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VIGANÒ, Roberto and CARULLI, Marina

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Methods and tools for supporting industrial design innovation

Roberto Viganò, Mechanical Department, Politecnico di Milano, Italy

Marina Carulli, INDACO Department, Politecnico di Milano, Italy

Abstract

The introduction of information technology (IT) systems to support designers' activities and data management have profoundly affected company structure and design organization. This evolution has brought the introduction of systematic methods, close to information tools skills and prerogatives, using computer management and data recovery skills as main design support. The use of the IT also improved information exchange among different work figures involved during product development process.

In this direction authors have intended to analyze the role and the implementation of systematic methods and tools within industrial designer area of the design process and their impact on the conceptual design phase in particular. Consequently, the research has been developed primarily in reference to design methods able to support the strict ideation stage of the Conceptual Design, that can be referred to two typologies: knowledge based and functional approaches. Subsequently authors have analyzed the information tools currently used during design process, as CAD systems, and some innovative, as Virtual and Augmented Reality tools, that can be used within industrial design area.

The result of the study has been a formalization of the course followed during idea conceptual phase in order to include and to arrange the design methods and tools analysed. The research proposes a structured view of a process of product conceptualization, usually considered as mainly heuristic, focusing on the integration of methods and tools to support project and its communication. In this area the research has highlighted industrial designer role characteristics during design process, changeable in reference of project development level, and also some important new questions have been identified about the interaction between industrial designers and the other design areas involved in the process. In this direction the study has highlighted the need to support knowledge exchange and recovery, introducing the possibility to extend the research to the whole process and integrate industrial design and engineering collaboration in a more effective way.

Keywords

Conceptual design process, Systematic innovation, Knowledge management, Integration

At the end of the last century design area has been subjected to an important evolution with the introduction of information technology (IT) systems to support designers' activities and data management. Those systems have profoundly affected company structure, work organization and design methods: indeed, it is today difficult to think about development process of new ideas without the support of any information systems.

Overall, this evolution has brought the introduction during product development process of new techniques, close to information tools skills and prerogatives, using computer management and data recovery skills as main support to allow the application of systematic design methods. In this direction some systems have been developed to support the designer during solutions research, based on principles, rules and strategies for indicating innovative solutions to problems. Naturally, this systematic approach does not would belittle the importance of personal experience and intuition, but it is finalized to improve designers' skills in order to elaborate more and better solutions (Pahl, Beitz, Feldhusen & Grote, 2007).

Another aspect imputable to the introduction of the IT systems in the company organization has been the radical disappearance of barriers among knowledge areas involved during product development process. This phenomenon, taking advantage from the improved information exchange, has allowed a closer collaboration level among different work actors, creating overall advantages on final results and on development process competitiveness. The most evident consequence of this situation has been the request of a better integration among cultural backgrounds, languages, methods and operational and theoretical tools of all design process actors, also in order to build an homogeneous, coherent and shared tissue of knowledge.

To maximize the benefits of these changes since the initial conceptual phase of the product design process, new approaches are required. In this direction authors highlight the role and the implementation of systematic methods and tools for supporting product development and innovation. Basing on a study devoted to formalize the course followed during idea conceptual phase, an analysis of systematic methods and tools was conducted and an arrangement of them into the activities of the design phase under study was proposed.

At the end, a verification of the proposed structure was carried out through case studies with industrial designers, in order to demonstrate the usefulness of methods and tools integration within the process.

The course defined in this work, regarding the conceptualization phase of the design process, is constituted by a series of activities starting from client request to executive design and engineering. The mapped process allows to identify the main activities in which it is possible to implement methods and tools appropriate to support the industrial designer, analysing in detail every phases, and highlighting where it is possible this implementation and for which goal.

To this end authors have developed, using interviews and study cases, a setting of design course oriented at the identification of most significant moments of the process.

Formalization of the design process

The authors have structured a standard process description in order to hypothesize the adoption of methods and tools able to manage the information involved during the concept design process. The nature, the origin and the implications that these information involving can be explained in the operational sequence followed by designers in their idea evolution. This process analysis has been oriented also to include methods and tools able to represent and communicate project idea. In authors' opinion, this approach is particularly important to highlight that the use of these elements could bring a better process organization and management.

The diagram derived from this part of the study, shown in figure 1, structures the process as a cluster of actions that have to be performed sequentially, through the use of appropriate intellectual and material resources, and that have to be subordinate to adequate controls (Ulrich & Eppinger, 2004). In the proposed process the industrial designer is not the only system actor: his/her role and his/her relevance change depending on the level of the product development process. In its first part the designer covers the role of recipient of the actions carried out; then he/she becomes the core of the process as holder of the design culture necessary to generate innovation and to coordinate professional figures with whom he/she works. Defined the concept, in the last process phase he/she, finally, becames a consultant for the management both of the engineering and of the manufacturing phase of the development process.

Initial step

Within this area of reference, the formalized conceptual process starts from the request for designing a new industrial product or modifying an existing one by a client, which requires industrial designer's involvement and cooperation. Condicio sine qua non for process starting is, therefore, the client sets at this stage some required design specifications on the product or product typology that can be functional, qualitative or about performance else identifiables in a more abstract request in order to satisfy a need.

Knowledge

Following this first step, an activity takes place defined as "consciousness raising" of the posed problem nature. This activity is aimed at putting the industrial designer under optimal conditions for the project management. Indeed, it is necessary to underline that the industrial designer's figure can be integrated into the corporate structure or external to it and, then, traditionally a freelancer. To prevent the change of status between the first and the second case gives an unequal level of information, potentially damaging for the cooperation efficiency, it is necessary to provide a cluster of information related to the company, its market target, its products, and so on. The collected information allows the designer to have all the needed elements to play his role without his work outcome or performance will be influenced by the type of collaboration that he has with the company. The required information is the result of a research aimed at collecting a series of data related to all aspects that influence the product. In this sense, after a first step of collecting unstructured data, it must follow a critical analysis of those.

