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Question/answer techniques within CAD environments: An Investigation about the most Effective Interfaces

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ABSTRACT

The paper aims at exploring the opportunities for improving the Human Computer Interaction (HCI) of Computer-Aided systems for supporting designers in carrying out the early stages of the Product Development Process (PDP). In details, the authors stem from the analysis of the latest advancements and issues in the field of Question and Answer techniques, which they have already implemented in algorithms for supporting the analysis of inventive problems. According to the analysis, they identify two basic directions to improve the HCI in such systems. Literature evidences concerning the different approach of designers according to their experience point out the need of producing more flexible systems, tailored for both skilled individuals and novices. Moreover, the need emerges to both foster creativity with meaningful stimuli and introducing pictorial communication within a dialogue flow, so as to follow the common cognitive path emerged by the analysis of design protocols. The discussion shows that the combination of textual and graphical interactions is crucial to support the cognitive processes in design. Such blend allows to introduce stimuli viable to reduce design fixation and psychological inertia, that affect negatively the outcome of the idea generation stage.

Keywords: computer-aided innovation, HCI, engineering design, cognition, emotion.
DOI: 10.3722/cadaps.2013.905-917

1 INTRODUCTION

A noticeable quantity of contributions addresses the need of CAD systems to better support the initial phases of engineering design cycles, such as product planning and conceptual design. Within these steps, less oriented to the optimization of the virtual model of a new product, the reasoning of designers and their creativity play a major role in defining the main features of the project and the layout of a solution. Some scholars have investigated the possibility of creating an environment where creativity is not only stimulated, but also fostered. According to their vision, computers can carry out and facilitate several functions playing a different role in affecting individuals' creativity. Lubart [42] states that computers can be partners in creative processes:

- by facilitating the management of the working process, encouraging the perseverance of designers in the research of innovative solutions;
- by easing the communication between design team members, since circulation and integration of ideas significantly contribute to the enactment of the creative process;
- by aiding the designer with a coaching activity, acting as an expert system that guides the user throughout cognitive processes;
- by cooperating in the creative process, thanks to Artificial Intelligence (AI) systems that stimulate the generation of ideas.

The efficacy of such computer systems in supporting the diverse activities of development processes in different contexts is still lacking sound evidence. Nevertheless, several commercial ICT products have been developed so far to support creative design activities. Some of these ICT products have been proposed as commercial software claiming to support the designers' creative processes for generating innovative ideas (Table 1).

Brainstorming-based software	*TRIZ-based software*
CMapTools, Paramind, Idea Fisher Pro, Idea Generator Plus	Creax Creation Suite, Ideation Workbench, Invention Machine Goldfire,

Tab. 1: Commercial software (partial list) for supporting the creative stages of the product development process. TRIZ, as opposed to the unconstrained and intuitive brainstorming, represents one of the structured methodologies currently embedded into such computer applications.

While the performances of these systems have been just evaluated from a qualitative point of view, as for instance in [4], their main drawbacks are well recognized by several authors [19, 40]. Indeed, among the roles highlighted by Lubart, the computer partnership in easing communication among people is probably the only one that has demonstrated its potential through practical applications.

With respect to the detected deficiencies, it seems that these systems miss to properly leverage the creative potential of individuals and teams with repeatable outcomes, if the users have not assimilated a solid background on creativity tools. Indeed, the simple implementation of design prescriptive procedures (e.g. the TRIZ-based ones) just forces the users into following a predefined path, whatever the situation to be tackled is. On the other hand, software embedding intuition-based methods (e.g. Brainstorming-based ones) work through thought-provoking techniques and may lead to the generation of a great number of concepts. Their intrinsic trial-and-error approach does not allow organizing cognitive processes according to an efficient sequence of steps and most of the generated ideas appear as poorly suited to or, worse, not capable at all to address the problematic situation.

