STUDY AND ANALYSIS OF COLLABORATIVE DESIGN PRACTICES

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ABSTRACT

Current digital design tools that have a high connectivity offer a wide range of possibilities for both co-located and remote collaborative design activities. However, from the point of view of conventional collaborative design practices we identified with practitioners and design companies, these tools lack integrated and comprehensive support during the ideation phase. Consequently, we propose a reference framework with solutions for supporting collaboration among professional designers with digital tools in the early stages of design.

INTRODUCTION

It is no secret that initial phases in a design-oriented process, be it graphical design, interaction design or product design, can be very chaotic. Although there is a strong body of knowledge on design processes and how to structure design activities, many design practitioners feel that the difficulties that come with creative processes make it too much of a burden to manage the process (Stolterman 2008). In part, this is because user-centred design requires several iterations and the involvement of stakeholders, like end-users, in early phases of the process (Haesen et al. 2008). In order to overcome these difficulties, we analyse current design practices with respect to the tools that are used and the communication streams that typically occur within and with design teams. Our analysis identifies a set of reoccurring issues, for which there are several possible solutions, but which design teams often overlook. This paper raises awareness of these issues and puts forward a set of new insights by proposing a reference framework to help design teams to improve their processes.

We classify collaborative design practices according to the characteristics of the workspace shared by designers, either physically or virtually, and how artefacts and tools are disseminated throughout each workspace. We use the Time-Space matrix (Ellis et al. 1991) as a model to categorize the settings of occurrence (i.e. where and when) of designers' activities, outlining collaborative interactions along the place (co-located – remote axes) and time (synchronous – asynchronous axes). Figure 1 illustrates the model as depicted by Dix et al. (2004) classifying non-computer communication technologies in the matrix.

	Same time	*Different times*
Same place	Synchronous, co-located (face-to-face conversation)	Asynchronous, co-located (post-it note)
Different places	Synchronous, remote (phone call)	Asynchronous, remote (letter)

Figure 1: Time-Space matrix.

At the onset of this study, we used a web survey to obtain a general overview of designers' practices, tool preference, and settings in which they collaborate with other team members. Our web survey revealed several interesting facts about design practices, for which we traced their rationale using focused interviews with designers. We start this paper by elaborating on how previous research relates to our work. The next two sections present the findings of both the web survey and interviews. Finally, we discuss the contribution of this paper, a reference framework that depicts possible solutions to support collaboration among professional designers with digital tools in the early stages of design.

RELATED WORK

Design is intrinsically a social, multidisciplinary process, covering a wide range of activities in various knowledge domains (Détienne 2006; Warr & O'Neill 2005). Regardless of the nature of these activities, collaboration, creativity and innovation have a central role in the process (Vyas et al. 2009; Warr & Neill 2005). This is especially true for the conceptual stages of design, where teams generate and converge on ideas, evolving incomplete, ambiguous design requirements into solutions (Détienne 2006).

Extensive research has been conducted for developing novel technologies to better support design activities.

Nevertheless, there still exists a gap between the proposed solutions and what design practitioners find effective in their everyday work (Houben et al. 2013; Stolterman 2008). Some reasons for this gap are the complexity of the design process, and that creative work is not easily formalized or rationalized due to its experiential, artistic nature (Stolterman 2008; Vyas et al. 2009). Nevertheless, this does not diminish the need for systems to support the "capitalization and reuse of design knowledge" (Détienne 2006).

We ground our research on the field of computer-supported cooperative work (CSCW), which conceptualizes that collaborative processes involve team members working towards shared goals, communicating to exchange information among them (Ellis et al. 1991). Consequently, it is important to consider the notions of activity awareness (Carroll et al. 2003; Gutwin & Greenberg 1999) and common ground (Clark & Brennan 1991), which involve team members establishing and maintaining a shared background, presence, tools, and resources for evaluating common outcomes.