Recent researches had underline that most information data, useful to the industrial designer activity, are present in the company in a non-structured way, or are the result of previous studies carried out in different areas of competence. The management and the call of knowledge acquired during past planning processes in order to support new design processes represents the opportunity both to use already structured knowledge and to optimize times and costs borne in this phase. In particular, from designer's point of view, the opportunity to have a structured store of knowledge concerning the various disciplines related to the project in an integrated way is the model to which refer, but that is traditionally achieved empirically (Kroll, Condoor & Jansson 2001, Lawson 1997). In addition, the learning of new knowledge by the industrial designer during the product development process, and the subsequent reuse of the same knowledge for new projects (Sim & Duffy, 2000), could be supported and improved using tools to transfer and apply the knowledge. In science and industry areas some methodologies and tools have developed, including data mining (Jankovic, Stal Le Cardinal & Bocquet, 2007), context-based system (Leake & Scherle, 2001), semantic system (Baeza-Yates & Ribeiro-Neto,1999), etc. to support knowledge management field. Some of these tools are still in prototype form, but can contribute significantly to achieve this step goal. The critical aspect of these methodologies implementation is the type of keywords used to research information and data. In fact, they are often difficult to define and at the same time strongly linked with the application field, its historical evolution and the specific research context, with the consequence of limiting an efficient data acquisition.

Brief

Consequently, in the common practice the brief stage is referred as the true project kick-off. This activity saw the profitable participation of the industrial designer as one of the main figures, together all professional actors involved in the design and product development process, and aims to explain the characteristics that the product should possess. Each competence partecipates in the activity making its contribution to the definition of product characteristics, which will become points of references later for the design activity.

In order to adopt the systematic methods and tools during the phase under study, it is necessary to explain the product characteristics in a format suitable for the purpose. Consequently, the brief stage has the aim to define three essential areas for the product characterization and the adoption of these methods:

Functions: defined as "what it does as opposed to what the physical characteristics of the product are." (Ulrich & Eppinger, 2004).;

Performances: define with quantitative parameters in which way (at what level) the required functions must be met;

Constraints: define the limits to which the product must submit, whether quantitative or qualitative; inside include both the constraints about design (technology, material, size/construction etc.) both of those ethical and moral.

Solutions search

More, the "Concept" activity is carried out: this happens when the industrial designer generates new project ideas with respect to identified features, performances and the constraints during the brief. In this context, then, the industrial designer assumes the role of the process engine and suggests conceptual images predominantly qualitative of design solutions. In particular, designer's goal in this phase is to explain the feelings that the product will communicate to the end user and the characteristics by which this process will take place. During the product concept definition the first action is the determination of the project direction to search the desired innovation. This process can be both of explicit nature, with a clear identification of the starting point on which to base the ideas generation process (eg technology of reference, users etc.), both on implicit nature, where decisions are taken without a conscious choice by the industrial designer. A recent Italian national research project (Maiocchi 2007) came to identify three items that are the levers for achieving product innovation: the form, the user and the technology. The choice of one or another lever influences the solutions definition course during the concept.

Determined the innovation lever, the concept is developed in order to search solutions for product architecture useful to meet all requirements. This process is traditionally regarded as "creative and unstructured", the result of the industrial designer's individual ability. On the contrary, the right approach to search for solutions through design systematic methodology requires a logic consequentiality of actions. The systematic nature of design approach, through methods as methodical design (Hubka, 1982), systematic planning (Pahl, Beitz, Feldhusen & Grote, 2007), axiomatic design (Suh, 1990), etc., tries to give form and substance to the final result of the process. There are two ideas about on are focused these methodologies:

the fragmentation of the design problem into sub problems which assign easier solution

the characterization of the required functionality aspects in order to make effective solutions research about similar issues.

The solution search typologies are based on the fact that reducing the problem can be found, using historical archives and databases, solutions already implemented that meet the same requirements and that can be, therefore, used. Such research bases much of its effectiveness on the solutions archives, that can be inspected by appropriate keywords, often directly associated with the design features that are required to solve. Some studies, especially related to TRIZ technique (Altshuller, 1984), are distinguished with the different approaches to the solution research problem. This technique bases its paradigm on the consideration that the designer is called to solve a series of contradictions into the project, often due to the required functions. In this sense, the problem analysis in a disconnected manner in relation with the operating environment, which often affects project choices, allows to take advantage a bigger domain, like that of patent solutions, through questions and different keys. In spite of this, we need to remember that some methods to support the creative ideas generation, such as "brainstorming" (Osborn, 1953) or "lateral thinking" (De Bono, 1993), while not being a structured approach to the problem, have been proposed and are used by industrial designers during the concept activity (Lawson, 1997).

Having imposed during the previous brief activity the project features, performances and constraints explanation, it is considered in the same way prerogatives (compared to form, use and technology) added by the industrial designer in this stage. The final result of the concept activity consists in design solutions that have to be combined and evaluated for the selection of those that will be proposed to the customer at the end of the conceptualization phase (Hubka, 1982).

Solutions evaluation & choice

In the next activity, the solutions evaluation and choice activity enables to highlight the satisfaction degree that reached by the proposed solutions in relation to the requirements. Also in this case, the traditional approach is not structured and, while based on certain objective factors of reference (eg industrial manufacturability, the satisfaction of specific ergonomic requirements, the possibility to use of existing technical components etc.), it is often done on the basis of subjective choices. This, of course, can lead to exclude interesting and potentially innovative design solutions due to partial and not objective evaluations.

