DIGITAL INTERMEDIARY OBJECTS: THE (CURRENTLY) UNIQUE ADVANTAGE OF COMPUTER-SUPPORTED DESIGN TOOLS

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Abstract

The TATIN and TATIN-PIC projects lies at the crossroads of preliminary design and Computer Supported Cooperative Work in Design (CSCWD) tools.

Those projects studied the impact of multi-touch, multi-users tabletop groupware for co-located teamwork. The projects aim was to observe an improvement of the effectiveness of the preliminary design process when mediated by a CSCWD tool. Along 4 years several design observations have been conducted on specific design methods; each result have been presented independently during past Design Society conferences.

This paper regroups and synthesizes all those results to draw a holistic conclusion. Digital intermediary objects represent the (currently) unique advantage of such CSCWD tools, as well as their greatest potential. Digital boosts their traditional role of inter-mediator improving teamwork's perceived productivity and confidence in the results, and open a wide range of possibilities like the interaction with AI systems.

Keywords: Computer aided design (CAD), Early design phases, Teamwork, Collaborative design, Research methodologies and methods

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1 INTRODUCTION

The need for computer tools for the early phases of the design process, called preliminary design, is a current matter of design research. As highlighted during the workshops "Bild & Begriff" the *CAD systems do not support the conceptual design phase* (pp. 204, Höhne and Torsten, 2003).
Two research projects were launched, following on Wang et al. (2002) supporting the need to *adopt a more pragmatic and aggressive approach through collaboration, supported by artificial intelligence, and fuelled by information technologies*.
TATIN (from the French: TAble Tactile Interactive) is the name of those projects of the University of Technology of Compiegne. Their goal is to build a collaborative multi-displays groupware for preliminary design co-located teamwork (Jones et al., 2012). This groupware belong to the Computer Supported Cooperative Work in Design (CSCWD) family (www.cscwd.org for the IEEE International working group). Section 2 will present the projects in details.
The hypothesis formulated during those projects is that this groupware *can greatly increase the effectiveness of teamwork during preliminary design* (Gidel et al., 2011).
In order to test this hypothesis, several comparative (Gidel et al. 2014) design observations have been performed along 4 years: 2010 - 2014. These observations paralleled a common preliminary design activity, but mediated by two different design tools: paper-based vs. computer-supported ones.
7-point Likert-scales were used to assess the perception of designers in respect of those different media, according to several criteria issued from the literature. Section 3 presents those comparative design observations. Each result has been independently disclosed during past Design Society conferences (ICED11, ICED13, DESIGN14).
This paper aims to regroup and synthesize all those results to draw a general conclusion about the impact of the groupware on co-located teamwork during the preliminary design process. Section 4 presents the analysis of these findings. This analysis led us to conclude that the observed groupware has a positive impact on the group perceived productivity and confidence in the results. Concerning all the other criteria there were no statistical significance in the results.
In section 5 we defend that the evidences of section 4 are attributable to digital intermediary objects. In fact, digital intermediary objects represent the (currently) unique advantage for a teamwork using CSCWD tools during co-located preliminary design activity. Digital intermediary objects prove to be "more open" (Vinck and Jeantet, 1995). This result boosts their traditional role of inter-mediator (Boujut and Blanco, 2003) improving teamwork's perceived productivity and confidence in results.
We conclude in section 6 with a reflexion about the implication of these findings for design research on CSCWD tools. They highlight the necessity for a better understanding of the interactions (human-artefacts and human-human) that occurs during the design process, thus that design community need to spend more efforts in understanding what is done by designers.

