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CONDUCTING PRELIMINARY DESIGN AROUND AN INTERACTIVE TABLETOP

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ABSTRACT
Our work lies at the intersection of preliminary design and tabletop groupware. We have constructed our own prototype, named the TATIN table, to begin developing applications for design teams. During the design phase of our system, by conducting an extensive literature review, we have indentified the early preliminary design phase of a project to be the area where interactive tabletops would make the greatest impact. Next, we developed software for group brainstorming sessions and conducted extensive usability experiments using this software. During the experiments, we administered subjective questionnaires and obtained extensive video footage of the session. We present our techniques for the analysis of these videos and report our results on collaboration and communication in this environment.

Keywords: collaborative design, multi-touch and multi-user surface, creativity, user testing, groupware

1 INTRODUCTION
Innovative technologies rarely transfer from research laboratories to commercial markets more quickly and effectively than multi-touch surfaces. The success of Apple's iPhone© and iPad©, as well as the recent refinement of Microsoft's interactive tabletop, the Surface© [1], leads us to believe that tabletop computing will enter the office environment soon. Designers have often been at the focal point of the introduction of such technologies, (e.g. CAD, PLM in the 1980's) and it is our hypothesis that this trend will continue with multiuser interactive tabletops. In anticipation of their arrival in the workspace, we must identify where and how they can make the most impact for design teams.
Long before preliminary design procedures were formally studied and proven to be effective, their use was widespread among design teams to create innovative products and services. Preliminary design refers to the conceptual work occurring at the beginning of a project, such functional analysis, risk management, mind maps or brainstorming. It is our hypothesis that interactive tabletops can greatly increase the effectiveness of this phase by increases collaboration and communication. In Section 2.1 we examine why pre-design is so critical to the project and what properties of pre-design make it a candidate for tabletop groupware. In section 2.2 we explain how interactive tabletop can increase collaboration and communication in pre-design, and therefore increase the effectiveness of pre-design.
Project TATIN (in french: TAble Tactile INteractive) was launch to closely examine the nature of group dynamics around an interactive tabletop for preliminary design. This necessitates the construction of a functional prototype of a tabletop environment (hardware) and the development of software for teams to perform collaborative preliminary design, so that we may test the appropriate scenarios to measure any optimization with the design process. The first preliminary design scenario we examine in project TATIN is the group brainstorming session, perhaps the most popular tool of preliminary design. Allowing the individual expert and the group to develop ideas equally, and then share these ideas freely amongst themselves, is among our primary design goals. In Section 3, we present the hardware of the TATIN platform and brainstorming software custom-built for this tabletop, named BrainTouch.
Section 4 details the protocol of the extensive brainstorming usability experiments we conducted to measure collaboration and communication on the TATIN platform and BrainTouch. During these experiments we administered questionnaires to measure subjectively what participants thought about collaboration and communication around the TATIN system. To complement this data, we obtained extensive video footage of the meetings and performed an analysis using video annotation software. The results from the questionnaires and the video annotation are presented in Section 5.1 and Section

5.2 respectively. In section 6, we discuss our results and share our observations. Finally, in section 7 we conclude and explore questions for future work.

2 COLLABORATIVE DESIGN AND MULTI-TOUCH TECHNOLOGY

The current state-of-the-art of preliminary design and interactive tabletops, leads to us to hypothesize that the two can have mutually beneficial relationship. In this section, we present literature that illustrates the advantages, tools, and methodology of preliminary design, and we present the literature which leads to our hypothesis that tabletop groupware is particularly adept in engendering the collaboration required by preliminary design.

2.1 Preliminary Design and Collaboration

The techniques used in preliminary design frame the design problem, clarify user requirements, and maximize the team's exploration of the design space of possible solutions. Primarily committed to the uncovering and classification of new ideas, this phase is essential for the success of a project: if only 5% of a project's budget is invested into this phase, the effect is a 70% reduction in overall spending [2, 3]. The MacLeamy curve serves as a testimony to the importance of preliminary design techniques [4]. 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. Researching and developing tools to facilitate preliminary design would significantly impact design projects.

