Abstract: This paper addresses a new method to describe the remote collaborative design process from the perspective of reflective practice. We aim at understanding the mutual effect between internal and external structures in remote collaborative design. According to the cognitive coding scheme of Suwa et al., we encoded the process into a set of indices—new, continual and revisited—that describe each primitive design move. In a case study which involved the authors as design collaborators, we identified the degree of dependency among these moves and developed a 3D graphical representation to account for reflective practice between us as collaborators. In this representation, we re-interpreted our collaborative process through three main axes: axis of idea exchange as lateral component, axis of idea development as vertical component, and axis of dependency as depth component. We believe this representation can be used to re-interpret the collaboration process among geographically dispersed design team members.

Keywords: Collaborative design, reflective practice, collective reflection-in-action, cognitive actions, design moves, dependency relationships, remote collaboration.

1. Introduction
Research in architectural design collaboration has focused on a wide variety of issues, including data exchange, understanding group interaction, identifying design tasks, observing participant interaction with digital media, and encoding social processes to develop effective communication tools [2, 12]. The goal of these tools is generally oriented towards enhancing teamwork communication and enabling better access to design information. The availability of web tools, desktop video and audio conferencing tools, and application sharing has made it simpler to work on design collaboration projects, share ideas and communicate effectively regardless of the remote location of participants. Many studies discussed such applications in different contexts [1, 3, 5, 11]. Cheng [2] describes two approaches that design collaboration researchers focus on in their investigation. The first approach involves data organization, information flow, and what software products offer to interdisciplinary teams. The second approach focuses more on how groups think and work together and with digital media. This social science-driven approach presents an important step for developing tailored computer software and data structures for collaboration support. Our work in this paper aligns with the latter approach. We focus specifically on reflective practice as a key aspect in understanding collaborative design.
2. Understanding Collaboration: A Reflective Practice Perspective

The concept of reflective practice, introduced by Schön [14], deals with thinking about and learning from one’s individual practice or others’ practices to provide insight and allow for informed actions. It typically starts with critical reflection, where the individual’s ideas are questioned, followed by a process of learning from positive or negative experience. It results in developing a rationale for subsequent strategies and actions informed by critically examined values about methods of practice and why they are performed in one specific way or another. This systematic inquiry develops through continuous reflection, or reflection-in-action as coined by Schön. It starts with individual reflection on one’s experiences, and can progress into “collective reflection-in-action” [4] if enlightened by interactions with other social participants or external representations that enrich the reflection process. Researchers have debated over the role of collaborative interaction in design. Some view it as hindering the search process for appropriate design solutions [4, 8] due to the competing problem space representations that exist between collaborators and the conflicts that follow with no suitable shared resources for resolution. Others view collaboration as aiding the process by offering new ways of looking at design issues as well as new problem space representations resulting from the distribution of expertise among collaborators [4, 6]. In light of this positive view of collective practice, the individual thought process, with all its problem space definitions, actions and justifications, is made public and open to the interpretation, manipulation and validation of other entities. This engagement of social participants provides new and unpredictable readings of situations and problems, and leads to a combined effort that is probably less feasible to reach without such collaboration.

Our study explores this process of “collective reflection-in-action” in the context of remote collaborative design. We represent the cognitive actions and interactions that occur in the process to better understand the role of reflective practice in remote collaboration. Specifically, we focus on the design process using an online desktop sharing application. Our research questions deal with the role of reflective practice in describing remote collaboration. The key question remains: can we understand the mutual effect between the internal structure – or the mind – and external cognitive structures in the collaboration process? Generally speaking, can we describe a design process in terms of collective reflection-in-action, and how can we represent it? How can we then use this representation to reinterpret remote collaboration?

3. Method of Research

In order to address our research questions, we developed a case study which involved the authors as remote collaborators in an architectural design competition. We identified the design moves and discussion sessions of the collaborators in their remote communication using a desktop sharing medium. We mapped the design moves to their corresponding cognitive actions, and traced the dependency relationships between these actions. We then represented these relationships in a three-dimensional dependency graph.

We build on previous work that involves studying design moves and cognitive actions [9, 10, 15]. The case study by Suwa et al. [15] addresses cognitive actions and their dependencies in a process that involves an individual designer. Our scheme follows a parallel but different approach, where the interactions and dependency relationships among collaborators are defined explicitly. We introduced a number of factors to account for reflective practice, including the participants in the session and the interactions among them, the typologies of collaboration, and the kind of medium involved during collaboration. We discuss these factors below.
3.1 Cognitive Actions and Dependency Relationships

The coding scheme in [15] classified cognitive actions to a finite number of levels; *physical*, *perceptual*, *functional* and *conceptual*. Each action denotes a target action that is dependent on precedent actions. This dependency works such that each action lies in a same, higher or lower category level than that of the target action. This also indicates whether each action is new, continual or revisited. The actions and relationships described in this scheme address an individual designer. Our concern is the interpretation of these cognitive actions in the context of collaborative design, and specifically how they address reflective practice (table 1).

