Coordination in Multi-Organization Creative Design Projects

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Abstract

We are interested in the coordination of design and planning decisions in large, multi-organizational projects and their implications for technology support. These projects are undertaken by goal-driven "virtual organizations", involving companies of different sizes, professional traditions, cultures, as well as geographic location. We have observed several months of planning and review meetings in a multi-national architectural project and have gathered volumes of design and planning documentation in the form of memoranda, faxes, project plans and design drawings. From our observations, we outline the requirements and possible features of useful coordination support.

1. Introduction

We are interested in processes and technology that aid coordination in project-oriented design work. Design involves the regular application of principles and procedures [2] and is therefore amenable to standard forms of tool support, but design is creative. Not only is it impossible to codify the design process, but it would be unwise to try. In large design projects that involve designers from several organizations, some unobtrusive coordination support is necessary. Yet coordination support would seem to require explicit description of the design process.

In this paper, we report a detailed study of coordination in an architecture project involving several independent organizations. Our goal is to develop technology requirements that are grounded in design practice. We start in the next section with the context for our study. We give a narrative summary of a major architectural project involving a leading architectural firm. We then describe our research methodology, which involved the gathering of qualitative project data from JPA [13]. In Section 3, we describe the coordination phenomena that we observed. In doing so, we draw attention to events and factors that do not lend themselves to technological support but which must be taken into account when designing coordination support tools. In Section 4, we discuss the implications of the study for the design of design coordination support, illustrating our general requirements and constraints with a concrete technology scenario. Finally, in Section 5, we discuss the study and its implications.

2. Project Description and Methodology

2.1 The JPA Project

The specific project studied is a large design and construction project covering a city block in Shanghai, China. The design architects are at John Portman and Associates (JPA), a firm well known and respected for its high standards of design and its experience in Asia. The client is a major conglomerate in Korea.

The development consists of four buildings, including an apartment building, a department store, entertainment center and retail galleria. The major building on the site is a 92 story tower, consisting of a set of office space a hotel at the top, with several additional observation deck floors. It will be one of the ten tallest buildings in the world.

A project of this size takes years to plan and negotiate. Alternative design concepts were explored for over a year, before the client agreed to proceed. At the official project initiation, the client and architects agreed on the amount of space to be built, types of the layout of the buildings and their exterior shape, and a general floorplan layout for the four buildings. We started tracking the project with the meeting approving the concept design. Normal architectural contracts break the design process into a series of stages: Concept Design, Schematic Design, Design Development, Contract Documents, Construction Document Administration as defined by the American Institute of Architects. These were agreed upon as the stages to be used within the project. We studied the project for a period of four months, which covered all of Schematic Design and the beginning of Design Development.

JPA was responsible for the initial design and its development through Design Development, which includes detail floorplan and definition of the various mechanical, structural and other systems. A handoff would be made to a Korean architecture and engineering (A&E) firm that would become the construction architects and do the working drawings and supervise construction. JPA would continue responsibility for the facades and lobby details. A Shanghai architectural association was also an associated architect. These were just the main architectural members of the design team.

A highly respected structural engineer was hired as a consultant, JPA also had structural engineers on their staff. A Canadian university consultant was hired to do wind tunnel simulations of the building, to better determine wind loading on the structure. Another respected firm was hired as the mechanical engineers. A curtainwall consultant was hired to deal with the building facades, and just before the concept design was approved, the client hired a large construction management firm, who was to oversee design work and later oversee construction. In addition to this main team, there were a large number of additional consultants, who were hired by either the design or construction architects. These included consultants for transportation and parking, building maintenance, fountains, exterior lighting, department store facility planner, hotel services consultant, etc. We counted at least 24 consultants hired during the project [7].