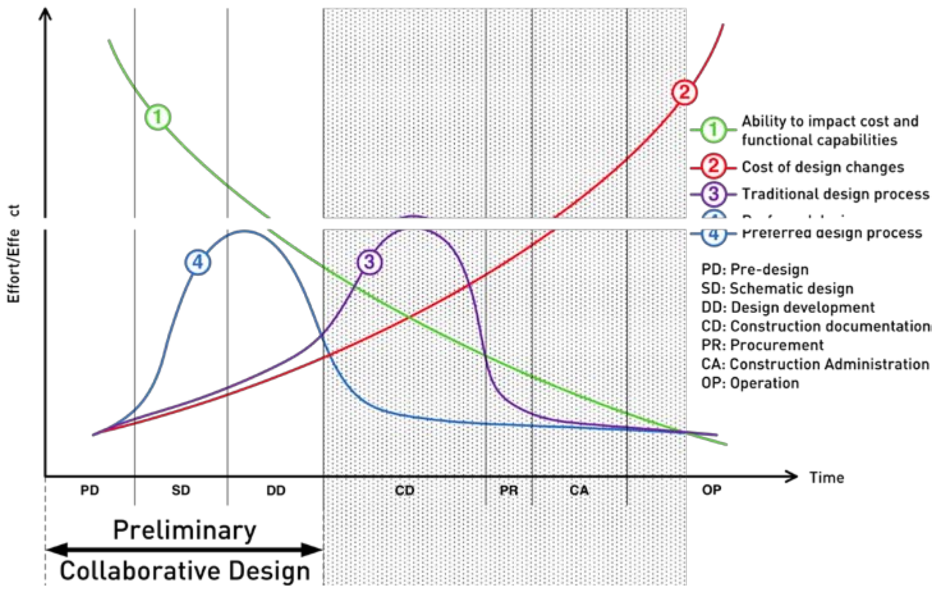

Figure 1. Illustrated here by the MacLeamy curve [4], a project that places significant effort in preliminary design increases its cost-efficiency.

This phase is critical in revealing hidden socio-technical aspects of group work and projects and this is why laboratories have been intensely researching this phase of the design cycle. Of all the methodological tools that are frequently used in the preliminary design phase, the most popular are causal analysis, functional analysis, and reliability solutions such as “FAST” or “FEMA”, or tools of innovation such as brainstorming or the method “TRIZ” [5]. Moreover, new approaches in methodology, based on the paradigm of design thinking, have arrived to mobilize these models into a methodological design cycle which alternates between stages of functional analysis, causal analysis, and risk management. Intermittently throughout the process, each step is capable of being expanded or influenced by brainstorming sessions and mind maps. These tools are as plentiful as they are diverse, but all ensure that the participants of the design process converge toward common objectives. The methods of design for mechanical engineering projects (our proposed domain) are well described in [6, 7]. More recent research base their results on the domain of cognitive science to propose approaches that allow a better understanding of the activity in preliminary design. As the preliminary design progresses throughout these stages, team members are coordinating their work to manipulate and build upon intermediary project artifacts from two categories:

- Intermediary artifacts that represent the product: drawings, sketches, and virtual and physical prototypes. [8]
- Intermediary artifacts that represent the project: concepts, functionality, planning, risks, and ideas. [9, 10]

These intermediary representations that are shared over the course of a meeting, not counting all verbal exchanges, exists in diverse forms: lists, tables, graphs, images, texts, diagrams, etc. where each one has their own unique properties and characteristics (mode of representation, colors, forms, positions, etc.). These can be created specifically for the design project, or could come from an existing database. They are usually created by team members during a working meeting where a moderator leads alternating phases of expansion and focus [11, 12]. According to this idea, there are activities of individual production followed by a collective regrouping, which often engender more discussion and idea generation. This brings expansion and divergence to the project. There are also activities of negotiation and decision-making. They bring focus, convergences and congealing, which allow for progress in design. The conceptual objects allow each member of the team to maintain common vision and objectives, and to share information vital to coordinated, informed decision-making. [13, 14] They contribute to the process of collaborative design: from the idea of a product/service, through to the concept, to the proof of concept, to the prototype, etc. It would certainly be possible to put each team member in a network, each facing a screen, but that would limit much of the interactions and the creativity necessary for high performance [9, 15].