Table 1. Interpreting levels of cognitive actions in terms of a collaborative design context

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Description (Suwa et al. 1998)</th>
<th>Interpretation in collaborative context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>D-action</td>
<td>Make depictions</td>
<td>Externalize (sketch/model/etc.) representation synchronously or asynchronously</td>
</tr>
<tr>
<td></td>
<td>L-action</td>
<td>Look at previous depictions</td>
<td>Reflect on a representation externalized by self and/or other social entity</td>
</tr>
<tr>
<td></td>
<td>M-action</td>
<td>Other physical actions (e.g. move elements, make gestures)</td>
<td>Demonstrate/communicate idea graphically, visualize elements of representation</td>
</tr>
<tr>
<td>Perceptual</td>
<td>P-action</td>
<td>Attend to visual features/spatial relations, organize/compare elements</td>
<td>Attend to design move/action/relation/form of self and/or other social entity</td>
</tr>
<tr>
<td>Functional</td>
<td>F-action</td>
<td>Explore interaction between artifacts and people, functional issues</td>
<td>Study functional issues synchronously and/or asynchronously</td>
</tr>
<tr>
<td>Conceptual</td>
<td>E-action</td>
<td>Make preferential and aesthetic evaluations</td>
<td>Evaluate/confirm/argue/critique conceptual idea of self and/or other social entity</td>
</tr>
<tr>
<td></td>
<td>G-action</td>
<td>Set up goals</td>
<td>Make critical decisions and goals based on internal/external reflection of ideas</td>
</tr>
<tr>
<td></td>
<td>K-action</td>
<td>Retrieve knowledge</td>
<td>Gain conceptual feedback from self expertise, communal knowledge and representations</td>
</tr>
</tbody>
</table>

We assume that any session consists of actions described in terms of four levels, starting from low level types of actions to higher level structures: (1) cognitive actions; (2) dependency relationships of design moves; (3) indices of problem solving tasks representing the continuity of actions in task-related sequences (e.g. new, continual, and revisited); and (4) design ideas, representing the aggregation of continual sequences of the three previous levels. Our analysis deals with the first three levels only. Our scheme of dependency relationships involves reflection-in-action in a collaborative design process, and breaks down the process into cognitive actions relative to each participant. At the lowest level of actions, we identify two kinds of actions for each participant. These represent actions which the participant performed for a specific design move (the dependent action), and actions upon which the participant relied to perform the move (the dependee action). This designation produces a set of dependency relationships between the different cognitive actions in the process.

3.2 Collaboration Typologies

According to our observations in this study, we noticed three major types of collaboration that our desktop sharing medium supports: *executional*, *visual* and *communicational*. By *executional* collaboration, we refer to resolving design problems on external representations like 2D drawings or 3D modeling. These can occur synchronously among participants or in asynchronous sessions where most of the actual work gets done [13]. By *visual* collaboration, we refer to the act of viewing, rotating, and zooming into models or representations, or
gestures to elements in the shared collaboration medium that allow for reflection by other collaborators. By *communicational* collaboration, we refer to the online text-based discussion and social interaction that occurs to elaborate ideas on external representations through a shared medium. This distinction is important to study our process, not only in a macroscopic fashion, but also at a microscopic level for individual design moves. By observing the degree of dependency among these actions, we assume we can understand new collaboration patterns, such as the explicit contribution of participants, the nature of cognitive actions performed by each participant across collaboration typologies, the nature of continuity of tasks among participants, and how each participant affected the flow of the process in a leader-follower fashion through continuous reflection.

4. Case Study

Our case study is an observation of our collaboration as a team in a proposal for the TU Delft International Building for Bouwkunde Ideas Competition, 2008. The goal was to rebuild the faculty of architecture building upon its destruction by a devastating fire. As remote collaborators, we organized our process through scheduled online meetings, where we held synchronous and asynchronous design and discussion sessions.

4.1 Selecting Collaboration Medium

The design team expressed a desire to work through a shared design medium. After some research, the team put three media in the spotlight: whiteboards, application-based sharing and desktop sharing. While whiteboards enabled flexibility and were effective as an externalization tool, there was more demand of a medium that takes the design to a further level by sharing modeling applications rather than an early sketching tool. The focus of the application-based sharing alternative was sharing plug-ins specific to modeling tools, such as AutoCAD, Google SketchUp or 3DStudio MAX, for further design development. This presented some challenges in terms of scope, practicality, run-time, and was time consuming in terms of model visualization.