In previous works, the authors have highlighted the potential benefits of computer–aided coaching systems capable to assist the designer during the definition of product concepts and embodiments. They proposed a general framework to support problem solving activities in design and defined an algorithm to support the analysis of design problems during the early design stages of the product development process [5-7]. The authors introduced a dialogue-based interface through which driving the analysis of problems, in order to facilitate the interaction among the user and the computer. Several testing sessions have been carried out to evaluate the performances of such systems, as witnessed in [8]. The experiments on the algorithm resulted in positive, but not fully satisfactory outcomes [4]. In details, many cases demonstrate how a not marginal amount of mistakes or misunderstandings of the users can be ascribed to design fixation, or feelings of frustration and boredom.

In this context, the authors want to investigate how Question/Answer (Q&A) frameworks implemented in CAD environments can be modified, so as to improve their efficacy. More specifically, major changes should be performed with the aim of marginalizing the potential emergence of problems affecting the design discourse and the human thinking. In this sense, the authors have analyzed the literature in order to individuate potential strategies to overcome the current limitations.

The following section aims at describing the most recent and relevant issues and opportunities emerged in the field of Q&A techniques in Human Computer Interaction (HCI). According to such evidences, the authors have chosen to focus on the aspects concerning barriers and opportunities regarding Q&A systems supporting the early design stages. The latest advancements of Q&A techniques and their emerging issues (Section 2) have been analyzed with respect to: the effects of previous experiences and expertise in both designing for the PDP and using computers (Section 3); the issues that emerge during design process from a cognitive perspective (Section 4). The final goal is to devise a more effective HCI capable of overcoming the limits of current systems showing poor usability and limiting the exploitation of human creativity. At last, Section 5 presents a summary of the paper together with the discussion into which the authors draw the profile of a more effective and efficient HCI using Q&A techniques for supporting design.

2 QUESTION AND ANSWER TECHNIQUES: ISSUES AND LATEST ADVANCEMENTS

In some of their previous works, the authors have pointed out that the implementation of Q&A techniques within computer-aided tools represents a suitable strategy to support the early stages of design. The interaction between humans and machines by the use of natural language is strategic to allow the users of Computer-Aided systems to feel comfortable with a flow of information provided in a common and familiar fashion. Moreover, questions posed by the use of natural language enable the removal of specific technical jargon concerning the specific domain of knowledge under investigation [7, 8]. Furthermore, said questioning procedures could trigger abstraction processes in the users as a means to ease the identification of analogies and of cause-and-effect relationships. As well, they can support the investigation of facets that are not necessarily taken into account by designers because of standards and consolidated practices [9]. At the same time, the introduction of natural language interfaces overcomes (part of) the drawbacks and limitations emerging with current Computer-Aided systems for the early phases of the design process (Problem Analysis, Concept generation, Idea Evaluation). Indeed, traditional computer applications straight implement design and problem solving methods without removing domain-specific symbols and jargon, which result unfamiliar to not trained users.

From this perspective, Segers [51] remarks that words have a not negligible role in design, despite the major focus of previous researches has been set on the role of sketches in the different stages of the product development process. Indeed, words support the transfer (and more specifically the externalization) of knowledge between designers (tacit-to-tacit knowledge), as well as among unanimated information sources and the designer (explicit-to-tacit). Even in case they are not organized in an articulated speech, they can enrich the definition of concepts by means of written marks and annotations on a design draft or sketch. In such a way words ease the complicated transformation of tacit knowledge into explicit knowledge by means of comments, questions, descriptions and so forth.

In one of his work of 2007, Dong [26] stresses the concept that language is an integral component of the design process. Consistently with the vision of Simon about design as a science concerning the generation and the development of artificial systems [53], Dong claims the existence of a lot of people designing without the need of sketches (as canoes or shacks builders). The thought of scholar supports therefore the belief that language is a constituent of design. Moreover, it is also evident that the proficient use of language is, by itself, a design activity, since the cognitive steps for building a sentence follow rules and constraints, like it happens for developing ideas.

With reference to these last visions, problems in design are tackled also by means of language. The design rationale can be then depicted as a progressive description, where problem and solution co-evolve in the shape of a dialogic discourse [27]. Design issues require answers that often lead to new issues in an iterative fashion that stops once the process converges to a unique, comprehensive and satisfactory solution. This kind of approach can be properly described with different nuances about the reliability of information, so as to map not just certainties, but also conjectures, with the Issue Based Information System (IBIS) notation. This kind of representation has been embedded into different software (e.g. DesignVUE - http://www3.imperial.ac.uk/designengineering/tools/designvue). However, the contribution of these applications is limited to the management of text and symbols for depicting the design discourse, which is modeled through cognitive flows between problem and solution domains. In such cases, computers do not generate questions, nor provide any hint for supporting the user in producing meaningful answers.