Our approach is based on results from Shiba showing that collaborative design promotes a more efficient construction of a shared vision, which makes the design team more effective [16]. The innovative design of products and services is predicated upon the participation of actors from different professions who are present from the start of the preliminary phase of a project. The effectiveness of collaborative work therefore depends on the ability of participants to agree on a common language of ideas and solutions.

These phases are part of a process leading to the formation of a device, a solution to a previously unsolved problem, which ultimately will be formed by a fusion of ideas and concepts under digital or physical representations. If the resulting artifact from the preliminary design sessions is to bring the greatest efficiency to the remainder of the design lifecycle, the artifact must be one that shares its authorship amongst all stakeholders and participants of the meeting.

2.2 Multi-touch, Multi-user tabletop computing

Marc Weiser, the father ubiquitous computing, proposed that the next user-interface paradigm after desktop computers would be "tabs, pads, and boards" [17]. Today, after seeing his prediction come to fruition for tabs (smartphones), and recently, pads (tablets), it would be wise to consider the future of board-size displays. Multiuser interactive tabletops began to appear in research laboratory in quantity around the turn of the century. They have several distinctive characteristics that must be considered. To begin, single display groupware, such as interactive tabletops are not designed for one single primary user (as are smartphones and pads), but rather a group collocated users working together on one computing system. They are fixed in position and belong to the environment, rather than to a single user. Furthermore, team members from different disciplines might be serving different roles and require different functions, and the tabletop computer can be designed to adapt for different profiles of users [17]. Interactive tabletops have larger screen sizes than typical paradigms of computing, facilitating collaboration, even requiring it: team members must assist others in passing documents from one end to the table to the other.

During the process of preliminary design, the available methods for manipulation of the intermediary artifacts introduced in 2.1 are often limited to a 2D representation on a sheet of paper or a screen. Moreover, much software and information systems available for the manipulation and production of these intermediary steps are generally designed to be used by only one person [18, 19] and suffer from a lack of interoperability. This is the case with software for CAD, creativity, value analysis, project management, risk management, ergonomic analysis, etc. Interactive tabletops, such as the TATIN system, are adept at addressing the preliminary design phase in particular for two reasons:

- traditional preliminary design techniques do not require the visualization or manipulation of physical prototype, and

- the objects that will be manipulated represent merely concepts [20] and are suitable for manipulation by participants of different skill levels, which ensures that all participants are able to collaborate.

Interactive tabletops by nature provide certain advantages:

- The objects will exist under digital form, therefore facilitating the task of distributing information to the team and allowing the team to maintain common vision and goals.
- Group dynamics are altered around an interactive tabletop, engendering communication and collaboration. Tabletops place all users on the same level, around the intermediary objects, as opposed to a whiteboard, which caters to presenter-audience style of interaction and can stifle collaboration.

These contributions can be particularly successful as it applies to preliminary design activities when multiple stakeholders who are engaged in collaborative design become involved and united, as illustrated by the project DigiTable [21].

The existing tools dedicated to collaborative product design in co-presence [22] (i.e. interactive whiteboards) neither meet the group's needs on a technological level nor support a well-designed set of interactions techniques to address all the tasks required by group meetings [23]. For example, traditional software used to support meetings only allow for single-user interaction, where one user acts as the “presenter” and other must wait for this role to be delegated to them by the software. This design unnecessarily obstructs the natural fluidity of meetings and restricts other members from playing a more dynamic role. These devices have typically recycled the same interaction techniques adopted from the WIMP (Window, Icon, Menu, Pointer) paradigm [24] instead of conceiving a new set that allow for multiple user interactions at the same time [25].