2 THE TATIN PROJECTS

2.1 Preliminary design process

Preliminary design is the phase of the design process where the design problem is framed (convergent-divergent thinking activities), user requirements are clarified, and the process itself is defined and planned (i.e. project planning activities). Preliminary design is mix of individual and collective tasks, performed by multidisciplinary teams either in remote or co-located teamwork. A number of paths within the problem-solutions space are explored during those crucial preliminary steps, seeking for a satisfying (Dorst, 1996) or adequate (Cross and Claybrun Cross, 1995) solutions. This exploration means a series of divergent and convergent activities to frame the problem and create the necessary knowledge to respond to it (Guerra et al., 2013).
During design meetings, designers share their conceptual ideas through intermediary objects, verbal and nonverbal communication (all are considered as external representations). Intermediary objects are *objects that lie in between several elements, several actors, or successive stages of a work process* (pp. 118 Vinck and Jeantet, 1995). They are co-constructed during the whole preliminary design process. Intermediary objects have different roles and three main features: mediation, transformation (or translation), and representation (Boujut and Blanco, 2003). Intermediary objects represent the common

objectification of a conceptual idea, and they serve as a mediator. Intermediary objects are related to the task or to the process. They can be product representations (ideas, concepts, functions, drawings, sketches, and virtual and physical prototypes.) (Darses, 1997) or project representations (activities, resources, planning, risks, and costs.) (Shen et al., 2002) (Gidel et al., 2005). Open intermediary objects (Vinck and Jeantet, 1995) are supposed to foster the creation of a shared mental model among the design team.
The MacLeamy (2004) curve serves as a testimony to the importance of preliminary design activities. It illustrates that as a project moves forward in time the level of influence of design choices will decrease, and the cost of the implementation of these choices will increase. MacLeamy explains that the optimal project plan calls for high initial effort in the preliminary design phase for a more effective, cost-efficient project (Gidel et al., 2011).

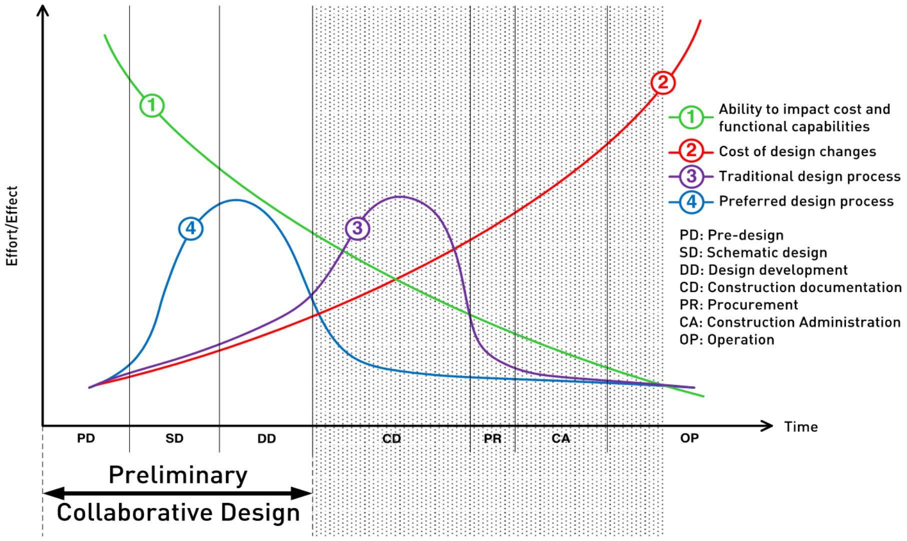

Figure 1. MacLeamy curve. A project that places significant efforts in preliminary design improve its cost-efficiency ratio.

Researching and developing tools to facilitate preliminary design would significantly impact design projects. Several authors pointed out the need for computer tools during the preliminary design phase (pp. 204, Höhne and Torsten, 2003) (Wang et. al, 2002) and explained their reasons (pp. 4, Sarcar et al., 2008). All these considerations originated the TATIN projects: TATIN and TATIN-PIC.