As outlined at the beginning of this section, language is also paramount for the search of meaningful information, so as to acquire knowledge capable of turning an ill-defined situation into a well-defined situation [52]. There are several evidences that the communication among designers is the preferred channel for transferring and retrieving useful information in the early phases of the design process [25]. This information exchange, being it verbal or written, occurs at least partially as a dialogue. Such an interaction among humans entails at least two of the actions pointed out by Lubart [42] for defining the role of computers in the creative processes: communication easing and coaching. Indeed, while it is straightforward that the information exchange requires dedicated channels to be eased, the coaching activity is required, although at different extents, every time designers ask for colleagues' knowledge and expertise. The search for this information is indeed carried out with the scope of relying on a richer source of knowledge, capable to suggest useful hints to overcome difficult situations in shorter time and with better proficiency. To this purpose, Cordick [23] further details the role of coaching into six more specific subcategories of actions:

- Asking Questions
- Showing illustrative examples
- Providing feedbacks
- Relating the task to previous and already existing knowledge
- Focusing on the goal to be attained
- Providing hints for being more efficient and effective.

Actually, these categories are just representing supporting activities, while the role of coaching can be effectively carried out by allowing users to improve thinking and design skills. In this context, Brahnam and De Angeli [16] have recently underlined how HCI is action and dialogue as well. This is due to the continuous feedbacks occurring between the machine and the human as textual and graphical communication, as well as by acquiring multisensory responses. Several textual-interacting applications have been proposed to address needs emerging in very diversified fields, e.g. education, health-care and business. The quality of such HCI has progressively enhanced. For instance, in this field, Apple's Siri represents one of the latest advancements exploited at commercial level. It acts as a personal assistant finding information and performing actions when asked by the iPhone user via vocal commands. The education context, among the abovementioned, shows the closest similarities with design, because both of them concern processes of knowledge acquisition. In this framework, Graesser et al. [32] developed AutoTutor, a computer-embedded coach capable to ask questions to learners and provide them suggestions and hints for answering. The scholars claim that the proposed tool prompts the user for completing the information set and discerning bad from good answers, while learning the content transferred during the interaction. In terms of opportunities for further development on different domains of application, it is worth saying that AutoTutor allows to obtain a human-like dialogue, since the testers are not capable of discriminating Human- from Computer-generated questions.

From an opposite perspective, information retrieval systems and the related queries represent the other side of the interaction: the user asks for new knowledge and the computer answers according to its own embedded knowledge. Guo [31] claimed that Q&A systems based on a semantic and ontological organization of knowledge permit to ask questions with daily life sentences and obtain very suitable answers (precision 86%, recall 93%).

The improvement of these results depends also on the size of the available organized knowledge on which the system can rely on. From this viewpoint, the introduction of systems capable to learn, i.e. to enrich their knowledge, represents a concrete challenge. Smith et al. [55] stress the need to improve knowledge bases. The definition of the right question to be posed is one of the issues the scholars address, so as to capture novel content, concretely increase the knowledge of the system and keep a meaningful conversation. The focus is therefore oriented to two aspects: the content of the question (for what concerns knowledge acquisition) and the affective side of the interaction. With reference to the latter, the naturalness of the dialogue holds a paramount importance. Their results show that it is already possible to introduce HCIs in which the user can interrupt the computer without significant voice overlapping, thus reducing user's disappointment and managing the timing of interactions more flexibly.

Flexibility represents besides a shared goal according to relevant contributions. Cordick [23] and McCuaig [44] claim that an adaptable system has to take into account the cognition and the expertise of the individual, as well as their affective state. In other words, the capability of new software to avoid the generation of users frustration is not less important than the cognitive load they borne. The first issue can be partially solved by designing system architectures that go beyond domain-specific applications, e.g. by defining a general structure to represent goals to be attained regardless of the subject under investigation. The second one requires, in turn, both the capabilities of perceiving the user's cognitive load and suggesting hints capable to stimulate thoughts towards more efficient cognitive paths.