In co-located collaborative settings, people establish and maintain awareness and common ground in a natural way, as face-to-face interactions facilitate mutual understanding over multiple channels (e.g. visual, auditory, gestures), rapid feedback to overcome misunderstandings, and shared references over mediating artefacts (Carroll et al. 2003; Gutwin & Greenberg 1999). However, collaboration becomes more complex and "clumsy" as it shifts to remote settings (Gutwin & Greenberg 1999). As distributed design teams become the norm, several tools have been developed to overcome restrictions such as reduced field of view, limitations in exchanged information, and difficulty to establish informal communication in this setting (Carroll et al. 2003; Détienne 2006).

Current research in CSCW focuses on enhancing existing, commonly available technologies to support collaboration. Notable efforts include activity-centric systems to incorporate activity management and multi-tasking in traditional desktop interfaces (Jeuris et al. 2014; Voida & Mynatt 2009); and adapting common technologies to better support collaboration, such as interactive whiteboards (Mangano et al. 2014), communication tools as text messaging, phone, and e-mail (Schuler et al. 2014), and shared repositories (Massey et al. 2014). Our research uses a holistic approach for understanding design practices and usage of current familiar tools, and builds upon this to identify reoccurring issues and solutions.

WEB SURVEY ON DESIGN PRACTICES

Design covers a wide diversity of fields, including graphic design, product design and interaction design. In order to gain a general understanding of designers' practices and tool preferences, and the settings in which they collaborate with other designers and stakeholders, we conducted a widespread web survey. The survey consisted of questions that considered several aspects of individual and collaborative design, including creation and use of artefacts and documents, use of media and devices, and difficulties faced during design activities. The survey was available for 5 weeks in December 2013 - January 2014. Designers were invited to participate via mailing lists for professional designers and social networks.

RESPONDENTS AND THEIR DESIGN PROJECTS

82 respondents, 32 female and 50 male, ranging in age from the category 26-30 to the category 56 and older and located in 14 different European countries, the USA and Australia answered the survey. The professional roles of the respondents range from user interface designer to visual designer and product designer. When asked to map their job to all related skill areas, 73 respondents map their job to the area of designer, 52 situate their job in human factors, usability, human-computer interaction and user research. 38 respondents map their job to project management.

56 respondents work as a practitioner, freelance or in a company, while 40 are involved in R&D and/or academia. The majority of the projects in which the respondents participate are applied research (52%) and industrial projects (43%). Other project types include art projects, open source/creative commons projects, and non-profit projects. The majority of the respondents work on projects that typically take 2 to 6 months

COLLABORATIVE DESIGN SETTINGS

45% of the respondents reported that the design team consists of 3 to 5 team members, while 25% of the respondents reported that their design team typically consists of 1 to 2 team members, while 25% of the respondents collaborate in teams counting 6 or more team members. The remaining 5% reports that it is difficult to specify team size because this differs for each project or because they work in gigantic teams.

With respect to the different settings of the Time-Space matrix, described at the Introduction section and illustrated in Figure 1, we asked the respondents how often they interact with team members and other people involved in the project in the four different settings (see Figure 2). 71% of the respondents interact often or most of the time synchronously at the same place, and 64% communicates or collaborates often or most of the time synchronously at different places. For asynchronous communication or collaboration the situations differ: only 29% of the respondents report that they often or most of the time communicate or collaborate at the same time, at a different place, while the frequency of communication or collaboration at a different time and different place is spread amongst the answers.

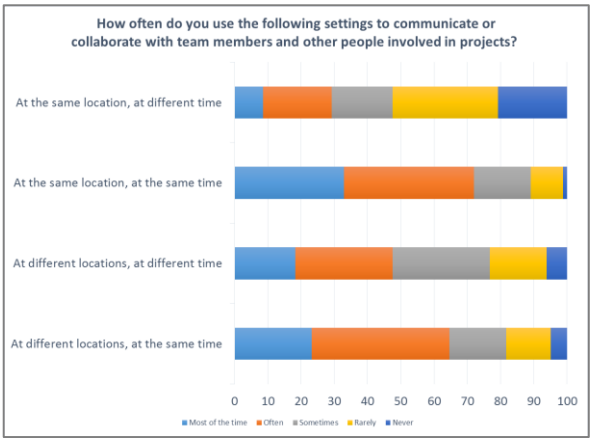

Figure 2: Chart showing the frequency of interactions with team members and other people involved in design projects.