Desktop sharing provided a medium that encompasses all tools, promotes real time interaction, and provides a suitable platform for discussion in synchronous and asynchronous modes. Not only did it enable better visualization and concept development, but also it provided access to a wider variety of resources due to sharing the whole desktop as opposed to a specific application. The other advantage was real time intervention. Once any team member needed to implement a design idea, he would take over mouse control and execute it. Continuous iterations in this sense speeded up the process and enabled a more reliable understanding of design development.

4.2 Design Process

The design team used multiple techniques to develop their design, both synchronously and asynchronously. The asynchronous mode was mostly executional in nature, while the synchronous mode involved mostly communicational and visual collaboration. The overall process timeline and stages are shown in figure 1. The process started by sharing preliminary thoughts through text in the form of emails describing the vision of each member. This was followed by a survey of architectural precedents and potential ideas through verbal online discussion. The team then discussed the site potentials and limitations through verbal discussion over shared site maps, satellite images, and site photos. Then they started an asynchronous phase, where freehand sketches and 2D drawings were developed individually. The output of this phase was scanned sketches and 2D CAD drawings overlaid on the site layout. These were shared, discussed and developed through chatting and texting.
The team used the available data to build a 3D model and develop design alternatives in parallel. They then evaluated the product and went through continuous iterations of sketching, re-modeling, and model enhancement to develop the design idea. AutoCad was used for building the initial model, Google SketchUp for visualization, and 3DSstudio MAX for assigning materials and rendering a photorealistic image of the proposal. The design team then studied the building function both synchronously and asynchronously. They performed and shared continuous edits in 2D and 3D to satisfy the program areas and to match the philosophical concept they developed, which commemorated the old building site. The final stage involved specific tasks for each member to meet the competition deadline. This included adding detail to the model, editing materials, resolving functional areas, and producing accurate 2D drawings. As the time constraint became tighter, less sharing and discussion activities were involved, and the main goal was execution and production through specific tasks.

5. Detailed Study

5.1 General Observations

In our analysis, we focus on synchronous collaboration, and explore the nature of design moves, cognitive actions and dependency relationships the design team attempted in the process. We recorded some of our shared desktop sessions. For the purpose of this study, we show a segment of text-based communication between the two members of the design team. This session lies between stages 3 and 6 on the timeline illustrated in figure 1. This encompasses an early stage of concept formation, which was a discussion session over 3 representations. These included 2 freehand sketches by one member, and a 3D model by the other using Google SketchUp. The recorded session is 7 minutes long. It starts by displaying what both members accomplished individually: a freehand sketch and a SketchUp 3D model. They then discuss form, orientation, layout, axes, and other issues. At this stage, they are still comparing alternatives, and so there is a continuous exchange of ideas. We observed that the continuous reflection of both members on their own ideas, through their interaction, and through the representations displayed on the shared medium was a key catalyst in developing the final idea. We specifically selected this segment as it participated to a great extent in shaping many of the critical decisions in the process.
5.2 Protocol Analysis

We used protocol analysis [7] for our detailed study. The raw data came from a screen video capture of 7 minutes of design activity. We transcribed the video into text that describes the communication that took place between the team members (figure 2). We recorded 51 design moves for both members in the form of text-based input, and classified them by type of activity. The input came from two sources: text extracted from the chat window of the desktop sharing application, and a description of the interaction on the screen to indicate attention to points of interest. A phrase like “as you can see there are different axes” denotes a clarification activity, whereas pointing to an element on a sketch to show alignment with the north direction denotes a demonstration activity.

We also classified each move according to collaboration typology. In this segment, the team members were concerned with discussing their ideas based on models and sketches they had developed earlier asynchronously, and thus there were hardly any executional collaboration activities observed. Communicational activities focused on discussion in the form of textual input, while visual activities included actions such as demonstrations on the shared desktop medium, and zooming and rotating moves for individual or shared visualization purposes.

As the shared medium allowed for the interaction of both users, we could easily track which moves were done by each team member, both in the case of textual discussion or visual demonstrations. We also recorded the type of external representation upon which the team members discussed their ideas, according to its display on the shared desktop medium. For example, we could identify whether the shared discussion was over a freehand sketch, 2D drawing, 3D model, map or design brief. We coded these representations according to the number of instances that appeared in the design sessions (e.g. Sketch 1, SketchUp model 2, map 3, 2D drawing 4, etc.).