3 THE TATIN PLATFORM AND BRAINTOUCH

As part of Project TATIN, constructing an interactive multi-touch tabletop enabled us to support a collaborative preliminary design sessions (Figure 1). The TATIN platform uses two HD video projectors positioned side by side to render the final double full-HD 83-inch image (1920 pixels × 2160 pixels and 1.60 m × 1.40 m).

The input device of the platform TATIN is based on LLP (Laser Light Plane) technology [26, 27]. Infrared lasers augmented by linear filters are used to create a laser plane flush with the top surface of the table. All objects or users' fingers in contact with the surface of the table disrupt the laser plane. Two infrared-sensitive cameras beneath the table are responsible for tracking the fingers illuminated by lasers. Next, image-processing software (extraction of background, high-pass filter, etc.) is 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).

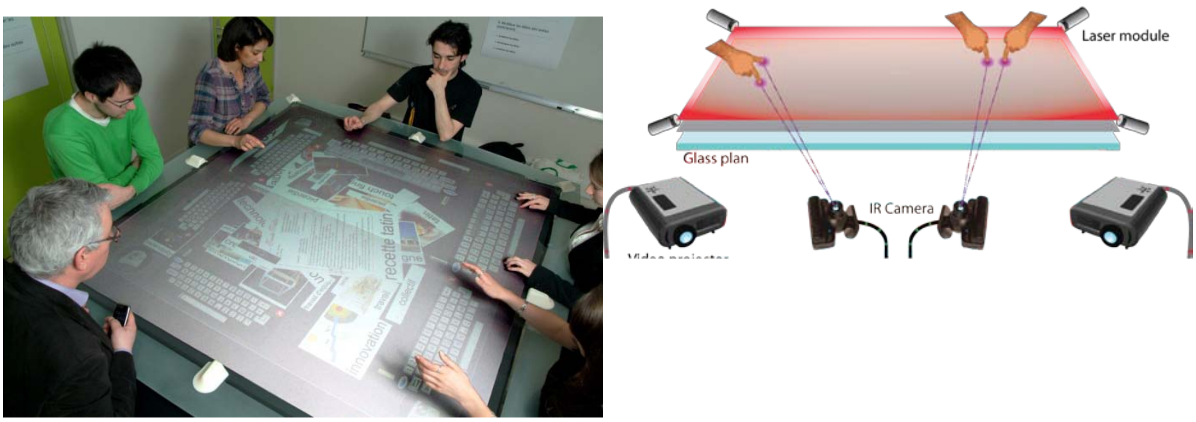

Figure 2. (left) Six users around TATIN Tabletop with virtual keyboard during the idea generation phase - (right) Hardware configuration of TATIN tabletop

The software BrainTouch was implemented using the toolbox MT4J [28]. The creation of digital Post-its take place as follows: each user has a virtual keyboard in front of her, from which they may generate new Post-it. After typing the text on the keyboard, the user can generate either a text Post-it by pressing the button “ENTER” or an image Post-it by pressing the button “GOOGLE”. Upon pressing this button, the application will use the entered text to search the internet using Google© Image.

After a moment, a series of fifteen images corresponding to the text appears in front of the user. By selecting one of these images, the user can generate the image Post-it (or, if the user finds no images suitable, the user can close the image selection window.) Possible actions by the user include: generating Post-its using the virtual keyboard, moving, resizing, and reorienting a Post-it, or removing a Post-it by dragging it to one of the trash icons placed at the four corners of the table. Generated Pos-its can also be slid under the users' keyboard where it can be stored for safe-keeping. Finally, the user also has the possibility of grouping Post-its to facilitate moving and categorizing them. To do this, the user must simply draw a circle with a finger around a group of Post-its. Groups of Post-it can be unbundled in the same way.

4 EXPERIMENT AND PROCEDURE

The experiments conducted with the TATIN table were modeled after a similar set of experiments conducted by the project DigiTable on brainstorming sessions [29]. This will allow us to corroborate our findings with established work in the literature. Our protocol was designed to compare the results of brainstorming sessions conducted in the control condition, on a conventional table with Post-its and pencils (Figure 3 - left), to brainstorming sessions on the TATIN table, through a software, BrainTouch, that creates digital Post-it (Figure 3 - right).