On the contrary, the use of the comparison and evaluation methods help to judge each solution in relation to the characteristics defined in brief and concept phases. In particular, the importance of a feature than another can be judged in relation to the project given direction: in this sense in some cases the parameter related to manufacturability can have a greater weight in the evaluation, while in other the product aesthetics could be more relevant, and so on depending on the project and evaluation aspects.

This activity, which have to carry out on the basis of objective criteria, is further complicated if the issue is divided into several parts. The fragmentation leads, in fact, to the need to analyze the whole of all combinations resulting from the joining of the found solutions. Quality Function Deployment (Akao, 1972), Analityc Hierarchy Process (Saaty, 1977), Design Structure Matrix (Steward, 1981), Morphological Matrix (Zwicky, 1948) etc. are techniques to support the selection activity, and developed over the years differ among themselves on the basis of objective criteria used for selecting among solutions.

Final step

The mapping of the design product conceptualization process ends with the developed project presentation to the client, and it is conformed to the four issues also identified in PRIN (Maiocchi 2007) research as the results of the design-driven process:

- aesthetic innovation;
- innovation of function and use;
- typological innovation;
- innovation of meaning.

The ideas presentation typically takes place through the use of specific tools used for communication both the overall project approach (system architecture, general layout etc.) and particulars which characterize it. Within this area are employed representation tools in order to obtain two-dimensional images (axonometries, orthogonal views, technical tables etc.), virtual models to test specific behaviours (functioning, interaction etc.) (Bordegoni & Cugini, 2005), physical models or maquette etc.

In this sense it seems important to highlight that the tools for the presentation and communication of project ideas to the client are different, or at least it is their use, compared to those traditionally used in the ideas generation and evaluation. The generation phase foresees, in fact, the use of tools that enable the industrial designer to represent his ideas and to dialogue with them in order to develop and refine them (Galloni, 2001), maintaining a low level of definition, but easy to evolve and change. On the contrary, the concept communication tools are designed to describe and highlight the main innovative features of the project, without opportunity to make changes in real time, and their use is based on specific types of innovation already defined.

In all project representation cases the industrial designer's goal is to communicate to the client how and in which direction his contribution has solved the given problem, or improve the existing industrial product in an innovative way. The presentation of concept ideas, already evaluated in the previous phase of the product development process, traditionally leads to a subsequent further selection, in this case carried out jointly by the industrial designer and the client in order to define the potentially interesting projects and, therefore, to deepen and develop in the following stages of the process.

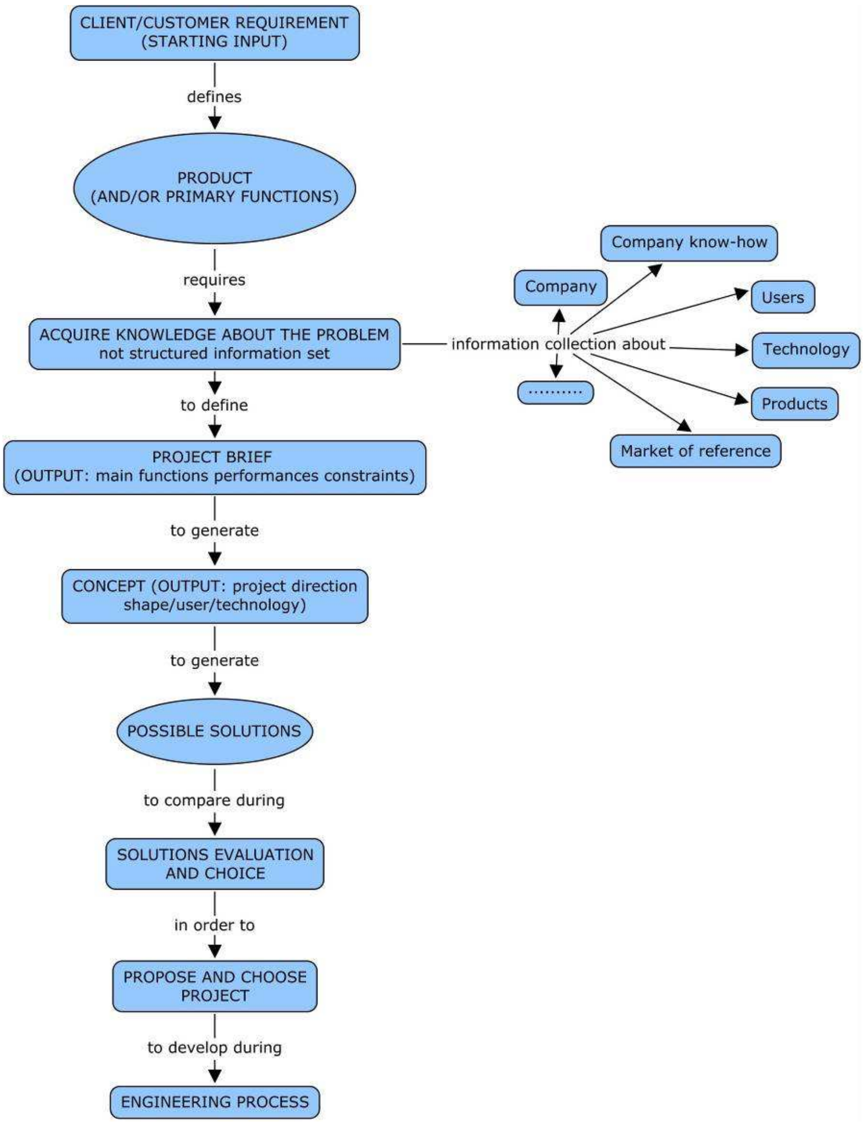

Figure 1: Maps of the industrial product conceptualization process

Validation phase

After the first research phase of structuring the described conceptualization design process, authors verified its use within a validation phase, carried out through case studies related to past design processes.