When asked "How often do you take the following approaches in your projects to exchange information with people who are involved (including team members, users, stakeholders, etc.)?" 95% of the respondents reported that e-mail is used often or most of the time. Furthermore, face-to-face meetings are used often or most of the time by 78% of the respondents. Cloud-based documentation services are often to most of the time used by 65% of the respondents, while teleconference is often to most of the time used by 37% of the respondents.

INDIVIDUAL VS. COLLABORATIVE SITUATIONS

In some questions, we distinguished three different situations for the respondents: (1) the individual creation of artefacts and documentation, (2) the collaborative creation of artefacts and documentation and (3) informing team members and other people involved in the project about designs.

For each of these situations, respondents were asked what type of artefacts or documentation they use. The results teach us that most of the respondents do not make a distinction between the three different situations when they create or communicate artefacts and documents. Furthermore, presentations and sketches are used by most of the respondents (87% and 78% respectively).

When the respondents were asked what type of applications they use, applications to edit documents appear to be used by most of the respondents (93%). Furthermore, 2D modelling software is also used by the majority of the respondents (84%). When considering the three different situations, we see that documents are used for all situations, while other types of applications such as 2D modelling software and video editing tools are more frequently used in individual settings than in collaborative settings.

Tools that were mentioned by the respondents vary a lot for 3D modelling and viewing (e.g. Solidworks, SketchUp and Rhinoceros). For 2D modelling, tools offered by Adobe Creative Suite are used the most, and were mentioned by 43% of the respondents, Axure is used by 10% of the respondents, while a wide range of other tools were mentioned by the respondents but seem to be used by a small amount of respondents (e.g. Visio, Fireworks, Balsamiq, OmniGraffle, all used by 5% or less of the respondents). For the editing of documents, MS Office applications are used the most (by 41% of the respondents), followed by Google Docs (13%), Keynote (12%) and OpenOffice (7%).

A similar question was asked regarding the media and devices used by the respondents. PC and pen and paper are used the most (98% and 90% respectively), Similarly to the use of artefacts or documentation, the difference in use depending on the situation is small, but for collaborative settings, the results show that whiteboard/flipchart are used by 69% of the respondents.

Finally, the respondents were asked what problems they experience in the collaborative situations (2) and (3). Most problems concern communication problems or technical problems, which is shown in Figure 3. For the two situations, similar responses are given. However, more technical problems or limitations appear when creating designs in collaboration with team members than when informing team members and other people involved. Some examples of communication problems that are mentioned by the respondents are the status of progress and communication of design decisions, while technical problems mentioned include versioning, tracking changes and difficulties to create and brainstorm remotely.

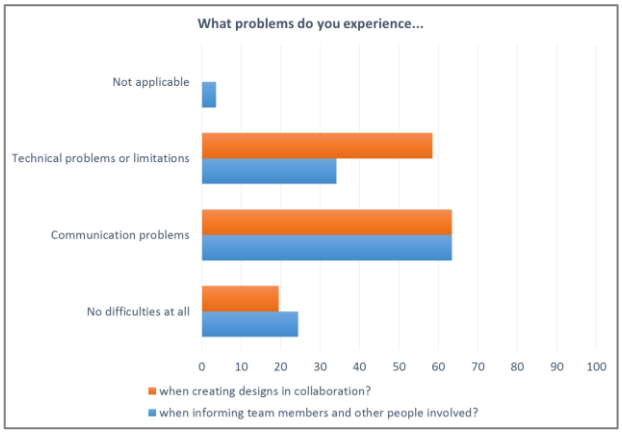

Figure 3: Chart of difficulties that occur when collaborating with team members and informing people involved in the project.