These experiments included a total of 48 testers divided into 8 groups of 6 people. The groups of users can be divided into two categories: 34 engineering students aged 20 to 25 years and 14 non-students (personal assistant, teacher, housewife, etc.) aged 24 to 50 years. For each of the eight sessions we conducted, a group would brainstorm on two separate topics so they could experience the conventional Post-it session (control condition) and the TATIN table session (TATIN condition), one after the other. The topics were the design of "a shared family calendar" and the design of "the Swiss Army knife of the twenty-first century" and, in particular, a list of functions that these devices would have. To reduce bias in the observations, the sessions were counterbalanced with the choices of brainstorming topics and the choices of the brainstorming methods. The experiments lasted 3 hours and were conducted during the afternoons over a period of 2 weeks. Each afternoon was divided into two phases, one for each of the experimental conditions, with a short break in between the sessions. The brainstorming sessions were organized as follows:

- 8 minutes of individual idea generation: users write ideas one at a time, using only one Post-it per idea.
- 10 minutes of pooling of ideas: each participant must present their ideas to the group.
- 12 minutes of categorization of ideas: the group must conduct a semantic cleaning (deletion of doubles) and then semantic grouping, where the group must also make a name for each category.

Figure 3. A brainstorming session during the Control condition (left) and a brainstorming session during the TATIN condition (right).

A questionnaire for the subjective assessment of the user experience on the TATIN table was given to each participant upon completion of the brainstorming session in the TATIN condition. A

questionnaire on the comparison between the pen-and-paper session and the TATIN table session was given to each participant upon completion of the two conditions. Due to counterbalancing, when the arrangement of the sessions within the experiments would experience the TATIN table as the second session, the users would fill the TATIN questionnaire first, and then the comparison questionnaire.
In each of the questionnaires, participants were asked to evaluate certain subjective criteria of their experience by a Likert scale of 7 points. They could also add written comments on each of the criteria evaluated. The results of the questionnaires will be compared with those obtained from the project DigiTable to allow us to gain insight on how the criteria are affected by the size of the table and the number of participants [29, 30]. We suspect the social mechanisms at work in a brainstorming session may be contingent upon the relation between the table size and group size.
The experiments were filmed and the videos will be analyzed to observe and evaluate the collaborative behavior of the group. The setup consisted of three cameras recording from three different perspectives, in addition to screen capture from the TATIN system during the experimental condition, and a microphone to record audio from the meeting.

5 RESULTS

Inferential analyses were performed by means of ANOVA. Two dimensions were investigated: the subjective experience of users from the questionnaires, and the collaborative behaviors by means of video analysis.

5.1 Subjective Analysis of Tabletop Group interaction

These questionnaires capture the user's subjective assessment of the paper-and-pencil brainstorming and the interactive table brainstorming. The variables measured by the questionnaire are, among others: ease of use, effectiveness, agreeableness, playfulness (entertainment), etc. Figure 4 summarizes the observed variables and values (averages and standard errors).