The case studies were organized on the basis of design process structure, asking to designers to retrace a particular design process already carried out in a recent period.

The verification of the conceptual design process inquires into:

- the information and data typologies usually searched during the design activity;
- the different procedures used to search and compare information;
- the modalities to use the acquired information (within the project or not);

in order to demonstrate the described conceptualization design process responsiveness to industrial designers' activity.

The designers subject of these experimental sessions were divided into different target groups (students and professional designers), in order to highlight in which way the personal experience could influence the used conceptualization design process and the relative methods and tools.

The first category, called "students", was composed by 9 work groups (totally 35 people, product designers and mechanical engineers), who participate into the Design Studio of the Design&Engineering Master Degree Course of Politecnico di Milano. Consequently, the past design process experiences were chosen commonly, in order to compare similar activities and courses. In this direction a common project theme about a concept car was defined, developed by students during the Design Studio.

The second category, called "professional designers", was composed by 6 individual cases, which are industrial designers chosen for similar backgrounds, educations and used design methods. In these study cases, in order to compare similar typologies of activity, the past design processes subject were chosen in reference of a medium-complexity industrial product, developed individually within the conceptual design process.

This approach is particularly linked with the "Learning in Design theory" (Sim & Duffy, 2000): in this case, it is possible to postulate that starting from the same designer's typology (with similar backgrounds, educations, design methods and thinking styles), the work experiences can influence project management, modifying also the use of tools to support the design process.

Consequently, the validation phase were structured in order to highlight different approaches to project management and, above all, in which way methods and tools to support the design process and data management could be useful for different designer's typologies.

In order to carry out the case studies, the activities were represented with concept maps tool (figure 1) and to each activity different methods and tools that could be used were identified. The conceptual process structure was used as reference for the case studies, both during the experimental activity and during the analysis of results.

Some materials were supplied to students and professional designers, in order to explain the represented conceptualization design process and to identify its progress.

In this direction, the case studies were structured supplying:

an introductory scheme about the conceptualization design process (figure 1);

cards differentiate for activities and repeated n times (figure 2).

The introductory scheme shows the conceptualization design process, in order to explain it to the designers subject of the experimental case studies.

The provided cards are structured to investigate simultaneously:

- searched information typologies, in order to identify the sequence of selection used during the process;

- used research typologies;
- modalities of results integration within the conceptual design process.

For this reason each card, specific for each conceptualization design process activity, is subdivided into three main parts, as shown in figure 2.

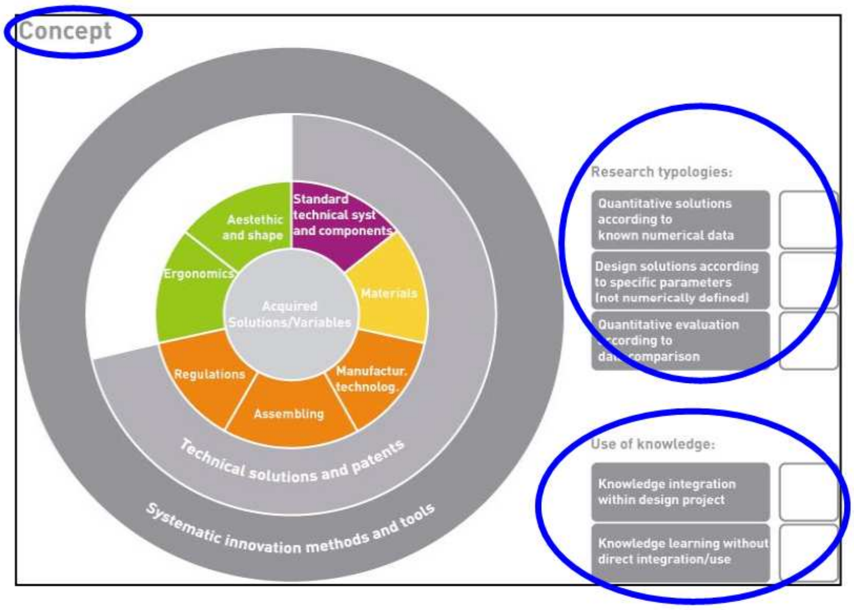

Figure 2: one example of the second cluster of cards

These cards were supplied to work groups in many copies (20 for each process phases for each group) and it was asked to students and professional designers to mark on each chart conceptual design process choices.

In particular, in the first part industrial designers have to mark the searched information typologies (one or more contemporaneously), the used research typology (one or more contemporaneously) and in which way the acquired information was used (simply acquired or integrated into the system).

The aim of this contemporary investigation is to inquire into designers' choices as a whole, but at the same time to share among information typologies and the typologies of research used to inquire into its.

All the experimental sessions were carried out using the Protocol Analysis method. The experiments were recorded using a video camera to record words, gestures, expressions, and cards compilation to support the post-analysis sessions.

Results' analysis

The analysis of the experimental sessions was carried out in different steps, in order to inquire each mechanism separately and, consequently, to integrate the partial results in a more overall view. Moreover, in this direction the results derived from students and professional designers clusters were analysed separately and compared in a next moment.

The first step of the experimental sessions analysis concerned the use of information during the design process, and in particular:

- which information typologies are used during the design process phases, and how often;
- if the information typologies are inquired/used separately or contemporaneously.

The use of information typologies during conceptual design process activities has been translated into quantitative form, quantify how many times each information typology has been inquired and used. The quantitative analysis was carried out counting all the filled cards, sharing out the results among process phases and clusters of target.