2.2 Research Methodology

To learn how the project was coordinated, we recorded and collected samples of written communications between the project participants. Over the course of four months, we attended many weekly coordination meetings held at JPA. During these meetings, the architects would meet with the construction management liaison and other consultants. The liaison was responsible for conveying the information and data requests back to the construction management consultants, the Korean architects, and the customer. The meetings would cover numerous items, including open issues, the status of current activities, feedback from design reviews, requests for information needed to finish parts of the design, and identifying design dependencies which were holding up progress.

We also examined many faxes, documents, and email transmissions. The faxes and documents included requests for information, answers to those requests, design reports submitted by consultants, and minutes from the various meetings. All of the data were entered into a computer and coded for content and context using a tool called NUD*IST® (Non-numerical Unstructured Data Indexing and Theory-building by Qualitative Solutions and Research). NUD*IST was primarily used for rapid search and indexing of the material. We analyzed the data, cataloging the different types of requests and obstructions that appeared.

3. Project Observations

We observed problems with the coordination in the project. The majority of these occurred between different project members and were strongly related to the contractual relationships and the working familiarity of the interacting participants. Interactions between team members of the same organization or between organizations with close working relationships tended to have fewer conflicts. Those between team members from different cultural backgrounds or organizational practices had more conflicts. We also observed behaviors in the meetings and communications that seemed to result from the large scale nature of the project. In the following sections, we present our analysis of those elements that either characterized or motivated the interactions and obstacles that we observed.

3.1 Shared Visibility of Certain Work and Responsibilities

During the coordination meetings, we recorded many discussions concerning task allocation. Decisions were recorded into the minutes, which were distributed to other team members. However, the minutes were not treated seriously or considered a source for allocating responsibilities. They were poorly formatted, updated inaccurately, and didn’t distinguish important from unimportant items. In one situation, the architects required the site elevations, which could be obtained from a survey showing the area’s different heights and grades. This meant that a geotechnical consultant was needed to perform the site survey and the responsibility fell to the CM consultants to hire one. Three months later, in spite of added notifications, such as “ASAP,” and date tracking to the action item in the minutes, the geotechnical consultants still had not been contacted. A visible and explicit mechanism for recording, disseminating and tracking information flow responsibilities was lacking.

3.2 Privacy Gradient

While the project needed high level coordination and dependency tracking between tasks, there were clear limits to the degree these internal operations were made visible to other organizations. The purpose of maintaining privacy is to protect some aspect or domain from intrusion or interference. During the project, the construction management consultants wanted all participants to record hours worked. The architects objected to this procedure because that wasn’t how they measured progress. By knowing internal work schedules, it would have been possible for an external organization to "meddle", suggesting changes to the workflow and schedules. This sort of action threatens the autonomy and distorts responsibilities. Thus if information flows between organizations were made explicit, then each organization needs to be able to control what part of their work was visible and what was kept private.

However, some tasks that relied on information gained by others was sometimes made visible. Similarly, some tasks that were ongoing in an organization were made public, including their expected completion, so that the source of information was made visible. The amount of visibility presented seemed to be based on the degree of trust that two organization may have developed over time from working together and on the requirements of the shared task.

3.3 Coordination through Shared Artifacts

Architectural work is coordinated through the regular integration and updating of drawings and their distribution to team members. This is known as a "release drawing set".

All the project members referenced the drawings and their state of completion to communicate progress. The completion milestones, expressed in terms of percentages, 15%, 25%, 50%, referred to the sets of drawings submitted at each stage. These diagrams helped to synchronize discussion. In cases where the design or drawing had ambiguities, the consultants would fax the drawing in question and ask for clarification.

Other artifacts used to coordinate the work included design reports containing technical specifications for materials, a wind tunnel analysis, and written descriptions of the building's different pieces. These were secondary supplements, describing details that couldn't be illustrated or that enhanced the drawings and the design detail.

The nature and scope of this project required all participants to have the same model of the building's appearance and functions. These artifacts created a common language for discussing the project that aided communication [10].