In conclusion, the web survey provided an overview of tools used by designers. Furthermore, the survey revealed that designers usually do not distinguish the situations they work in for selecting their documentation, artefacts, applications, media and devices. As the survey results do not explain the reasons for these findings, a series of interviews focusing on specific approaches taken by designers was conducted. This study is presented in the following sections.

INTERVIEWS WITH DESIGN PRACTITIONERS

To investigate the underlying rationale of the responses to the web survey, we extended our study by organizing interviews with design practitioners.

METHODS

We recruited 9 volunteers by contacting the respondents of the web survey that explicitly agreed to participate in a follow-up interview while responding to the survey. To expand the number of participants, several designers were invited via e-mail to join the interviews. In total, 20 design practitioners (14 male, 6 female) from 15 different companies were interviewed in August 2014 - January 2015. Participants ranged between 3 and 20 years of experience practicing one or more design disciplines, including graphical, product and user experience (UX) design. 12 participants were interviewed face-to-face at their office (all located in Belgium). Each of these co-located interviews took 90 minutes, and were followed by an observation of the workplace. 8 participants were interviewed remotely (via Google Hangouts), each meeting lasted 60 minutes.

Interviews were conducted using a semi-structured protocol. For the first part, participants were briefed about practical considerations (e.g. privacy concerns) and prompted to talk about their background and current work position. After this, participants were asked to create a mind map to aid them visualize and collaboratively reflect on their design practices (Huybrechts et al. 2012; Wheeldon & Faubert 2009). For this, participants were presented with a visual representation of the Time-Space matrix in either a flipchart paper (face-to-face setting, Figure 4) or a shared Google Drawings canvas (online setting), and briefly introduced to the characteristics of each setting of occurrence.

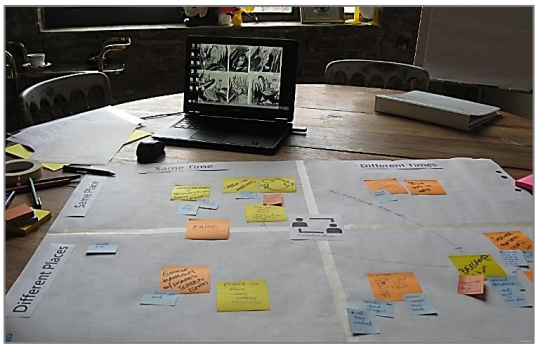

Figure 4: Setting of face-to-face interview with paper version of the Time-Space matrix.

To start creating the mind maps, participants were asked to describe the early stages of a specific design project. Then, they were invited to use the available materials (pictured in Figure 4) to populate the mind map by adding keywords (e.g. tools, tasks, challenges) to illustrate their collaborative practices within the Time-Space matrix. The facilitator explained that there were no right or wrong answers, and also contributed by adding keywords and clarifications to the mind map.

DATA ANALYSIS

The audio transcript and finalized mind map of each interview were examined to search for recurrent collaborative design practices, with a focus on the people involved, the tools they used, the communication that takes place within and with the team, and problems that were raised during the interview. This was done using an adaptation of Grounded Theory (Glaser & Strauss 1967).

REPORTED COLLABORATIVE WORKFLOWS

Our analysis of the data leads us to a set of typical workflows that map how designers communicate, what tools and infrastructure play a role and what information or artefacts are shared with others. Since we gather data from designers, the workflows are also centred on the reported practices of designers, which are sometimes inconsistent with the features of the tools they use. By consequence, our approach is useful to both map the actual collaborative process as well as highlight mismatches of the usage of design tools for these creative processes. Clearly, designers tailor their tools to their preferred work practices rather than adapt the practice according to the tools used.

We use sequence diagrams to depict the interactions between people and tools, shedding light on the approaches that could be better supported by technology. This notation is common in software engineering to present how several components communicate, but we found it equally useful to provide a structured overview of the collaborative processes. The notation presents a vertical timeline for each actor in the process (human, tool or infrastructure) and lays out the streams of communication between these lines. Each diagram illustrates a concrete approach to collaboration described by a participant and reflects on recurrent practices.