The results were transferred within some graphs (shown in figures from 3 to 7) in order to show trends in information typologies research and use frequency during conceptual design process activities.

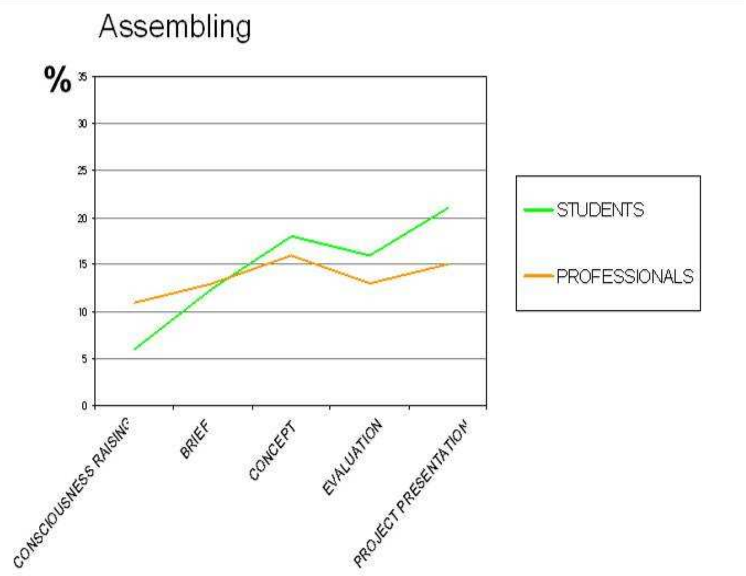

Figure 3

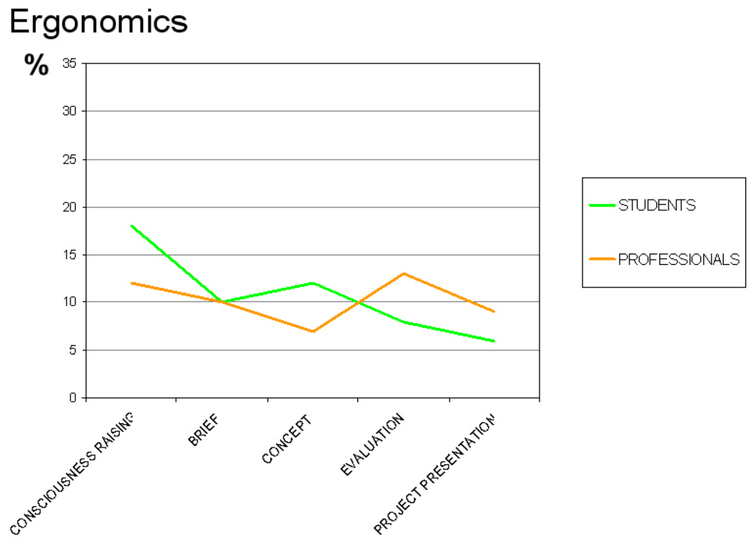

Figure 4

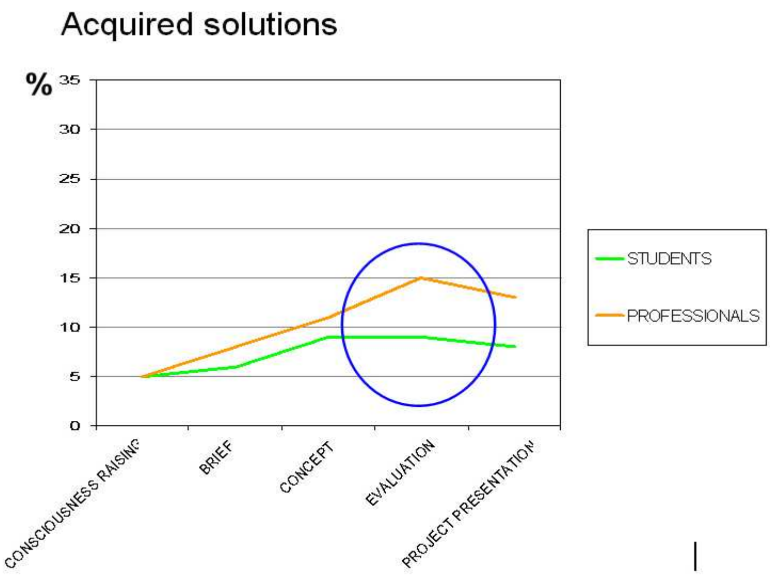

Figure 5

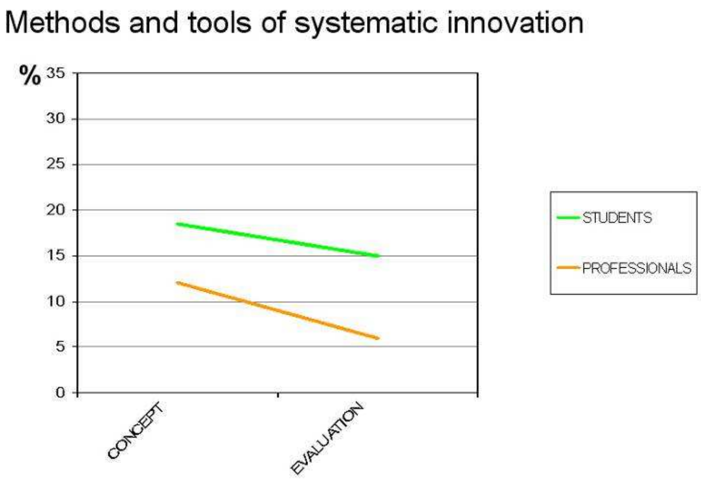

Figure 6

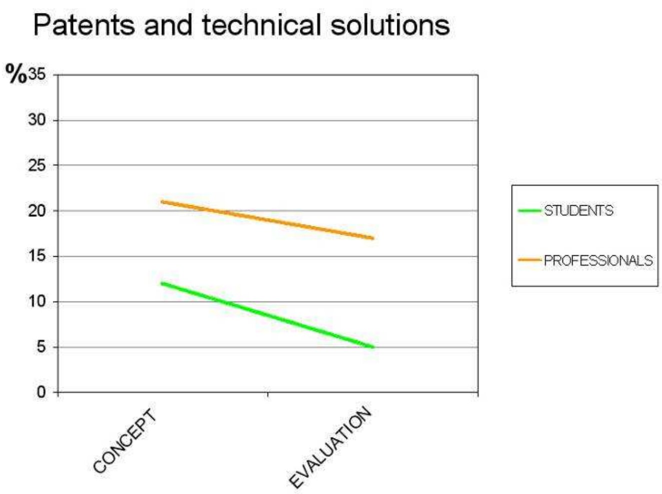

Figure 7

The next graph concerns the contemporary researches and use of information typologies within the design process activities. This parameter was investigated in order to highlight the existence and importance of multiple researches, and in which way this approach influences the design process.