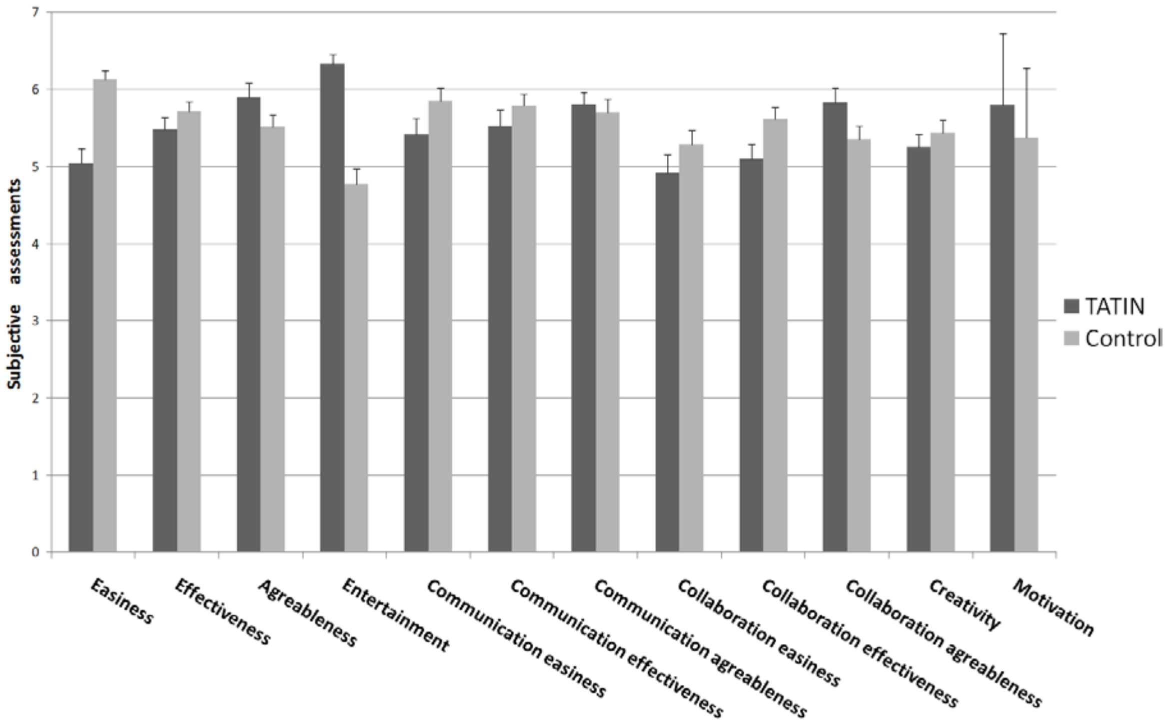

Figure 4. Comparison of subjective criteria between the TATIN condition and the Control Condition

When the criteria are evaluated by averaging the results from the Likert scale of the questionnaire, the criterion with the greatest difference between the control and the TATIN condition is playfulness. This difference in playfulness strongly favors the tactile experience ($\bar{x}_{TATIN} = 6.33$ vs. $\bar{x}_{Control} = 4.77$; $t(47) = 6.67$, $p < 0.001$).

The feedback from the questionnaires highlight the attractiveness of the new technology, particularly the features that facilitate the process of brainstorming: the option of adding images, the simulated physics of the digital Post-its experienced when sliding them to others, circling Post-its with a finger to create groups of Post-its for categories.

We observe a slightly higher motivation for the TATIN condition then the control ($\bar{x}_{TATIN}$ = 5.80 vs. $\bar{x}_{Control}$ = 5.38 ; $t(47) = 5.6$, $p < 0.001$) but when evaluated qualitatively, using the written comments of the users who attest for the motivational impact of the table, the difference becomes more apparent. Indeed, the interactions allowed by the table facilitate brainstorming sessions by reinforcing the desire to accomplish the task properly.

The willingness of users to employ the functionality of the TATIN table, coupled with the playful user experience offered, makes collaboration more enjoyable ($\bar{x}_{TATIN}$ = 5.83 vs. $\bar{x}_{Control}$ = 5.35 ; $t(47) = 2.23$, $p = 0.03$) and creates a stronger rapport among team members by encouraging a higher number of verbal and digital exchanges.

The observed ease of use during the sessions with TATIN proved worse than the ease of use during the control condition ($\bar{x}_{TATIN}$ = 5.04 vs. $\bar{x}_{Control}$ = 6.13 ; $t(46) = 4.36$, $p < 0.001$). The efficiency of the collaboration was likewise judged to be worse in the TATIN condition ($\bar{x}_{TATIN}$ =5.11 vs. $\bar{x}_{Control}$ = 5.62 ; $t(46) = 2.19$, $p = 0.034$).

5.2 Collaboration: video analysis

The participants' collaborative behaviors were annotated from video recordings of the sessions. To annotate video excerpts, we used a tool called ANVIL [31] (Figure 5). It enables manual coding of observed events on a video window in a practical way. It is configured with an XML file that represents the code scheme used. The output of ANVIL consists of an XML file containing the annotation results, which were processed by statistical calculation programs that we conceived [32].

