare similar types of activities, as for the specific past design process to be simulated, the participants were asked to choose a moderately complex industrial product, developed individually from the concept to the approved design.

The experimental activities have allowed the authors to verify the effectiveness of the framework in improving students learning capabilities and designers activities, but also to check its usability during team design activities, and to identify which kind of features of the integrated framework are considered more useful within the engineering and design educational areas.

Some materials were distributed to the students and to the senior designers in order to explain the structure of the integrated framework, to track progresses in the design process and to collect designers' remarks and feedback. Specifically, the participants have been provided with:

- An introductory diagram of the framework structure (useful to explain it to the participants);
- Differentiated cards for each phase, repeated several times;
- A final questionnaire with open questions to enable them to provide comments.

The three parts of the cards were arranged as follows: the first was dedicated to the structure of project variables, graphically expressed as the base of a cone; the second referred to the types of research; the third referred to the use of acquired knowledge. While in the first two cards (for the concept and provisional design phases) the project variable diagrams included systematic innovation methods and tools and technical solutions and patents, these two variables were not available in the other cards.

These cards were distributed among the working groups in many copies (20 for each process phase for each group) and both students and professional designers were asked to mark their relevant procedural choices on each card. The participants had to mark the project variables they used, the types of research they carried out and the ways in which they used information (simply acquired or integrated into the system). The aim of this contemporary investigation is not only to examine Design & Engineering students and senior designers' choices as a whole, but at the same time to share between variables and the research typologies used to inquire into them.

Finally, a questionnaire was distributed to collect participants' remarks about their behaviour during the design process. The questionnaire was focused on several issues, as personal knowledge and knowledge acquisition during the design process, multidisciplinary team, use and differentiation of the design process phases. The final questionnaire allows designers to become more aware of the course of the design process, the importance of working in groups and the relevance of personal knowledge within the project development process. The participants were also interviewed in order to inquire into their impressions about the process, their skill levels before and after the experiments, their roles during the design process and their feelings about other participants and their skill levels, roles, goals, design methods, etc.

All the experimental sessions were carried out by using the Protocol Analysis method [32]. The experiments were recorded using a video camera so as to record words, gestures, expressions, and cards compilation thus enabling for post-analysis sessions.

3. Discussion

The collected data have been quantitatively investigated for identifying, for each single phase of the design process:

- the frequency of use of each *project variable*;
- the simultaneous research and use of *project variables* by participants;
- the types of research used to investigate *project variables*;
- the use of acquired information, which could be used directly for the project development or acquired as personal knowledge.

The analysis of the experimental data and the derived graphs show some important elements about the use of the proposed system by designers,