The sequence diagrams are composed by the following elements: (1) parallel vertical lines depict a person involved in the design team, in order to distinguish roles (e.g. designer, client). Dotted lines indicate mediating tools. (2) Horizontal arrows indicate interactions, and are annotated with details about communication, messages exchanged, and data types. (3) Boxes signal the different processes (i.e. a set of activities) in the workflow. Each relevant process of the workflow is numbered with a blue circle. (4) Critical points of collaboration are marked in the grey boxes.

We identified three workflows to represent prevalent examples of collaborative design practices: an external communication workflow ("coordination with clients and stakeholders"), an artefact-centred workflow ("versioning artefacts and documentation"), and an internal communication workflow ("setting up a shared workspace"). In the next three sections we discuss each workflow separately.

WORKFLOW 1: COORDINATION WITH CLIENTS AND STAKEHOLDERS

The workflow illustrated in Figure 5 represents the cycle that was described by 17 designers (85% of the participants), in which they receive feedback on a shared artefact from clients and stakeholders, and then iterate over the artefact with this feedback.

In this workflow, the Designer (1) uploads an artefact to a cloud storage and sharing service, Dropbox being the most mentioned by participants. Afterwards, the Designer sends an e-mail to the Client including the link to access the artefact, which is usually accompanied by details and rationale of the shared artefact. As a second process in the workflow, the Client (2) accesses the file using the link and replies to the e-mail of the Designer, sending back their feedback on the artefact. In some situations, especially on project milestones or situations where misunderstandings are likely to occur, the Designer (3) organizes a meeting with the Client to discuss the artefact synchronously.

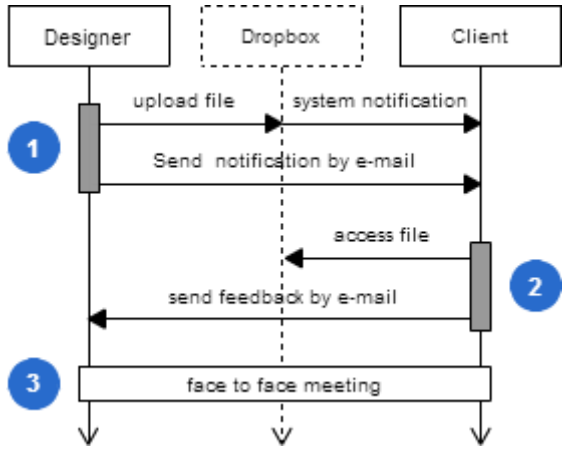

Figure 5: External communication workflow for coordinating with clients and stakeholders.

In the next paragraphs, we highlight two critical points in this workflow where collaboration breakdowns were frequently described by designers: sharing updates with clients (Figure 5, process 1), and conveying visual ideas with text (see Figure 5, process 2).

All participants mentioned that they frequently share updates of their ongoing design activities with their client and/or stakeholders, as represented in Figure 5, process 1. 90% of the participants do this over cloud services, such as Dropbox or Google Drive, which include automatic system notifications to increase awareness of modifications to a shared workspace. However, designers consider these notifications as ineffective.

19 designers (95% of the participants) mentioned that they notify their clients and stakeholders about updates mostly via e-mail, which confirms the results of our web survey. However, they do not consider it as an ideal communication tool. A popular alternative to using e-mails is to use centralized applications, such as Basecamp, as an effective approach to coordinate processes such as sharing artefacts and communicating while keeping a record of the project. This is described in Transcript 1.

> "I really like it [Basecamp]… it keeps track of everything (...). It's like a tape recorder, you know? All the decisions are in there. That's the discussion place, but also the deliverables' space... That's how I see it."
>
> *[P13, Interaction designer]*

Transcript 1: Quote on using Basecamp for coordination with clients.

As illustrated in Figure 5, process 2, another critical point in the workflow is the interpretation of the client of the design artefacts that were shared. Since artefacts only show the results, but lack the rationale on how they were obtained, the clients might misinterpret them. For example, a graphical designer involved in game design mentioned to use "square-shaped villains and circle-shaped heroes" to convey the role of each character. The client, unaware of this personal convention, thought of it as erroneous until the designer explained the rationale.