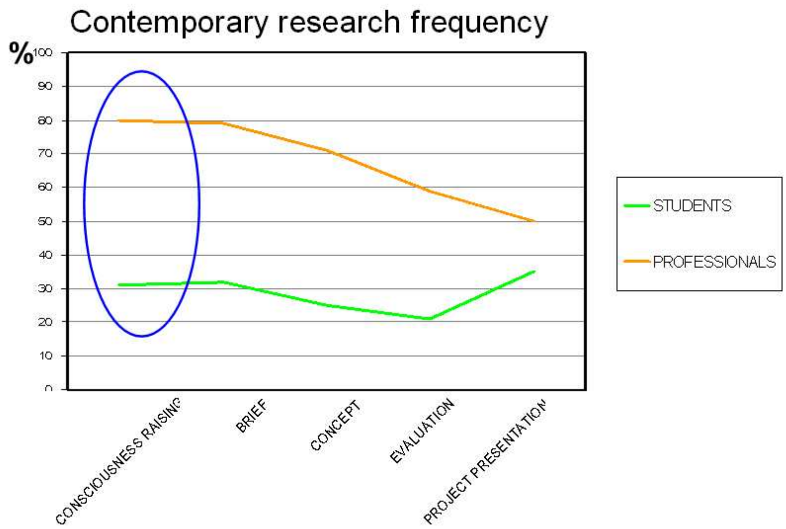

Figure 8

The next step of the experimental sessions analysis concerned the research procedures used to inquire into information typologies.

In particular, the aim of this step is to highlight which is the relationship between research procedures and conceptual design process activities, and if students and professional designers choose in different manner the research typology.

The next graphs concern quantitative data and show research typologies trends divided about clusters of experimental sessions subjects, both in singular cases (when these are carried out singularly) and in multiple ones (more researches carried out contemporaneously).