![Figure 2](image-url) An extract from the protocol analysis sheet for our detailed segment of study

We also interpreted what design moves denote in terms of cognitive actions, according to the coding scheme of Suwa et al. [15]. For each move, we classified these actions and their categories into dependent and dependee actions. For example, the move “pointing to the axial lines in sketch” represents a physical action of pointing, which is an M-action. This action is dependent on another action which was performed (whether by the same or different team member) in an earlier design session. In this case, it points to “axial lines in sketch”, which denotes an external representation depicted earlier. Thus the dependee action is a physical action of drawing, or a D-action. We describe the resultant cognitive action, or dependency relationship, here as “M on D”.

<table>
<thead>
<tr>
<th>NO.</th>
<th>MEMBER</th>
<th>REF.</th>
<th>DESIGN MOVE</th>
<th>Text Input</th>
<th>Type of Activity</th>
<th>COGNITIVE ACTION</th>
<th>TASK INDEX</th>
<th>COLLABORATION TYPOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>2</td>
<td>Sketch 1</td>
<td>I noticed that you are allocating the shapes in the main area which is perpendicular to the north direction*</td>
<td>Clarifying</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>Sketch 1</td>
<td>The north orientation is one of those*</td>
<td>Clarifying</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>18</td>
<td>1</td>
<td>Sketch 1</td>
<td>“I noticed that you are allocating the shapes in the main area which is perpendicular to the north direction.”</td>
<td>Clarifying</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>Sketch 1</td>
<td>Painting to the point of attention showing the perpendicular alignment with North direction</td>
<td>Demonstrating</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>Sketch 1</td>
<td>What we can control into the main direction, as the other buildings of the campus*</td>
<td>Questioning</td>
<td>Conceptual</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>Sketch 1</td>
<td>It seems a good point*</td>
<td>Clarifying</td>
<td>Conceptual</td>
<td>Action</td>
<td>0-action</td>
<td>Functional</td>
</tr>
<tr>
<td>22</td>
<td>2</td>
<td>Sketch 2</td>
<td>Opening a new file, another sketch where it did previously to extend the discussion</td>
<td>Organizing</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>Sketch 1</td>
<td>“I think that’s a good idea”</td>
<td>Confirming</td>
<td>Conceptual</td>
<td>Action</td>
<td>0-action</td>
<td>Conceptual</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>Sketch 2</td>
<td>I had another alternative that had to happen*</td>
<td>Clarifying</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>Sketch 2</td>
<td>You had other alternative and points at the main masses</td>
<td>Demonstrating</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>SketchUp 3D</td>
<td>Is this what you have modeled using Sketchup?*</td>
<td>Questioning</td>
<td>Conceptual</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
<tr>
<td>27</td>
<td>2</td>
<td>Sketch 2</td>
<td>I also visualized the old elliptical shape you modeled before, but introduced an entrance from west direction*</td>
<td>Clarifying</td>
<td>Physical</td>
<td>Action</td>
<td>0-action</td>
<td>Physical</td>
</tr>
</tbody>
</table>

Figure 2. An extract from the protocol analysis sheet for our detailed segment of study
For each cognitive action, we identified a task index, as described in section 3.1. This denotes whether the action is considered new, continual or revisited [15] in context of the overall collaboration process. For example, the phrase “the north orientation is one of those [axes]” is a new action which shifts attention to the topic of orientation. In this example, all the related actions that follow are considered continual. Together they represent a chunk of actions that revolve around a specific topic of interest or design idea. The move “brings up the other alternative and points at the main masses” represents a revisited action, where one of the team members revisits an action that was performed in an earlier session. In this case, he brought up a design alternative that one of the members had developed previously in order to clarify his idea. We found that this notion of continuity of tasks is very crucial to understanding reflective practice. It presents a way of tracking how collaborators respond and reflect on their own actions and the actions of their counterparts. The fact that these actions can be either continual within the same session or revisited from previous sessions adds yet another dimension.

5.3 Three-dimensional Dependency Graph

Our main observation from the protocol analysis was that all the factors introduced in section 5.2 (cognitive actions, dependency relationships, task indices, collaboration typologies, etc.) contribute to the realization of the term “collective reflection-in-action”. We developed a graphical representation of this term based on our observation, and called it the 3D dependency graph (figure 3).