2.2 TATIN: TAble Tactile INteractive

TATIN is the first version of the CSCWD platform research prototype developed at the Université de Technologie de Compiègne from 2008. TATIN groupware is composed of a tabletop and its associated software. TATIN tabletop uses two HD video projectors positioned side by side to render the final double full-HD 83-inch image (1920 pixels x 2160 pixels and 1.60 x 1.40 m). The input device of the TATIN platform is based on the LLP (Laser Light Plane) technology. Infrared lasers augmented by linear filters are used to create a laser plane flush with the top surface of the table. Users' fingers, when touching the surface, disrupt the laser plane. Two infrared sensitive cameras beneath the table are responsible for tracking the fingers illuminated by lasers. Then, image-processing algorithms from Community Core Vision (CCV) are applied to the camera images to determine the position of different contact points on the surface of the table and transform them into software events. Figure 2 (left) shows the TATIN tabletop.

2.3 TATIN-PIC: TAble Tactile INteractive – Plateforme Intelligent de Conception

The lack of a vertical surface was the origin of the TATIN-PIC project, i.e. the introduction of a vertical board in 2011. The evaluation process of TATIN (Guerra et al., 2013), corroborated by literature (Kruger et al., 2005), pointed out that a vertical surface is needed to better support convergent thinking while creativity is improved by horizontal surfaces (Rogers and Lindley 2004). The TATIN-PIC vertical display has a screen size of 2.05m by 1.15m, and the screen resolution is of 2730 pixels by 1536 pixels. The input device technology follows the principle of the plane flush disrupted by the contact of fingers, with solely one difference: instead of lasers an infrared overlay frame was used. Figure 2 (right) illustrates the TATIN-PIC groupware.

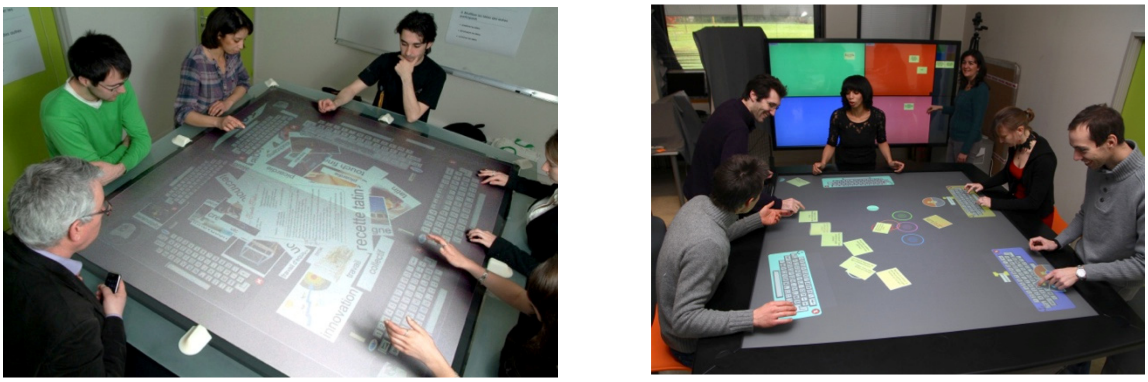

Figure 2. (Left) Six users around TATIN groupware with virtual keyboard – (Right) Six users around TATIN-PIC groupware. ©TATIN-project

3 DESIGN OBSERVATIONS ALONG THE TATIN PROJECTS

Three design observations have been conducted from June 2010 to June 2014 to assess the impact of such "TATIN" CSCWD tool on co-located teamwork during preliminary design activities.
The hypothesis formulated during those projects is that those groupware *can greatly increase the effectiveness of teamwork during preliminary design* (Gidel et al., 2011).
These observations paralleled a common design activity, but mediated by different design tools: paper-based vs. computer-supported ones.
7-point Likert-scales were used to assess the perception of designers in respect of those different media, according to several criteria issued from the literature. Each result has been independently disclosed during past Design Society conferences. Table 1 resumes those contributions.
This paper aims to regroup and synthesize all those results to draw a general conclusion about the impact of "TATIN" CSCWD groupware on co-located teamwork during the preliminary design process.