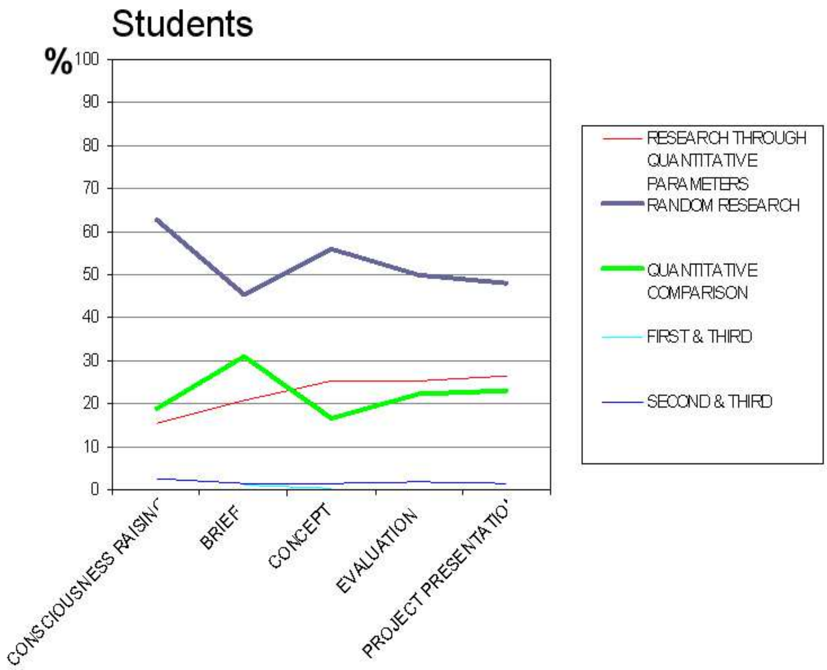

Figure 9

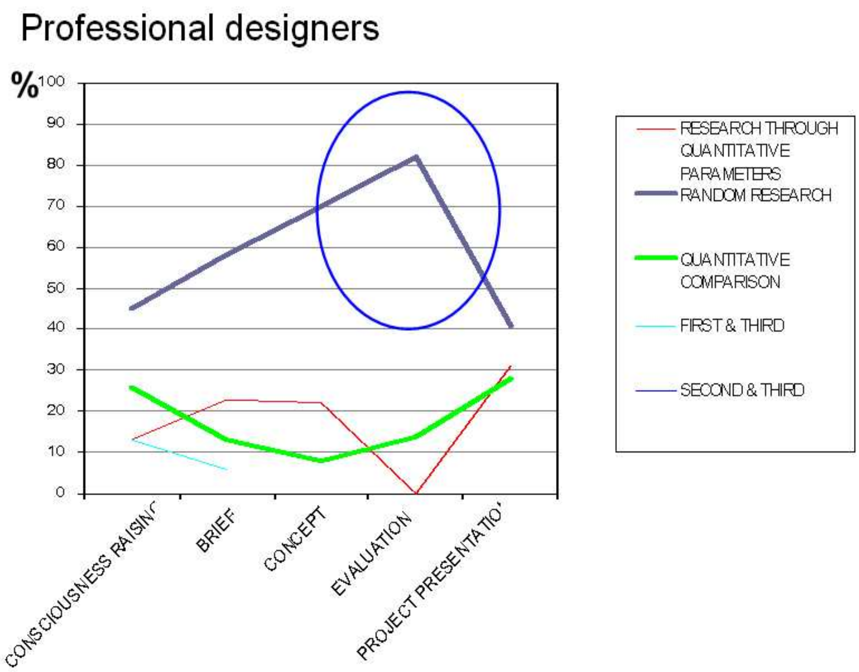

Figure 10

The last step of experimental session results analysis concerns the use of acquired information, which could be directly used for the project development or acquired as personal knowledge and then the learn mechanism that could take place during the process.

Moreover, this is particularly important because distinguish between students and professional designers, both for already acquired knowledge during past design processes and for the consciousness of the importance of new knowledge to acquire.

The next graphs highlight information use (integration or acquisition) trends during the conceptual design process activities, divided about clusters of experimental sessions subjects.

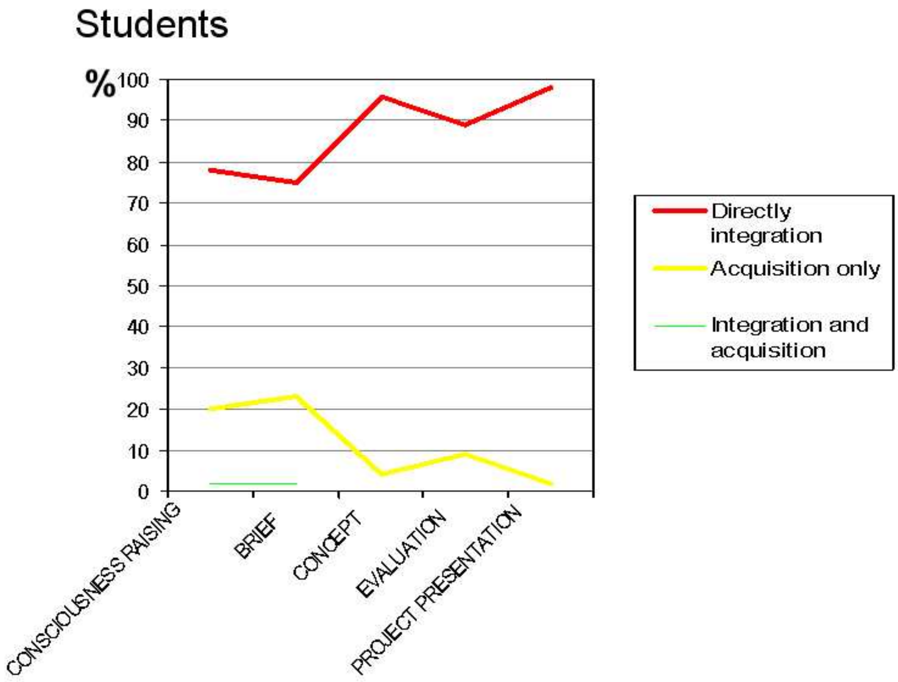

Figure 11

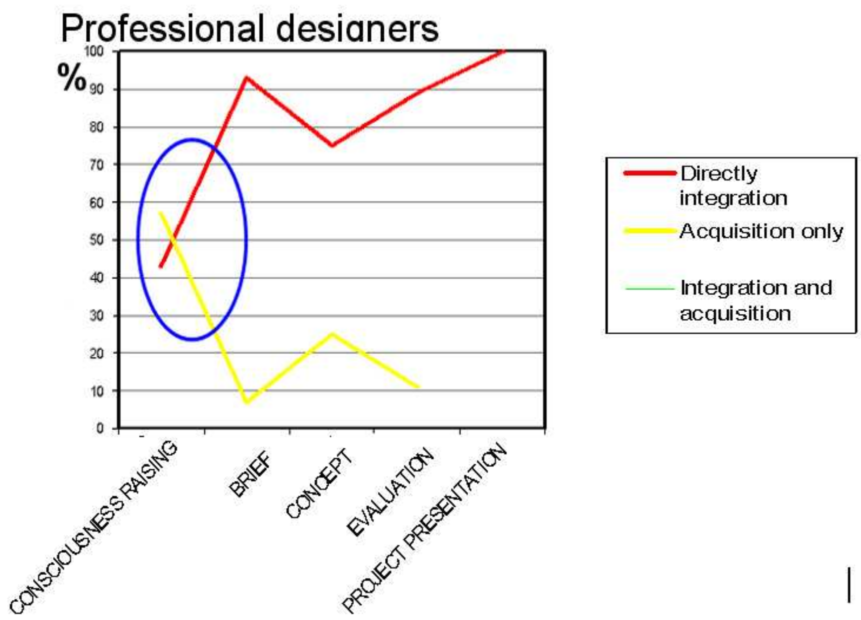

Figure 12

The collection of these experimental results and their analysis shows some important elements that demonstrate the use of the proposed conceptual design process by industrial designers, both students and professionals. Moreover, these data highlight some peculiarities about information research and use within the project and the possibility to acquire new knowledge. These last elements are strictly linked with methods and tools to support the design process, and highlight the concrete possibility and opportunity to integrate them within the industrial design conceptualization process.