The mutual interactions between cognition and emotion is out of the scope of the present paper; however, it is worth mentioning here that the growing interest of the emotional state of the individual in HCI has also produced some advancements in the field of Q&A techniques. For instance, Bickmore [14] showed that Embodied Conversational Agents (ECAs, otherwise called chatterbots) carrying out dialogues with the user, may have an active role in affecting both cognition and emotions. An appropriate design of such agents is therefore very important because it is important to avoid triggering bad emotions. Brahnam [16] recognized that both the gender and the age of the ECA affect the HCI. Therefore, a various set of chatterbots may allow very different situations to be properly managed.

According to this overall framework, the present paper focuses on the most relevant facets that emerged as challenge or opportunity in the field of Q&A techniques for HCI. Therefore, two main areas of interests have been considered as the most urgent according to the review of recent scientific contributions:

- Effects of background experiences;
- Cognitive load, creativity and related phenomena.

They will be examined in the following sections from both the perspective of the impact on the design process and on the HCI (when possible). The overall purpose is to depict the expected evolution of Q&A techniques, so as to improve the experiences of future users of Computer-Aided systems. More specifically, the intent is to set the basic framework for a new HCI to be implemented into the algorithm for inventive problem analysis the authors have developed.

3 EFFECTS OF BACKGROUND EXPERIENCES

Before going into the details of the differences between experienced and novice designers, it is necessary to clarify some concepts about the cognitive process that occurs in the generation of ideas, since some of the most relevant differences appear in this context. The ideation process has been computationally recognized as a search within a design state space where individuals' knowledge can be leveraged with the purpose of moving from a problem state to a goal state [52]. From this perspective, AI research has highlighted that several kinds of actions can be deemed as creative in the design space. Three different models of creativity have been highlighted from a computational point of view: Combination, Exploration, and Transformation [15].

First, the goal state can be reached by means of the Combination of already known solution concepts. Second, it is possible to explore the design space so as to operate generative rules that produce a new concept. Both these cognitive processes produce outcomes that can be represented within the initial design space. The third cognitive process, on the contrary, produces a Transformation of the design space, so that the produced solution concept can be only represented in a design space that differs from the initial one, because some of its dimensions have radically changed or even disappeared. From a different point of view, the co-evolution process describes a result of dynamic and iterative definition of two design spaces: problem and solution spaces get progressively reframed until a satisfactory matching between the two of them is found.

In this context, experienced designers show a pronounced approach towards co-evolution of problems and solutions, rather than starting with a complete and comprehensive activity of problem framing/scoping [25]. Experience in the field of the problem domain tends to trigger an approach mostly focused on the identification of potential solutions. This likely results by the self-confidence gained during time, that reduces the inhibition towards the formulation of conjectures. The same outcomes are obtained also by Atman et al. [3], who conclude that seniors make assumptions more easily than freshmen. However, the scholars cannot assess if this effect emerges as a consequence of a major confidence in the owned knowledge or as a shortcut to avoid spending time in searches for obtaining information with uncertain results. With respect to this theme, Cross [25] catches a surprising evidence emerged from the behavior of expert designers. Despite it is expected that those holding higher expertise rely on shortcuts and already consolidated cognitive paths, they tend to formulate problems tougher than they are [3], often also as open-ended problems. Marked differences rather stand between novice and expert designers in framing problems. The former show, in many cases, a practical impossibility to conclude the analysis of the situation at hand before progressing to the generation of solution concepts. On the contrary, as mentioned above, experts' reasoning can be better described according to a problem-solution co-evolution framework. To this regard, the radical and highly creative changes in the design space (e.g. Transformation) that happen abruptly during the whole process are more common in experts than in novice designers.