To prevent miscommunications, a frequent approach of designers is to carefully craft an e-mail including details and rationale of the shared artefact. Nevertheless, they consider this as a cumbersome communication activity, as it is time-consuming to "point out" visual elements using text, especially with stakeholders that have a different background (e.g. project managers, developers). Moreover, they mentioned to have difficulties with managing all conversations while they are scattered over different e-mail threads, and frequently forgetting to "Cc" relevant stakeholders.

A widely used approach to overcome this limitation is for designers to organize a synchronous meeting with the client where they can share their screen to point out elements in their design. These meetings are preferably done face-to-face, but remote meetings are mentioned as equally useful if using VoIP tools with screen sharing functionalities (e.g. Skype and Hangouts). These meetings allow designers to negotiate design decisions, and help the clients to understand how to go through and review designs.

Guidelines for the external communication workflow

As a guideline to support collaboration within this workflow, we highlight the current disconnection between tools for sharing artefacts and communicating design rationale to externals. To avoid this loss of context, we propose creating a common space where designers can upload artefacts annotated with the design rationale and initiate asynchronous communication (e.g. to notify about updates). This common space should evolve over each iteration, developing a common visual vocabulary between designers and clients.

WORKFLOW 2: VERSIONING ARTEFACTS AND DOCUMENTATION

Mediating artefacts are highly relevant for the iterative nature of the design process, as they store information and express ideas (Détienne 2006). Figure 6 maps the

collaborative workflow between the creative team and an account manager for versioning documentation.

The workflow starts as Designer A (1) creates a file and shares it with Designer B, both members of the creative team. 11 designers (55% of the participants) mentioned to use tools, such as Google Docs, for editing files synchronously. When the file is ready to be shared, Designer B (2) exports the file to a MS Word document (i.e. .doc file), and shares it with the Account manager. The Account manager (3) adapts the original file into a predefined MS Office template, and shares it via e-mail with the Client. The Client, in return, replies with feedback on the document, which is afterwards forwarded to the creative team. The Client's feedback triggers the creative team to (4) discuss the feedback face-to-face, coordinating a new iteration on the file using MS Word. Simultaneously, the Account manager also iterates on his version of the Word file.

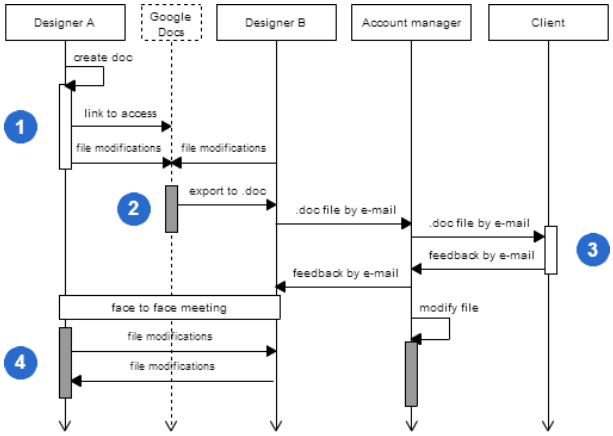

Figure 6: Artefact-centred workflow for versioning documentation.

We describe two critical points in this workflow where collaboration breakdowns are found: synchronous co-editing of artefacts (Figure 6, process 2) and conflicting versions (Figure 6, process 4).

We found that, while being very efficient and highly appreciated synchronous editing tools, Google Docs and Evernote still have limitations. For instance, and as illustrated in Figure 6, process 2, designers mentioned that they stop using Google Docs at a certain point in the process, as this tool does not offer enough functionalities for formatting documents. An approach of designers, as illustrated in Transcript 2, is to "estimate when to stop" using synchronous tools, so they do not have to overwork on formatting later on.