Table 1. Summary of the design observations along the TATIN projects

Year	2010	2012	2013
Design Society Conference	ICED 2011	ICED 2013	DESIGN 2014
Preliminary Design Activity	Brainstorming	Planning	Value Engineering
Number of sessions observed/ number of pers. per group	1 / 6	2 / 5	13 / 5
Number of subjects observed/ ordinal of the session	48/1st	20/1st, 20/2nd	54/1st, 20/2nd to 13th
Reference	Gidel et al., 2011	Guerra et al., 2013	Guerra et al., 2014

The protocol for these observations has been derived from Buisine et al. (2012). According to their article, the best mean to evaluate the impact of those CSCWD tools is a *paradigm evaluation*, or

comparing the fulfillment of the same task on a groupware system against a given control condition (such as pen-and-paper). We assume that this comparison is nomologically possible (Guerra et al., 2013), even if it poses a wide range of difficulties (Gidel et al., 2014).
A total of 122 subjects have been observed. They are engineering design young practitioners, almost equally shared between male and female, aged from 22 to 39 years old. The design teams (which size change from 4 to 6 according to the design observation) have been randomly composed. The participation to the experiment is on voluntary basis and participants are offered refreshment (snack and sodas) as reward. The participants share a standardized (though basic) knowledge concerning preliminary design methods and the groups have an appropriate level of familiarity with each other, having worked together on weekly projects for four weeks prior to the design observations (except in the case of brainstorming where people never worked together before). The choice for which group has to be in the control condition or in the experimental one is casual. For more details, see the referenced articles.
Those observations are recorded with cameras. Audio is captured through directional microphones. The independent audio and video streams are synchronized after the observations, in a two or four camera view. Figure 4 shows an example frame of this work for both conditions.

Figure 4. Comparative design observations during TATIN projects: control condition (left) and experimental condition (right) ©TATIN-project

At the end of each session a feedback questionnaire is given to each participant. In each of the questionnaires, participants are asked to evaluate certain subjective criteria of their experience on a 7-points Likert-scale. The criteria used are presented in Table 2.

Table 2. Summary of the common criteria measured during the three design observations of the TATIN projects

Criteria (how they are perceived by the users)	Definition
Personal involvement	If the designer enjoyed the design activity
Media effectiveness	If the designer considered the media effective in supporting his/her work
Group productivity	If the designer felt that the group was productive
Confidence in Results	If the designer thought that the results were satisfying or adequate for the assigned task
Report Generation	If the structuration of the content for their diffusion was easy or not
Time management	If the designer felt that time was spent in a fruitful way
Circulation among vertical and horizontal surface	How the designer felt the shifts between vertical and horizontal surfaces
Communication effectiveness	If the designer perceived the communication as easy, effectiveness and enjoyable
Coordination effectiveness	If the designer perceived teamwork easy, effectiveness and enjoyable

All experiments were conducted in French and therefore the results were translated to English by the authors.

4 RESULTS

To better understand the value of the following results, several factors must be taken into account.
There is a huge difference in the cognitive behaviors of experimented and young practitioners. Engineers with good skills and experience probably act differently as students with less knowledge. Thus, this study has a limited value for the performance of experienced engineering designers.
Inferential analyses were performed by the means of ANOVA. We are aware that the use of Likert-scales as interval scale is still controversial, we discussed this topic in details in Guerra et al. (2014).
A problem with comparing different technological set-ups that have their own distinct features and interaction styles is the difficulty of controlling both the independent and dependent variables. This problem is discussed in (Rogers et al., 2009).

4.1 BRAINSTORMING

Table 3 presents the result of the comparative observation on brainstorming detailed in (Gidel et al., 2011).