Another remarkable difference regards the perspective assumed by experts and novices when observing a technical problem. Designers of higher experience often face problems starting with a broad perspective that allows them to both see the problem from different points of view and individuate a wide range of opportunities to solve it. This approach is referred as breadth-first and it minimizes the design efforts by optimizing the time spent in devising a suitable solution. Conversely, the depth-first approach better characterizes the behavior of novice designers, who scrutinize specific details of a sub-problem. The very specific objectives, set with this kind of approach, allow therefore to focus on just a few elements at a time, reducing the cognitive load [25]. For what concerns the time spent in the analysis, there are no significant differences between experts and novices, even if the perseveration in searching for good solutions leads novices in producing better design proposals [3]. Nevertheless, the most frequent switches between the problem and the solution space of design determines a non-surprising unbalance between the time spent by experts and novices in generating ideas, thus implying that problem framing tasks are carried out with a significantly higher efficiency by experts.

An interesting research by Göker [30] studies the commitment of brain areas during design activities through EEG, so as to better understand the design-characteristic cognitive processes. The outcomes show that experts mostly concentrate their cognitive efforts in visual-spatial reasoning. On the contrary, novices show a more intense brain activity in the area concerning textual and verbal reasoning. It follows that experienced designers rely on their previous visual, thus solution-oriented, knowledge. Also McGown [45] highlights the exploitation of visual reasoning by expert architects. To his conclusions, the various drawings, sketches etc., are more and more important once they gather further information, such as annotations, comments and symbols. They allow to better characterize the meaning of the information added to the graphical elements, resulting in a concrete support in the definition of new solution concepts. This integration of textual and visual representations can better trigger the identification of abstract and functional features of artifacts, which is one of the characteristics that expert designers already have and that novices need to acquire with time. From another perspective, Atman et al [3] show how experience affects the amount and the variety of information collected during the design process. The study reveals that experts rely on information more than their younger colleagues.

4 COGNITIVE LOAD, CREATIVITY AND RELATED PHENOMENA

The previous Section has pointed out that product development is not a mere idea generation process. The definition of one or more design proposals usually entails a more articulated sequence of steps. The systematic/prescriptive design methods [46] usually define the steps that bring to the definition and the selection of a design concept to be further developed into a finite product during the latest stages of the PDP. Despite several differences emerge among the different contributions available in literature [24], the workflow is characterized by a first phase aimed at defining requirements and objectives. Just once the situation to be addressed has been properly analyzed it is possible to generate novel and useful ideas.

Moreover, the whole set of ideas+ has to be further scanned in order to select the most promising one and discard the others having a poor potential. Such organized sequence of actions is also confirmed by the various studies concerning the behavior of designers in very diversified fields of applications [35]. On the other hand, still according to said studies, the cognitive processes of designers do not always allow a proper exploration of the potentially available design alternatives. In such cases, it happens that the generated ideas are very similar to each other, showing a poor variety both in terms of implemented working principles and structural characteristics. The phenomenon hindering the generation of a wide variety of concepts goes under the name of design Fixation [34]. A blind adherence to previous concepts and ideas limits the generation of design alternatives. Nevertheless, this condition of being "stuck" along the PDP can also take place during the definition of the problems to be addressed for attaining an overall goal. Atman et al. [3] observe this phenomenon in protocol studies and note that it affects non-expert designers more frequently. Hence Design Fixation manifests both within problem setting and during new ideas generation.

The authors of the present paper have already addressed the issue of overcoming fixation occurring at the problem definition stage. A tailored module for a computer-aided application urges designers to catch relevant features for reframing the problem space with a wider perspective. Consistently with [42], the authors propose means that enhance users' perseverance in the exploration of the design space, while allowing them to browse different detail levels of the same problem within different time frames [10]. The attempt to provide a holistic vision is supported by literature evidences [2] that show how very creative results in design come out when the overall problem space is heavily restructured. This leads to the exploration of completely new fields and domains where to find the right solution.

Nevertheless, Design Fixation is more straightforwardly identified when it is necessary to synthesize new solution concepts. From this perspective, analogy is probably the most studied operator that produces creative outcomes. As witnessed by Cai [18], Goldschmidt defines Analogy as the capability to create the link among different examples by identifying, at a higher level of abstraction, shared characteristics. Abstraction processes can produce a valid contribution to improve the identification of meaningful analogies. The process of blending multiple abstract concepts requires to find the intersection of the classes which traditionally include said concepts. Still consistently with the vision of Goldschmidt, abstraction is considered the process of extracting a number of common attributes (features) from a number of existing objects [57].