3.4 Tentativeness of Commitment

Architectural design also involves many dependencies and sequencing. The difficulty of later rework encourages designers to make only tentative commitments towards fixing a design until all the variables and issues have been examined. Once the design has been approved and released, it will only change small details unless something significant is discovered, such as a government regulation or a functional flaw.

For example, most of the design concept was created early in the process. Only minor changes were made afterwards to the tower and most were internal. The architects defended the external features vigorously and only permitted slight changes for functional or slight aesthetic improvements.

In addition to these early commitments, any work flow schedule for large architectural projects must be able to constantly adapt to changes. The complexity and numerous variables that affect the design and construction of the building necessitates this flexibility. We observed workflow adjustments throughout the project. A rigid schedule and workflow process would have only produced frustration and impeded the ability of the project members to respond to these types of changes [9].

3.5 Process Knowledge as a Basic Aspect of Professional Expertise

A fundamental aspect of the expertise of JPA was the ability to know how to deal with various kinds of complex design issues. These ranged from how to move a project through the Shanghai inspection process to how to coordinate the various consultants and what specific responsibilities they should have. We witnessed numerous occasions when project members referred to historical cases to illustrate a point or defend a decision.

Currently, procedural knowledge is carried in the heads of senior people, making some of them indispensable. Unfortunately, preserving process knowledge in individuals creates problems in large scale coordination. When a mismatch in processes or a poor decision comes up, the experts have to spend some time educating the less experienced project members. In a worse case situation, effort may be expended towards repairing a problem that could have been solved with prior notification from an expert. It is clear that some form of external process representation that preserves this workflow expertise would greatly aid project coordination.

3.6 Technological and Procedural Heterogeneity

Different organizations use technology differently, have differing levels of technological commitment and sophistication, and have different work procedures. In this project, there were some significant variations in the quality of that technology and the capabilities of each team member to adapt to the needs of the group. These different practices often forced everyone to revert to the lowest common denominator within the project team.

While all the main participants that were producing drawings were CAD drafting proficient, they used different CAD systems. This required time to generate and render the drawings into compatible formats. In spite of the format conversions, they still encountered situations where the recipient could not open the files that had been delivered and resorted to mailing sets of printed drawings. Even with next-day, international, air service, the time and financial cost of such a failure adds up over the course of the project.

Most design projects are not this large, do not involve as many organizations, and do not span continents. However, the project is a harbinger of a trend that is leading, to projects involving several organizations in different places and with different organizational cultures or professional traditions working together as a virtual organization [4]. The inexorability of this trend toward heterogeneity, distribution, virtuality, ephemerality, and diversity of project organizations imposes an essential requirement on any coordination technology to support heterogeneous technologies and ways of working.

3.7 Adaptive Process and Meta-Level Discussions

Significant aspects of the coordination process were the subject of protracted and continuous background negotiation.

Each participant had organized practices and communication protocols for coordinating work and preserving information within their own offices and respective domains of expertise. Unfortunately, this internal efficiency did not extend to coordination across the project.

For example, it took two months after the project start-up meeting for someone to produce procedures for managing information and document flow. The chart that described the document and drawing flow helped to illustrate the contractual responsibilities of each individual but did little more than show that the primaries have to copy each other on any outgoing information and the construction management company would distribute the rest as needed.

In spite of the poor process, participants were able to get the necessary pieces to one another using informal negotiation. Consultants with one degree of contractual responsibility to a primary team member showed the best process connectivity. The architectural team and their mechanical engineering consultants frequently copied each other on the fax transmissions and letters.

Many problems could have been avoided by discussing and approving coordination procedures and processes at the beginning of the project. Instead, the project team had to evolve a standard for coordinating and communicating with one another, requiring some unnecessary expenditure of time and effort.

3.8 Professional Trust

Different organizations with different disciplines and cultures will develop different expectations of work and delivery. While external regulations from international organizations or from local governments standardize some of these expectations, the methods by which the group reaches each goal state can cause contention.