> "By now, we know more or less when to stop using Google Docs... When we're really working on the layout and defining how the final document is going to look like, we move to [MS] Word. If we continue working in Google Docs, we'll have a lot of editing work later."
>
> *[P8, UX researcher]*

Transcript 2: Quote on using Google Docs collaboratively.

A second critical point in this workflow (Figure 6, process 4) occurs when designers have conflicting versions of documents. A lack of awareness of the ongoing activities of other team members often leads to "dirty updates", when a previous version of a document is updated with a change that conflicts with an update in a newer version.

To keep control of versions and modifications, 17 designers (85% of the participants) mentioned that artefacts such as CAD files and UI prototypes are owned and modified by only one person for the entire lifecycle of the artefact. Certain documentation files, such as project logs and templates, are frequently modified by two or more team members. As a result, it is usual to have conflicting versions of such artefacts.

Guidelines for the artefact-centred workflow

This dirty update issue and lack of floor control support implies that there is a stringent need of tools for designers to maintain awareness and control access over shared artefacts. However, versioning tools such as GitHub and Redmine are not tailored for the needs of designers. An integration of versioning support within the design tools becomes a necessity. We identify three possible strategies: (1) integrating versioning and access features into existing design tools, with which designers can keep control of changes and older versions of documents, (2) using an independent external tool (such as GitHub or SVN) and ensuring that file formats used allow for comparing files, or (3) always using a shared version of the file and handling versioning and locking as a central service. From our interviews, we noticed practitioners are most likely to choose for solutions resembling option (3), but with additional degrees of freedom (e.g. making copies to work individually and merge later on).

WORKFLOW 3: SETTING UP A SHARED WORKSPACE

Designers will often try to set up a virtual shared workspace that can act as a partial substitute for a physical shared workspace. Easy access to artefacts and the possibility to share and collaborate are their primary concerns.

The workflow illustrated in Figure 7 reflects on the processes for keeping common ground among co-located team members. In this approach, Designer A (1) uploads an artefact to Dropbox, sharing a URL to access the file via Skype with Designer B, who (2) opens the artefact, reviews it, and gives comments to Designer A via Skype, frequently initiating a synchronous conversation. Afterwards, Designer A iterates over the artefact based on the feedback. Whenever needed, Designer A (3) looks for Designer B to have a quick, informal discussion about the artefact, which will be, most likely, followed by another iteration.

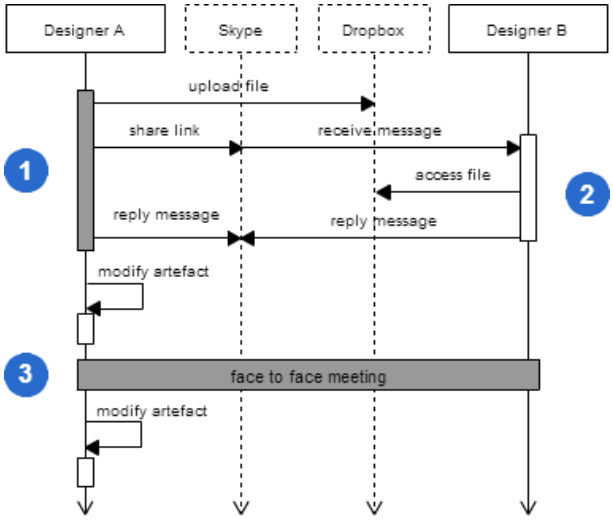

Figure 7: Internal communication workflow for setting up a shared workspace.

We found two critical points in this workflow: the traceability of artefacts (Figure 7, process 1) and selecting adequate media (Figure 7, process 3).

When it comes to strategies for tracing back artefacts, 7 designers (35% of the participants) from 4 companies mentioned that their company had standardized protocols for naming and storing files, while the rest of the participants mentioned to do it according to what seems logical for each project or artefact. Nevertheless, as illustrated in Transcript 3, organizing files is usually a "messy task".

> "We have templates [for deliverables]... But it's a mess... It's always like... Is this the latest one? (...) We're a bit struggling here to make sure that everything is really organized (...). We're always working on projects, and it's bit difficult to organize such stuff."
> *[P7, UX designer]*

Transcript 3: Quote on organizing files on shared repositories.