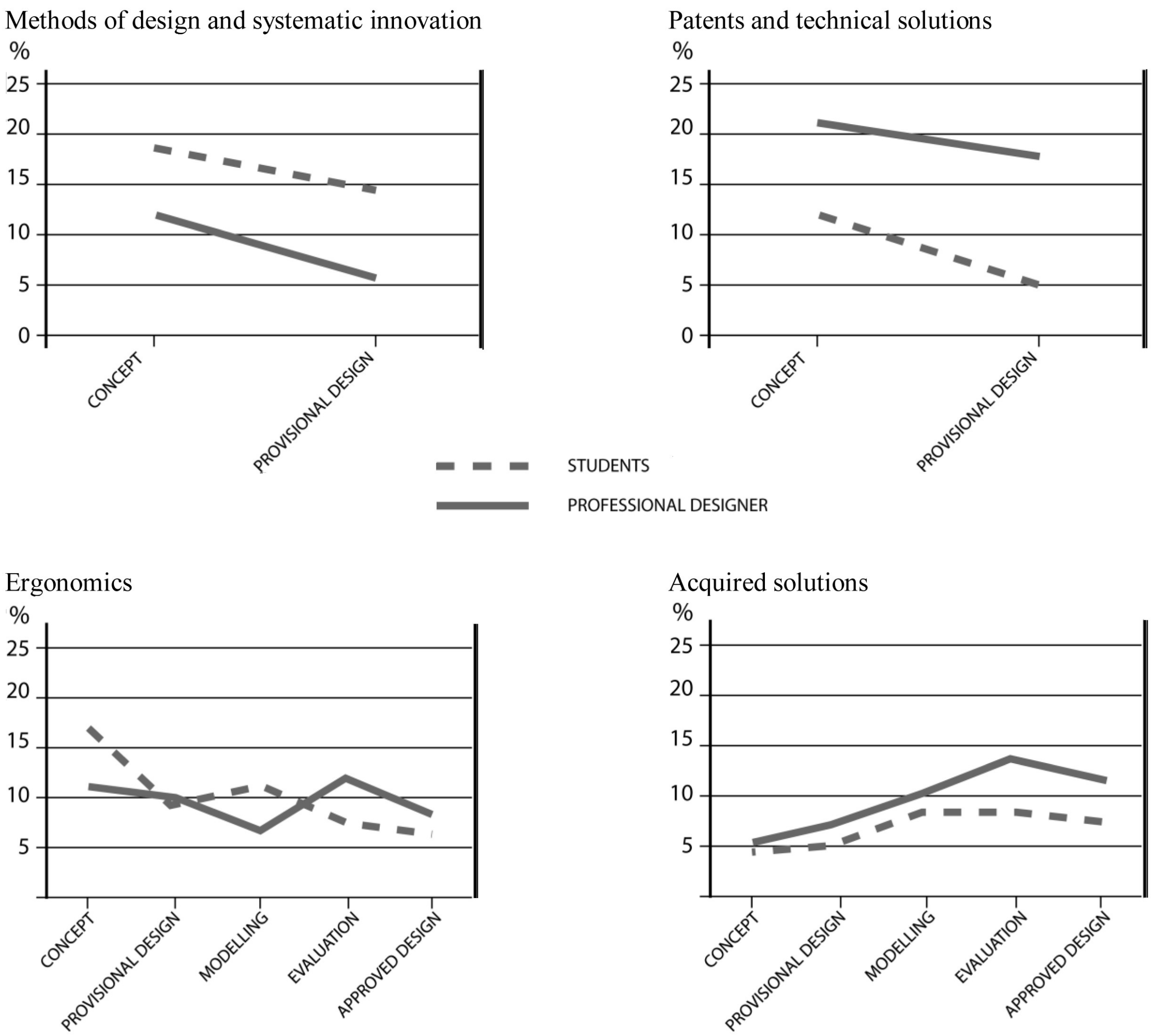

Fig. 5. Examples of graphs about the trends of information typologies research (in the horizontal axes the phases of the product development process, from concept to approved design, in the vertical axes the frequency of use in respect to the other project variables, in percentage)

both Design & Engineering students and senior designers: some of these graphs, reporting some trends of research and use of project variables, are presented in Fig. 5.

The analysis of the collected data shows some distinctive elements about searching for and using information during design activities and the possibility of acquiring new knowledge during the process. Specifically, some key remarks can be made about the validation phase results:

- Different design process phases correspond to different frequencies of information search and use: the different types of information are searched and collected during the *concept* and *provisional design* phases, and are subsequently applied for generating design solutions within the other phases of the design process.
- Some types of variables follow, more or less, similar trends, while the variables *methods of design and systematic innovation* and *patents and technical solutions* are searched and used in inverse proportion by students and professional designers. With regard to the *acquired solutions* variable, it was used extensively by senior designers, but not so often by Design & Engineering students. This indicates that senior designers are more keenly aware of their own experiences and background and are more conscious of how they are putting them to use while designing. Then, it is possible to affirm that they archive the knowledge acquired in past design process in a more structured way, and consequently they can easily manage and re-use it.
- Designers need to be able to access and work with several types of information at the same time, by

integrating information according to project parameters; senior designers use integrated information searches more than students, so it can be postulated that they tackle projects as a whole, while students tackle them sequentially.

- The various kinds of search are used during all phases of the design process, becoming more and more specific. Moreover, there is a need for constant evaluation and comparison of design solutions, greater for students and to a lesser extent for senior designers (the latter rely more on their personal experience).
- Information collected is then used in different ways during different phases: students use the information directly within the project and tended not to perceive that they are acquiring new knowledge, while senior designers use some design process phases (above all the *concept* phase) to acquire knowledge about the project and only subsequently apply it for generating design solutions.