Some remarks, in fact, can make about validation phase results:

- to different conceptual process activities correspond a different frequency in using information typologies. In particular, the different typologies are searched and collected during the "consciousness raising" activity, and consequently are used within the next activities of the conceptualization process. Moreover, while some information and typologies follow similar trends, others specific about "Methods and tool for systematic innovation" and "Patents and technical solutions" are used above all during the concept activity, and in inverse proportion by students and professional designers. Finally, with regard to the "acquired solutions" area of knowledge, the use of that is fully board by professional designers, but not so many used by students. This could indicate a greater awareness of one's own experience by professional designers, and consequently the consciousness of using its within design processes.
- there is the need to consider and manage more information typologies at the same time, integrating information according to the project parameters; professional designers use more than students the integrated research of information, and consequently it is possible to postulate that they manage the project as a whole, while students manage it in sequence.
- the different research typologies are used during all activities of the conceptualization design process, becoming more and more specific. Moreover, there is the need for constant evaluation and comparison, with a greater impact for students and smaller for professional designers (they refer more to their personal experience).
- the modalities of using researched information are identified during all activities in differently ways: the students use the researched information directly within the project, and they have not perception of acquiring new knowledge, while professional designers use some design process activities (above all the "consciousness raising") for acquiring knowledge about the project and only in a second step to apply it into the design process.

Conclusions

The collected elements and the resulted remarks demonstrate the possibility, by the industrial designers, to follow and implement the proposed conceptual design process, and moreover the opportunity to use the proposed methods and tools within the design process for supporting it.

In particular, it is plain that the proposed conceptual design process rises and follows actual designers' activities, but while at the present moment usually these activities are carried out empirically, the proposed structure and the relative methods and tools could support the design process development in a more organized way.

This comes from different competences integration: on one hand the "creative and free" conceptual design process carried out by industrial designers, on the other the use of methods and tools for supporting product development and innovation. With this research it is demonstrate that these two approaches, seemingly at the opposite, can be integrated in a more comprensive and structured process, in order to support and improve new ideas generation to obtain more and better solutions.

In fact, the possibility for example to integrate some of the introduced methods and tools for systematic innovation and patents collections can lead to support designers during solutions research, and the same can happen about the others project areas (technical, ergonomics, manufacturing etc.).

Moreover, the possibility to research information and data for the project should bring to acquire new knowledge easier using the inductive method, and consequently to improve designers' own knowledge about project area. This is particularly important for industrial designer students that usually need to acquire quickly information and, consequently, to improve their knowledge about project variables in order to approach correctly conceptual design processes. A similar hypothesis can be make about professional designers that usually have a own high knowledge level, but often are faced with several companies and several product areas: for this reason the possibility to acquire quickly a lot of information about the problem and related elements can improve their work and constitute a competitive element.

The possibility to use methods and tools for data management represents one of the most important identified factor: the knowledge about the design problem is a crux both for students and professional designers, also if for different reason.

Finally, the possibility to research information with different research typologies and to compare designed solutions on the basis of defined parameters can support designers' choices during the conceptual process activities. In particular, while some research typologies can be used differently in comparison with design problem and designers' knowledge level about the problem, the possibility to compare problem solutions allows a better evaluation (more objective) and, consequently, a more consciuos solutions selection.

From these observations is then assumed the possibility to apply the presented conceptual design process and the related methods and tools both in academic and professional worlds, also with different goals. In the academic world, in fact, it could be represent the possibility to support industrial designers students about the management of the design process, the related information and the solutions selection activity. Moreover, in this area it could be useful for improving the learning activity, using the inductive method in order to acquire new knowledge about project area.

Instead, in the professional world at the possibility to improve the managment of the design process it is important to associate the opportunity to collect in a profitable way and then reuse information and data acquired during past design processes or other company's activities.

The research has also highlighted that many questions are open about the tools able to support the industrial designer during the conceptual process.

For example, tools able to collect the information in function of a particular contest requirement are required and a major awareness into the capacity of the representation and simulation tools by industrial designers could bring a better integration and communication ability with the other design actors.

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Roberto Viganò

Associate Professor in Computer Aided Drafting & Design at the Politecnico di Milano.

At present he is teacher of both Computer Aided Drafting & Design course and Industrial Drafting and Communication course at the Politecnico di Milano.

His research activity is mainly dedicated to the fields of Computer Aided Design, Virtual Simulation and Industrial Engineering Design Methods.

Recent researches are devoted both to the application of methods and to the choice of tools able to support the designer during the initial phases of the definition of the product solutions and during the design phases, supported from virtual simulation tools, of the product analyses.

Some studies are devoted to propose the use of the Computer Aided and Knowledge Based paradigms on phases of the product development not canonical. For example, the use of Knowledge Aided Design systems during the initial estimating phase of the design of industrial plants or by means of not conventional tools for the engineering analysis.

Marina Carulli

Industrial designer, she graduated in 2003 in industrial design with a project for "Shace Shuttle mobile kitchen". She is a Ph.D at Design Department of Politecnico di Milano; her Ph.D thesis, in collaboration with Mechanical Engineering Department of Politecnico di Milano, is about the innovation of design methods using virtual shaping techniques.

She worked for 6 months at Mechanical Engineering Department of University of New South Wales (Sydney, Australia), collaborating with Prof. Reidsema in design methods research area.

She collaborates in Design&Engineering Master Degree at Design Faculty of Politecnico di Milano with Prof. Trabucco and Prof. Ingaramo.

Researcher within research projects of the UdR PP (Design Research Unit – Politecnico di Milano) concerning innovation in industrial production and design.