Figure 5. Example of the annotation of a video. The upper-middle window is responisble for the playback of the video. The lower middle window contains the annotation elements that are manually inserted. The column on the left of this window displays the modalities considered. Time is represented by the horizontal axis of the window: each box stands for an annotation element representing a behavior with a starting and ending time.

The coding scheme that we devised comprises the following behaviors: assertions (e.g. giving an idea), information requests (e.g. requesting a clarification about an idea), action requests (e.g. asking a participant to "send a note over"), answers to questions, expression of opinions, communicative

gestures related to the task, and off-task talks. The “communicative gestures” variable includes for example pointing to a Post-it (deictic gestures), moving a Post-it (handling gestures), interrupting someone (regulator gestures) or requesting a speech turn by a gesture (metaphoric gestures), which can be observed in both conditions (control and TATIN conditions). In the TATIN condition, it also includes gestures-inputs on the table, with the exclusion of creation/edition/suppression/group actions which were not considered as communicative gestures.
We analyzed the raw behavioral data for each participant, and then we converted them into percentages to assess the respective contribution of each participant in the group. Such an index finally enabled us to compute the difference between the actual collaboration pattern of each group and a theoretical perfectly-balanced pattern (a sixth of the total contribution from each of the six participants).
With regard to collaborative behaviors, the variable “expression of opinion” and “off-task talk” comprised too many missing values to be analyzed. Other raw behavioral data showed no significant difference in the absolute number of any variables, except for the communicative gestures category: TATIN Tabletop led to more communicative gestures than the pen-and-paper control condition (*F*(1/76)=3.87, *p* =0.062).

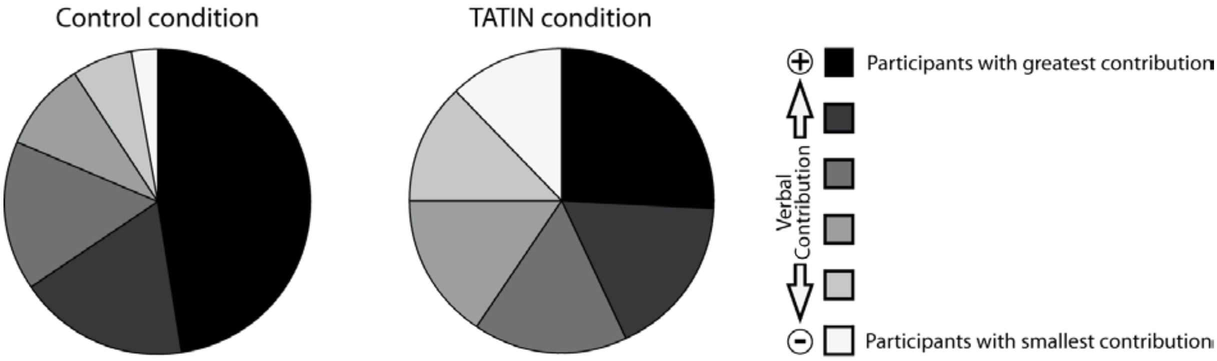

Figure 6. Collaboration patterns in control (left) and tabletop (right) conditions.

The analysis of collaboration patterns showed that participants’ verbal contributions (sum of behaviors without communicative gestures) were significantly more balanced in tabletop sessions than in the control condition (*F*(1/76)=7.93, *p*=0.013) – i.e. they were significantly closer to the theoretical perfectly-balanced pattern. Figure 6 presents the average collaboration patterns in both conditions: to obtain this figure, we ranked the participants of each group from the one who contributed the most (the leader) to the one who contributed the least (the follower) and averaged the data for 8 groups. The same result applies for communicative gestures: the gestural contributions were significantly better balanced in the tabletop than in the control condition (*F*(1/76)=8.94, *p*=0.007).
Our future work will continue the analysis of video to measure the collaborative behavior and creativity of groups in TATIN, so that we may compare them to those of the DigiTable project.