We observed professional differences in measuring the quality of the deliverables. In one instance, the architects were very critical of a set of drawings delivered to them by another consultant. In another, a consultant expressed a dissatisfaction with the percent completeness of a set of deliverables.

When multiple organizations begin working together in a project of this size, their ability and willingness to work together depends strongly on the level of professional trust accorded to one another. Some explicit negotiation and delineation of professional expectations at project initiation may help to aid coordination and the working relationships.

3.9 Face-to-Face Interaction

Architectural design and coordination require face-to-face meetings. These allow participants to understand the design concept more deeply than if the drawings were the only means of communication. These meetings also allowed participants to debate and discuss issues with a greater degree of depth and flexibility than would have been allowed with faxes, phone calls, or email.

We observed that the only means of recording information came from the handwritten notes of all the meeting participants, with each member writing down the issues relevant to their individual work. But many meeting decisions and discussions were never communicated to the rest of the team. An improved recording and issue tracking methodology would have helped to preserve these discussions.

4 Technology Implications

What can we conclude about the requirements for coordination technology in such project organizations? Below, we summarize the requirements for such technology and the constraints that successful deployment must overcome. We then describe a technology scenario to illustrate these requirements and constraints.

4.1 Technology Goals and Constraints

4.1.1 Shared visibility of work and responsibilities

The Shanghai project lacked a visible mechanism for recording, disseminating and tracking information flow responsibilities. Project plans were prepared with standard planning tools, and most participants accessed plans only as paper reports that the construction management company produced (using Primavera®). They circulated Gantt charts at meetings and tabulated team members' responsibilities and deadlines in agendas. Other team members could not access the dependencies from which these plans were derived, and designers saw planning partly as something being done to them rather than a coordination activity in which they participated and which supported them. This leads to the requirement that work plans and responsibilities should be shared.

- *Shared visibility of work plans and responsibilities.* The project plan should be shared. A work plan should be prepared by the team member closest to the performance of the work in question. A standard dependency representation should be used, and milestones and responsibility summaries should be derivable from it.

Standard representations of work fail to show dependencies that are typical of design work. One seldom needs to know that one's task is dependent on another task, only that it is dependent on the provision of specific information. Task-based plans exclude many information dependencies, because most arise from relations arising in a particular design.

- *Incorporation of information dependencies*. It should be possible to record that a task dependent on information from another participant without having to create a dependency on the information-producing task or even to know what it is.
- *On-the-fly recording of dependencies*. Designers should be able to record information dependencies as they work on the design.

4.1.2 Privacy Gradient

Not all parties in a multi-organization project want their work to be visible to the others until well-defined release events. Technology should support a privacy gradient, minimally of two steps (public and private to a specific participant) or possibly reflecting the contractual relationships among participants.

- *Privacy gradient.* Participants should be able to designate as private any unreleased task or information. Any participant may view public information.

4.1.3 Coordination through Shared Artifacts

Architects coordinate mainly by sharing drawings, which are necessarily different from planning documents. Designers often recognize their need for information while designing with a CAD tool.

- *Coordination from CAD models*. It should be possible to trigger coordination actions, such as the recording of an information dependency, notifying others of a change or requesting information, from a CAD model.

Conversely, the coordination model itself should be available while designing.

- *Coordination models as shared artifacts*. Coordination-specific information should be accessible from points in the design artifacts that are represented in the coordination representation. For example, the milestone chart should be accessible from a drawing when any information in the drawing is selected that is dependent on another task.

4.1.4 Tentativeness of Commitment

Design coordination is the coordination of commitments: decisions where to place components and at what orientations, selection of materials, sizing, etc. An unreleased design may contain information on which others depend. Often, an estimate is good enough for them, but they need it immediately.