Another important challenge is for designers to keep track of the changes and updates that were applied on a shared artefact. For instance, figuring out what were the last modifications done to a document, or which version clients have approved. A common strategy for this is to use the track changes functionality or add comments/ annotations to a file.

In a similar approach to that described in workflow 1, designers start with either synchronous or asynchronous communication to notify about the changes (e.g. send Skype message with summary of modifications). They also tend to create a log file summarizing the most relevant design decisions and milestones, which is then shared through the internal file server. These strategies were mentioned as effective to some extent, but time consuming and confusing in some situations.

This workflow also illustrates that designers prefer to converge with colleagues in organic, unplanned, and informal meetings. All participants mentioned that these informal meetings are vital to promote creativity, and consider them as the cornerstone of the collaborative design practices. Nevertheless, a critical point (Figure 7, process 3) occurs as these meetings are not logged, and thus can lead to missed information, as illustrated in Transcript 4.

> "We sit next to each other (...). Our chairs have wheels, so we just roll over and give each other feedback on our designs. That happens a lot (...), so most of the internal communication is just short meetings. (…) The only thing with this, is that there is no written transcript, and sometimes that can be a problem in a later stage."
> *[P6, Graphical designer]*

Transcript 4: Quote on having informal meetings with team members.

Guidelines for the internal communication workflow

For remote or multidisciplinary teams, convergence becomes more challenging. Designers may not share the same tools or understanding for analysing artefacts. For example, a design studio mentioned to have the common practice of posting mock-ups on the wall to reach convergence between the graphical and interaction designers and the software developer, as all use different, mostly incompatible tools (e.g. Photoshop, Axure, and HTML). Moreover, using diverse tools creates a "context switch", which is identified as a source of interruptions and project fragmentation (Houben et al. 2013). Therefore, we propose an activity-oriented workspace, where designers and their team members can trace back artefacts and tool usage to converge asynchronously (Houben et al. 2013; Jeuris et al. 2014; Voida & Mynatt 2009).

DISCUSSION

While the interviews were meant to be an in-depth exploration of the issues that were revealed in the web survey, other important information surfaced during the interviews. This allowed us to analyse critical issues in the collaborative processes that are used. Collaborative issues appear to be related to the interplay of communication and the design authoring tools. Since designers use incremental and iterative processes, as is usual in User-Centred Design [ISO 9241-210:2010], our guidelines to possibly solve these issues are focused on tools and infrastructure.

Table 1 introduces a reference framework for setting collaborative configurations. This framework is formulated in consideration of the guidelines proposed throughout this paper, and categorized according to its coverage of the Time-Space matrix. We propose for design practitioners to use this framework for selecting digital tools that are appropriate for their collaborative design practices.

The framework is simple to use and reads as follows: when attempting to (activity and setting of occurrence) but avoiding (possible critical issues), implement a (digital tool solution) to achieve (expected outcome). We want to stimulate others to build upon this and extend the framework where appropriate.

When attempting to…	*But avoiding…*	*Implement a…*	*To achieve…*
Converge over a remote, asynchronous setting	Disconnection between sharing & communicating design rationale	Common workspace to combine artefacts & communication	Common grounding and a shared visual vocabulary in multidisciplinary teams
Diverge over a remote, synchronous setting	Dirty updates & conflicting versions	Version and floor control systems integrated with design tools	Workspace awareness for controlling versions, comparing & merging files
Converge over a co-located, asynchronous setting	Context switch, file incompatibility & project fragmentation	Activity-oriented workspace	Artefact traceability and shared vocabulary between co-designers

Table 1: Reference framework for setting collaborative configurations.

The exploration of current practices and tools, its analysis and resulting reference framework are also meant to inform future developments of design tools and setting up collaborative environment. Our findings have the potential of improving the outcomes of design processes by reducing the collaborative issues, allowing design practitioners to focus on their creative input in design activities and solving design problems instead of miscommunications.

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