6 DISCUSSION

We can combine and compare our results with those of the experiments that were conducted during the DigiTable project [29, 30]. Like the experiments presented in this paper, the DigiTable experiments also observed simulated creativity and brainstorming sessions on an interactive table compared against a control group. The two experiments also contrast; the DigiTable's experiments utilize an interactive capacitive surface (only one point of contact allowed per user) of 42 inches with groups of four compared to the TATIN's experiments that utilized an interactive LLP tabletop (several points of contact allowed per user) of 83 inches with groups of six. Moreover, the control group for project DigiTable was conducted with the user around a paperboard with one participant in the role of meeting organizer.
The first observation we make on the comparison between the two projects is that the results from the questionnaires are similar. For each of the criteria, it is often the same conditions that are ranked higher, whether they come from the TATIN questionnaire or the DigiTable questionnaire, and often at

similar proportions. The results of our work thus confirm the subjective assessment of project DigiTable's creative sessions conducted both in the interactive table condition and control condition.

Next, we find that the overall satisfaction is higher on average for TATIN's efficiency ($t(1/76) = 6.39$, $p = 0.014$) and agreeableness ($t(1/76) = 4.61$, $p = 0.035$). We can hypothesize that TATIN's large workspace surface and the fact that it allows a greater number of participants to work together offers more comfort to users, a clearer view of more team members and a more suitable distance for communication to improve working conditions when compared to DigiTable.

On a related note, we had expected that the differences between the TATIN condition and the pen-and-paper condition by the subjective questionnaires would be even greater. Certain elements may explain why the interactive table was considered less easy to use:

- The amount of time we allowed the users to interact with the table before the beginning of the experiment was likely far too short to overcome the learning curve of the interactive tabletop. We believe that, with a longer initial training period, the users would feel more comfortable in interacting with the device.
- Entering text using the table's virtual keyboard is fundamentally slower and more labor intensive than a pen and Post-it note.
- During our sessions with the interactive table, users witnessed several bugs in the software. Some bugs were more trivial than others, but all degraded the usability of the table and the quality of the experience. Given the high number of comments made about these defects in the free response section of the questionnaires, the hypothesis can be made that the ease of use of the table would have been significantly increased had we developed more stable software for the experiments.

7 CONCLUSION AND FUTURE-WORKS

As part of our research is committed to improving the process of collaborative preliminary design, project TATIN considers the benefits of interactive devices such as extra large multi-touch tabletops. As there were no options available on the market, we were required to design and construct a table and multi-user software ourselves. This table enabled us to conduct experiments and compare the traditional method of brainstorming against interactive tabletop brainstorming.

Our analysis of the results from the subjective questionnaires of the experiments show the interactive multi-touch tabletop has a positive impact on the motivation and satisfaction of the users, and increases collaboration. In the free response section, the users express their appreciation for the features that the BrainTouch software brings to the brainstorming sessions (photos, physics). The extra-large size of the table also plays a role in the agreeableness of the brainstorming sessions. These results have been corroborated with the findings from brainstorming experiments with the DigiTable interactive tabletop.

Our analysis of the video and audio from the experiments complement our initial findings, and reveal that group communication and collaboration around interactive tabletop surfaces are greatly affected. The contributions from participants were more balanced and distributed throughout the group when using the BrainTouch software, while the sessions that used the traditional method of post-it-and-pen brainstorming, were, on average, dominated by one participant.

Building upon our analysis of video, we have initiated a new follow-up project, TATIN-PIC to significantly revamp the collaborative environment. We have plans to add an interactive whiteboard, additional input modalities (gesture/voice) and intelligent agents to facilitate the retrieval of documents and data similar to [33].

We plan to extend our work beyond brainstorming software and build a preliminary design suite of applications, including software for multi-user functional and risk analysis. Further work must ameliorate the gesture-based interaction and interoperability of the software. In the context of tools used by teams for design projects, we will investigate advanced interaction techniques for CAD applications that will overcome the design challenges of multiple users interacting with the same screen.

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