Table 3. Comparison of subjective criteria between the experimental condition and the control condition – BRAINSTORMING

	CONTROL condition		EXPERIMENTAL condition		DOF	P Test	Significance
	Mean	σ	Mean	σ			
Personal involvement	5.5	1.0	5.9	1.3	1/47	p=0.12	no
Media Effectiveness	5.7	0.9	5.5	1.1	1/47	p=0.29	no
Group productivity (creativity)	5.4	1.2	5.3	1.1	1/47	P=0.34	no
Confidence in results	5.62	1.07	6.46	0.66	1/32	p<0.01	**yes**
Report generation	absent	absent	absent	absent	abs	abs	abs
Time Management	absent	absent	absent	absent	abs	abs	abs
Communication effectiveness	5.8	1.0	5.5	1.3	1/46	p=0.31	no
Coordination effectiveness	5.6	1.0	5.1	1.2	1/47	P<0.05	**yes**
Circulation among vertical and horizontal surface	absent	absent	absent	absent	abs	abs	abs

The only results with a statistical significance are the confidence in the results and the effectiveness of the coordination. In both cases the CSCWD tool performed better that traditional supports. Report generation was not possible. The observed design teams did not manage the time and worked only on a horizontal tabletop.

4.2 PROJECT PLANNING

Table 4 presents the result of the observation conducted on project planning (Guerra et al., 2013).

Table 4. Comparison of subjective criteria between the experimental condition and the control condition – PROJECT PLANNING

	CONTROL condition		EXPERIMENTAL condition		DOF	P Test	Significance
	Mean	σ	Mean	σ			
Personal involvement	5.2	0.8	5.5	1.0	1/17	p=0.51	no
Media Effectiveness	5.8	0.6	5.7	0.8	1/47	p=0.76	no
Group productivity	5.5	0.8	6.4	0.7	1/18	p<0.05	**yes**
Confidence in results	6.2	0.6	6.6	0.7	1/18	p=0.20	no
Report generation	absent	absent	absent	absent	abs	abs	abs
Time Management	5.2	1.0	4	1.6	1/18	p=0.07	no
Communication effectiveness	5.8	1.0	5.5	1.3	1/46	p=0.31	no
Coordination effectiveness	5.5	1.0	6	0.7	1/17	p=0.21	no
Circulation among vertical and horizontal surface	absent	absent	absent	absent	abs	abs	abs

The only result with a statistical significance is the group productivity. In this case the CSCWD tool performed better that traditional supports. Moreover, even without considering statistical significance, there is not a clear overall difference between control and experimental condition.
Report generation was not possible. The observed design teams did only one shift between the horizontal and the vertical surface; thus, the related criterion has not been evaluated.

4.3 CAUSAL ANALYSIS

Table 5 presents the result of the observation conducted on causal analysis (Guerra et al., 2014).

Table 5. Comparison of subjective criteria between the experimental condition and the control condition – CAUSAL ANALYSIS

	CONTROL condition		EXPERIMENTAL condition		DOF	P Test	Significance
	Mean	σ	Mean	σ			
Personal involvement	5.15	1.31	5.28	1.38	1/33	p=0.94	no
Media Effectiveness	5.04	1.12	4.92	1.25	1/32	p=0.56	no
Group productivity	4.8	1.2	5.78	0.70	1/33	p<0.01	**yes**
Confidence in results	5.62	1.07	6.46	0.66	1/32	p<0.01	**yes**
Report generation	4.62	0.91	3.00	1.15	1/10	P=0.06	no
Time Management	3.42	1.12	5.07	1.07	1/33	P<0.01	**yes**
Communication effectiveness	absent	absent	absent	absent	absent	absent	absent
Coordination effectiveness	absent	absent	absent	absent	absent	absent	absent
Circulation among vertical and horizontal surface	4.56	1.51	5.5	0.98	1/17	P=0.13	no

The only results with a statistical significance are the confidence in the results, the group productivity and the Time Management. In both cases the CSCWD tool performed better that traditional supports. Additionally, even without considering statistical significance, there is not a clear overall difference between control and experimental condition. Concerning communication and coordination, we did not have a sufficient number of answers to extrapolate any results, even without a statistical significance.