The search for appropriate analogies has however a conflicting effect in the design process. On the one hand, it allows the introduction of useful cues for overcoming phenomena of design fixation. On the other hand, when fuzzily defined, it may determine inefficiencies by confusedly broadening the design space in search of useful sources of inspiration, thus reflecting the same drawbacks that characterize trial-and-error approaches [54]. Another limitation concerns the need to define the most appropriate type of analogy in any specific design situation, still resulting an open issue.

In order to ease the search for analogies or however to grasp useful concepts, several sources of inspiration can be taken into account to produce creative stimuli. They range from basic geometrical shapes to works of art, from objects to phenomena from nature. Bio-Inspired design methods, for instance, initially define the functions required by a design concept at an abstract level. Subsequently existing biological systems are identified that potentially fulfil similar requirements through specific physiological functions or characteristic shapes [58]. Such abstraction process also allows mapping existing physical, chemical and geometrical effects as a means to structure a knowledge base from where to extract effective drawing solutions [1]. The role of stimuli in supporting creative design is, however, still ambiguous. On the one hand, it may release the designers from a static and fixed solution space. On the other hand, it may trigger design fixation by making the designer adhere to initial ideas and solution features.

Viswanathan et al. [59] explore the varying capabilities of stimulating representations in conveying relevant information according to designers' experience, but the validity of such results has to be proved yet. Therefore, stimuli have been classified as within-domain or between-domains, depending on the distance between the world in which the designer works and the exploited source of inspiration. From this viewpoint, Cai [18] shows that different kinds of design may lead to very different types of visual analogy. It is acknowledged that this phenomenon contributes to overcome design fixation. To this purpose, it is also worth saying that the various sources of inspiration may have different detail levels. They can be presented in the form of abstract text or design sketches, more detailed architectural precedents or technical drawings with a less ambiguous representation. In details, prototypes or more defined and detailed drawing produces more within-domain analogies (surface analogies). On the contrary, sketching produces more distant-domain analogies (structural analogies).

Furthermore, a stimulus can be perceived both in the real world and in the internal representation of the designer (Interpreted world), e.g. an object or a pictorial image and a mental imagery, respectively [29]. Examples presented in pictorial, textual, three-dimensional formats, are still not well understood. However, evidences suggest that more ambiguous stimuli tend to be less fixating, enabling designers to produce more -and more diverse- ideas [33].

The illustrated analysis has partially neglected the impact of the cognitive load on the overall design performances. It has to be remarked how pictorial communication plays a relevant role in design cognition, as witnessed by Purcell and Gero [48]. In other words, design thinking is a creative process transforming designers' mind to its corresponding visual image [20]. Also Cross [24] claims that the different phases of the PDP are characterized by different types of drawings, from the unstructured and ambiguous sketches more typically depicted during conceptual design to the more detailed representation of concepts occurring in embodiment and detailed design phases. Segers [51] shows that benefits can be appreciated in terms of efficiency of the design process, when drawings are combined with textual annotation to both convey relevant information to other designers and to release the designer's mind from concepts that can be externalized. Nevertheless, word graphs collecting terms that are relevant for the problem under investigation in the form of a semantic network, do not enable the overcoming of design fixation. The concept of externalization and releasing of cognitive load from individual's mind has been also studied by Römer [50]. Sketching, indeed, is considered as instrumental to support the definition of a mental representation, producing beneficial effects on memory and interpretation of concepts. This is consistent with the need to design by interpreting concrete and abstract things according to the memory of previous experience [28]. On the same wavelength, Company [22] shows the different functions that sketches may have in the design process: driving non-verbal thinking, supporting discussions with colleagues, submitting information to draftsmen. The supported functions can be linked with the design tasks requiring the greatest extent of individual cognition. Consistently with this vision, Römer shows that sketching plays a relevant role on the reduction of individual's cognitive load, thus positively affecting the capability to think and to rely on previous memories [50]. Bilda et al. [13, 14] report conflicting outcomes with regards to the effect of sketching on visual memory and on the cognitive load of individuals. Despite sketching is recognized as a need by designers [36], the scholars examine the behavior of blindfolded designers that have to solve a design problem without sketching. The experiments have given rise to both good results and drops in design performances. This suggests that visual imagery has an impact on the overall outcomes of a design process and that it overloads individual cognition being the whole process carried out on the same abstract level. Such limits do not seem to characterize everybody, since some expert designer can skip this unpleasant situation apparently easily by producing design proposals of good quality as well.