The graph consists of three main axes (as shown in figure 4): (1) axis of idea exchange as lateral component, which represents the flow of design moves across the timeline; (2) axis of idea development as vertical component, which represents the levels of cognitive actions; and (3) axis of dependency as depth component, which represents the degree of dependency between cognitive actions. Solid lines are used to join every continual group of cognitive actions together. The X, Y and Z component of these lines correspond to the lateral, vertical and depth axes of the graph. The resultant line indicates a dependency relationship between two consecutive cognitive actions based on these components. The graph also distinguishes between the team members to illustrate which actions are performed by which participants. It also shows which collaboration typology (executitional, communicational, visual) is involved along the shared medium.
As the lateral component of the graph involves design moves, it is concerned with the lateral exchange of ideas among team members. It depicts the sequence of idea initiation within continual actions and the “leader-follower” pattern among team members. For example, if member A starts a new topic for discussion, he is considered a leader on that topic. As member B continues discussion, he is considered a follower on that topic. The nature of reflective practice for this topic depends on the mutual effect of this leader-follower pattern and the constructive exchange of ideas, where ideas are developed based on consecutive responses in text-based form. At the same time, each member builds on what he visualizes on the shared desktop medium. This happens not only through abstract external representations, but also through demonstrations and interactions of other members. This complex reflection is unique to collaboration and does not occur in the case of an individual designer.

The vertical component of the graph involves the difference in levels of cognitive actions among team members. This indicates transforming the primitive design ideas that are proposed by a specific member to other levels, thus developing the initial idea. For example, if member A points to a specific mass in the design (physical M-action), then member B discusses its form and orientation (perceptual P-action), and member A changes its form (physical D-action), this fluctuation between high and low levels of cognitive actions enriches the design and develops the idea tackled by both members. This can be common to the practice of individual designers, but is more elaborate here due to the higher frequency and constructive nature of the transformation of ideas in collaboration.

The depth component of the graph involves the degree of dependency between cognitive actions of the team members. We assigned the degree of dependency according to the difference in levels of cognitive actions between the dependent and dependee action for each move (figure 4). For example, if the dependent action for a move is a P-action and the dependee action for it is an L-action, then the difference in levels of cognitive actions is +2. We assigned this value to the depth component of the graph, and considered it as the degree of dependency for that move. This component describes reflective practice yet from another viewpoint, where cognitive actions are described in terms of their dependency on other actions that are different in level and location in the timeline of the process. It follows that this component can track idea development throughout the evolution of the design.

We observed multiple high level representations or “views” of the graph. One can study the graph for example from a collaboration typology view, or task continuity view, or dependency relationship view. Below we discuss a view of the graph that is specific to reflective practice. We call this the internal/external reflection view (figure 5). This view looks at chunks of continual design moves and addresses the contribution of each design team member.
Within each chunk of design moves, reflective practice occurs as a result of multiple processes of both internal reflection and externalization of actions that happen at different levels of interaction. On one level, each node representing a social entity of the collaboration process receives a design move from another social entity that exists in the shared collaboration medium, reflects on it internally, and sends another move back to the medium. On another level, the same node receives a dependee cognitive action, reflects on it internally, and sends back a dependent action. In both processes, external reflection occurs at different levels of cognitive actions due to the accumulative effect of internal reflection and dependency. Added to collaboration typology and task indices, these complex relationships explain how “collective reflection-in-action” is built up for each group of design moves.

6. Discussion and Future Work

In this paper, we discussed the role of reflective practice in the context of remote design collaboration. We represented the process by means of a 3D dependency graph. Through the three main components of this graph (idea exchange, idea development, and dependency), we described how the collaboration process among geographically dispersed team members could be re-interpreted in the context of reflective practice. By analyzing the outcomes of this graph, the role of reflective practice in the collaborative design process can be understood along two main paths. One path involves the collective construction of ideas and design concepts through the continuous process of idea exchange, development and reflection augmented by collaboration. The other path involves studying fixation points along the process that may occur partly due to variance in the level of expertise and background of the participant designers. Detailed analysis of the process should depict how these two paths pertaining to collaboration act towards supporting or aiding the design process.

Such analysis feeds directly into the areas of collaborative problem solving and solution generation. Many aspects could be determined and analyzed by design researchers, such as tracking the evolution of collaborative
design, developing more robust process models for collaborative design environments, identifying potential points of critical design decisions and areas of growth of design ideas in collective contexts, envisioning what-if scenarios for generating design alternatives through understanding complex dependency relationships, identifying points of strength and weakness across communication methods and media, and other issues.

Quantitative analysis of the graph and its relationships will lead to a better understanding of the collaboration process. It will provide tailored information and insight into issues like the percentage of contribution among design participants, continuity of design tasks, the role of collaboration typologies and external representations in the collaborative process. Further work would focus on involving larger design teams. Two specific points of interest are studying expert and novice performance, and studying interdisciplinary groups of designers in action.

7. References