5 CONCLUSION AND DISCUSSION

The goal of the TATIN projects was to evaluate the impact a computer-support tool on the preliminary design process. The computer-supported tool is a groupware composed of interactive multi-touch multi-users interactive surfaces.
The assumptions behind this research were that preliminary design is the most impacting phase in terms of costs and strategic decisions on the whole design process and that preliminary design lacks of computer supported tools.
The aim was to measure an improvement of the effectiveness of the teamwork, while mediated by this new "TATIN" CSCWD tool. We briefly summarized the whole set of design observations performed during the TATIN projects. According to the analysis of section 4, only two criteria have a statistical significance in at least two out of three observations: the confidence in the results and the group productivity. In both circumstances the CSCWD tool performed better than traditional paper-based support tools.
A better perceived group productivity and confidence in results are caused, in our opinion, by an improved shared understanding and a strong collective cognition of the team.
Shared understanding, shared mental models, shared representations, and group cognition are influence by intermediary objects (Vinck and Jeantet, 1995). Intermediary objects are necessary to foster co-operation among various actors of the design process (Blanco and Bojout, 2003). A particular focus on open intermediary objects can explain the observed results. Open intermediary objects are supposed to facilitate distributed cognition among teams, but also organize and enlist human participations (Vinck and Jeantet, 1995).

We support that digital intermediary object have a "more open" nature than physical intermediary objects in early design phases. A digital object is easier to modify, to share, and so it can better play its role of inter-mediator between designers' divergent mental models. Quoting one of the observed subjects: *Being able to interact together with the objects on the platform, let us easily create a common vision of the problem and thus to share better our personal concepts,* said subject T4 in the group B2 of the project planning observation.
The digital nature of intermediary objects generates also an increased perception of a positive time management in casual analysis (Table 5). Minute's meetings are automatically generated and exported in several formats; the transition between surfaces is near to a seamless flow of information. These findings are similar to Illi (2014) for whom the real benefit of groupware comes in when existing intermediary objects needs to be shared, organized, grouped, and modified. Moreover, if the trajectory for design tools is the one proposed by Wang et al. (2002), intermediary objects are the fuel for any AI information system and Knowledge Management (KM) approaches (Vezzetti, 2013) (Vezzetti et al., 2015). The present globalized market is forcing many companies to invest in new strategies and tools for supporting knowledge management (Vezzetti et al., 2011). So if since the earliest phase of the design process, open digital intermediary objects fuel a KM system, all the related Product Lifecycle Management (PLM) approaches will have a beneficial impact in term of knowledge capitalization and re-use (Vezzetti et al., 2010) (Vezzetti et al, 2015b).

Ultimately, after four years of observations, we conclude that digital intermediary objects represent the (currently) unique advantage, for a teamwork using CSCWD tools during co-located preliminary design activity. It is interesting that Olson et al. (2002) have proposed quite analogous conclusions, but without mentioning the role of intermediary objects. They focused on *shared electronic objects, editable displays*, and *large high-resolution, editable objects*.

6 IMPACT AND PERSPECTIVE FOR DESIGN RESEARCH ON CSCWD TOOLS

Those results stress the need for more design observation on the role of digital intermediary objects, and in a broader sense they claim more efforts in understanding what designers do. We share the position of Claudia Eckert and Thomas Howard during last Design Conference debate (Design Conference, 2014). We know so little about the human-human and human-artifacts interactions during design activities. Our role as designers should to better understand those dynamics. The actual risk is that we continue to propose new tools and new methods without knowing who will use them, how, and why. If we want to propose solutions to improve the design process, we should put a lot of efforts in knowing designers doing design. Computer supported tools for preliminary design will be used anyway by industry, whether design researches prove or not their efficiency or effectiveness on the outcomes of the design process, as it happened for the TATIN-PIC groupware, it's up to designers to decide if participate in their development or simply wait for them to come.

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