The collected data and remarks demonstrate that both students and senior designers are able to adopt the integrated framework structure, which was proposed to them, that they can use the framework to assist them throughout the design process and, moreover, that consequently the knowledge learning related to the project is fostered.

In particular, the integrated framework structure follows and improves designers' activities, and while at the present moment these activities are usually carried out empirically, the proposed system could support the design process development in a more structured way. For example, the possibility to integrate some methods and tools for systematic innovation and patents can support designers in their search for solutions, and the same can be said for the other project variables.

Moreover, the possibility of searching for information and data for the project should make knowledge acquisition using the inductive method easier, and consequently improve the students' awareness about their own knowledge. This is particularly important for Design & Engineering students who usually need to quickly learn a wide range of technical information and improve their understanding of project variables in order to approach the product development process correctly. This aspect is closely related to the inductive educational method, and highlights the concrete possibility and opportunity to integrate the framework within the Design & Engineering teaching activities. A similar hypothesis can be made about senior designers, who are generally very knowledgeable but often are faced with several companies and several product areas: for this reason, being able to quickly acquire a lot of pieces of information in relation to a given problem and re-use information and design solutions already in one's possession can improve their work performance and give them a competitive edge by reducing design times and costs. In this area, some researchers have estimated that up to 70% of past design data are requested by designers during redesign, while others have underlined the importance of reusing rationale triggers, showing that over 50% of designers' data needs are related to questions that can be answered by reusing the rationale triggers [33]. While at the present moment designers are often not motivated to reuse information since they can feel overwhelmed by the increasing quantity of information available in an archive [34], with the system as a personal tool, structured using customized parameters, searching for and reusing information could be facilitated.

Finally, the possibility of searching for information by using different modalities and comparing design solutions on the basis of defined parameters can help designers, and above all students, in making choices throughout the development process. Specifically, the tool for the evaluation of design solutions has been structured to be used during the whole process, and consequently not only at the end, but also during the engineering phases. In this way, the critical points of a project can be seen in advance via the three dimensional model, helping students and professional designers to improve and fix them, thus reducing the time and the costs associated with developing not completely satisfactory products.

4. Conclusions

The research presented in this paper firstly defines the guidelines for developing an integrated framework to support the Design & Engineering education and the multidisciplinary design process based on a structured integration of knowledge and tools currently used by the two main areas of reference. Then, the data collected in the experimental activities have demonstrated that designers, both professionals and students, were able to use the integrated framework as support throughout the whole design process. Furthermore, it is possible to affirm that the integrated framework has proved to be feasible as support for the multidisciplinary and collaborative design activities so as to obtain in the first instance the reduction of the gap and of the loosing of information between the concept-provisional design stages and the following ones of the design process, but also for the re-use of information and design solutions and testing project characteristics during the design process. Also, the use of the integrated framework could improve the knowledge learning related to the project and the designers' awareness of their knowledge level.

From these observations, it is then assumed that the framework and its related methods and tools have its firstly application in the academic world, and furthermore it can be applied also in the company sector.

In the academic world, the innovative system could help Design & Engineering students regarding how to manage the design process, related information and how to select solutions in a structured manner. This approach, particularly important during the learning period, does not imply that individual creativity and reasoning capacity are excluded, but rather promotes these skills if necessary. Furthermore, in this area the inductive method could be useful to learn more about the project area. The framework, as a Design Studio, starting from a datum problem, pushes and supports a structured (and not random) research towards new information and design solutions. In this way, Design & Engineering students learn by tackling specific problems, so as to complement theoretical lessons and their approach to learning. Also, for students the possibility to create a customized archive of solutions, evaluated through objective parameters, could represent a reference for future design processes.

The second possible application of the framework is in the company sector: the implementation of the innovative system would supply the possibility of improving the management of the design process as a whole, and consequently improve different departmental activities within companies.

Moreover, bringing the framework into a company's design department would be important in terms of the opportunity to collect, classify and then reuse information and data acquired during past design processes or other companies' activities. In this way, it could also help ensure better distribution and interchange of corporate knowledge in design, in order to obtain products that move closer and closer to the corporate identity.

Finally, being able to find company information and solutions easily, along with the possibility of bringing the evaluation component forward within the design process through the integrated framework could be useful for reducing design times and costs, which are always fundamental aspects to be taken into account for improving a company's competitiveness.

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