Within the Computer-Aided Design world, many systems integrate pictorial communication in order to enhance the outcomes of the design process. The employment of images, graphical feedback and concept maps is mainly referred to collaborative design and especially to e-learning. As well as educational reforms address the need to employ alternatives than text-based instructions, Lunsford et al. [43] illustrate the benefits of using inscriptions in science teaching. Chou and Hsiao [21] assess the equal contribution of static images in the form of concept maps and pictures within the comprehension support of students in a computer-based environment.

In another context, Li et al. [41] shows the advantages of integrating information representation schemas within Decision Support Systems. Won [60] assesses the relevant role played by sketches and visual thinking as a support of Computer Aided Design systems. Kokotovich [39] demonstrates the utility of schematic representations in a graphical format, such as non-hierarchical mind maps, in engineering design. His survey shows how such instruments represent a valid aid since they allow designers to "see" simultaneously both the big picture and the investigated details of the project. Furthermore, Kokotovich and Purcell [38] highlight that 2D sketches are more suitable for overcoming design fixation and psychological inertia for those designers who use them more frequently, such as graphical designers, while 3D representations provide the same benefits for industrial designers.

Within this context, Buchal [17] claims that current CAD tools are capable to support the early stages of the product development process, since their features allow human memory to be extended, thus addressing the same need of traditional sketching. Moreover, to his opinion, current CAD systems should achieve further advantages if compared to pen-and-paper sketching, because of their improved support in reducing the ambiguities of interpretation with more realistic representations of ideas. However, the ambiguous nature of the sketches and drawings characterizing the early phases of the PDP allows to spark the light of human creativity. To this purpose, Bilda et al. [12] show that the cognitive processes in the individual are radically different when people produce representations with traditional or digital means. In opposition to the assumption of Buchal, they hypothesize that the cognitive load can increase in performing digital representation because of the consolidated routine of using pen and paper to figure out concepts. Nevertheless, both Buchal [17] and Jonson [36] focus on the need to integrate the pictorial communication together with textual communication including annotations and other information, because of the paramount role of language in thinking and design [26].

In this perspective, for what concerns the improvement of HCI through Q&A for supporting the early phases of the PDP, it is worth mentioning that Jonson [36] considers design, as well, a form of interaction between visualization and language. It follows that a more natural interaction between human and computer has necessarily to deal with both the visual and the textual media. Company [22], similarly to [12, 36], points out that there are great differences between the activities of sketching and 3D modeling, drawing future opportunities of development for Computer-Aided tools. In such a way, the computer can represent, as for Lubart [42], both a coach and a facilitator for carrying out the early phases of the PDP with greater efficiency and relying on familiar interfaces. To this purpose, Chen [20] suggests the introduction of more straightforward means for imitating the sketching activity with pen-and-paper also in a digital environment, overcoming the limitations of the largely diffused mouse-based point-and-click interfaces. On the same topic, Tang [56] too stresses the idea to replicate pen-and-paper interaction, so as to allow the user to exploit its standard way of thinking, thus without overloading individual cognition. Nevertheless, such systems for simulating a more natural action of sketching suffer from poor usability. Moreover, with the aim of favoring the employment of pictorial communication means in chatterbots, Pirrone et al. [47] propose a system for both text-based and graphical interaction between humans and machines.

Recent advancements suggest to further reduce the cognitive load by distributing it more evenly with the different channels of communication which are engaged during the interaction. To this purpose, Kim [37] propose more immersive interfaces for dealing with concepts and ideas through Tangible User Interfaces as substitutes for the standard mouse, keyboard and displays. Indeed, classical 3D modeling reduces the naturalness of direct hand sketching and inhibits what can be instead fostered with an immersive interface. Rahimian et al. [49] suggest improving the support to human cognition of current CAD systems through the introduction of Virtual Reality and Virtual environments. On the one hand, they facilitate collaboration within a social dimension of design. On the other hand, they also support cognition by relieving the cognitive load from sensorial information that can be directly perceived and not just conceptualized.

5 CONCLUSIONS

The present paper reviews the most recent and relevant contributions in the field of Q&A HCI, showing that it is progressively possible to rely on ECAs. Said agents should allow to carry out the design dialogue with a verbal, instead of written, channel resulting in an improved quality of the conversation. Moreover, it emerges with renewed strength the idea that language is integral to design and the introduction of textual interaction is crucial to give meaning to representations, being they mentally visualized or expressed through drawings and sketches. Besides, different barriers and issues concerning the development of these HCIs have been discussed. In details, the paper investigates the effect of experience and expertise in design and HCI. At last, the manuscript presents which other issues should be addressed to carry out with greater efficiency the early design phases, so as to depict an improved profile that better meets the needs emerging as a consequence of supporting design activities.

According to the above analysis, the following discussion describes the authors' vision about the development of such Computer-Aided Innovation systems. A guideline is also suggested to improve their previous systems by introducing a more flexible and suitable HCIs for designing with computers.

Going beyond the evidences emerged in the field of Q&A techniques, it seems important to additionally pursue the goal of flexibility by addressing the diverse exigencies of novice and expert designers. According to the literature about cognitive studies in design, Computer-Aided systems supporting the early phases of the PDP have, therefore, to adapt his framework and HCI, so as to ease the switch from the problem domain to the solution domain for expert designers. On the other hand, such systems should behave as a coach capable to trigger a learning-by-doing effect on novices, to enrich their knowledge and experience by also progressively easing the mapping between the current situation and the goal to be attained. Moreover, the HCI should allow the Q&A to enforce the perseverance of designers, since, according to [3], such persistence results in design outcomes of higher value.

A new and appropriate approach to the HCI of Computer-Aided systems for the early stages of design is required in order to reduce the cognitive load of designers, as well as to limit the emergence of undesired phenomena such as psychological inertia and design fixation. As a result of the presented investigation, the Q&A interaction should firstly support the appropriate exploration of the design space. Additional requirements regard the possibility to combine the content conveyed using also different media with the objective of better distributing the resources among textual, verbal and visual channels of cognition.

Said capability is tuned with the need of not negatively affecting the cognition of designers, hence allowing them to organize their cognitive load. In this perspective, the main outcome emerged from the above analysis shows that current CAD systems are not suitable for supporting the early design stages. Moreover, current computer systems still suffer from the scarce balancing between textual and pictorial interaction. Since sketching is a crucial part of the design process for both socially communicating ideas and individually clarifying concepts, the exclusive adoption of a simple Q&A HCI in Computer-Aided systems is not completely efficient. The introduction of natural means for sketching and introducing annotations should become part of those systems by means of highly usable devices that imitate the natural pen-and-paper interaction to the greatest extent. In this context, the most promising solutions are represented by multi-sensorial environments allowing to prevent the conceptualization of products and ideas that can be perceived and touched through the different senses.

Moreover, such systems allow also to face one of the most critical phenomena emerging during design activities: design fixation. Indeed, the introduction of pictorial communication within Computer-Aided systems for the early phases of the PDP should allow to submit the users questions, as well as to introduce hints and stimuli. They should play the double role of releasing from previously conceived ideas and suggesting to reframe alternatives in order to depict the design space in a more efficient and creative way. Consistently with [42], these new systems would be then capable to behave as a coach that can push the user in examining different facets of the situation at hand, holding wider perspectives, so as to replicate the efficient way of thinking of experienced and talented designers.

Nevertheless, it is worth mentioning that for what concerns the tasks of analysis, synthesis and evaluation, the current CAD systems may have a very dedicated role in supporting the visualization of embodied solution concepts, with the capability of easing the selection among the various alternatives proposed during the PDP.

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