- *Requesting of tentative information and limited visibility of private information*. A project participant should be able to request private design information. The requestor creates an information dependency and the environment routes the request and any reply.
- *Notification of changes and commitments.* Information provided in response to a request should be flagged. The requestor should be notified if the information is tentative. Whenever it is changed subsequently, or when tentative item is made firm, previous requestors should be notified.

4.1.5 Process Knowledge as a Basic Aspect of Professional Expertise

Most professionals have evolved patterns of professional activity and its coordination that are not necessary to specify formally. Such information comes from experience and is carried in the heads of senior people. JPA sees the capturing of process information and its reuse as a potential business benefit. But events happen fast early in a project and cannot always wait for elaborate planning. Designers are unlikely to articulate hitherto tacit process knowledge without a visible benefit.

- *Process by example*. It should be possible to select fragments of the plan from a previous project and store generalized coordination information as a template for use in future projects. Template generation includes selective generalizion away from specific information.

It is unrealistic to introduce process knowledge support as a purely technological fix. Parallel organizational interventions are also required, the most suitable depending on the firm in question.

4.1.6 Technological and Procedural Heterogeneity

Writers on technology diffusion [16] caution innovators about the factors that encourage or inhibit adoption of new tools. To overcome adoption barriers, technology should be simple, compatible with current ways of working, possible to adopt incrementally and with managed risk, and should have perceived benefit to the adoptees themselves. These points are more important in heterogeneous organizations or projects because what is simple or compatible for one participant may not be for the rest.

- *Simplicity of use*. Elaborate dependency-management plans and prespecification of processes and plans are unlikely to be adopted by virtual organizations in which the participants have little experience working with each other. Much of the recording of dependencies and their tracking should be done on the fly while supporting mainstream design tasks.
- *Compatibility with current ways of working*. Any coordination technology likely to be used by a heterogeneous organization will be based on existing and widely familiar project planning representations. Although these representations do not show information dependencies of the kind we have shown to be important for design coordination, they afford the most familiar starting point for extensions.
- *Incremental adoptability*. It should be possible to adopt a coordination technology as an extension to existing practices. Conversely, more elaborate features of a technology could be introduced gradually.
- *Clearly perceived benefit*. Coordination technology should provide a clear benefit to designers in terms of designing. The following features all serve the design function directly: obtaining information that one needs even if tentative, notification of changes, sharing of coordination information regarding who is responsible for what parts of the design, and support for reminding oneself about coordination implications of a design element .

4.1.7 Adaptive Process and Meta-Level Discussions

Creative design work depends on the appreciation of dependencies between design commitments, not documents. This suggests that most planning and coordination documents and messages should be tied to and wherever possible derived from design artifacts.

- *Adaptive process*. It should be possible to refine dependencies and the process rules on which they are based (for example, who to notify of changes).
- *Meta-level discussions.* It should be possible to annotate dependency networks with process issues in need of discussion. These discussion items should be differentiated from those concerning design elements.

4.1.8 Professional Trust

Professional boundaries do not stop at technical expertise; they also affect ways of working. Architects and engineers typically have different outlooks toward planning and the need for precise reporting of progress. A coordination system based on explicit specification of work items, their duration and resource needs, is unlikely to be useful in most architecture projects. Thus, a coordination system should, as far as possible, not embed values about what constitutes a successful project, and certainly not the assumption that the only measure of success is conformance with a predefined schedule.

4.1.9 Face-to-Face Interaction

Commitments are often made during meetings that are forgotten, not followed up, or followed up unnecessarily. Decisions should be recorded and disseminated.

- *Meeting commitment recording and dissemination*. It should be possible to record issues and their resolution in one or more master lists in lieu of specific meeting minutes. When an issue is resolved, it is removed from the active list. Open should be routed to the appropriate participant in exactly the same way as a request made from a design, and the resolution of an issue should be disseminated to all consumers of the relevant information.
- *Issue tracking*. Simple tracking of issue status should also be possible, such as reporting on how long an issue has remained open, who is waiting for its resolution, and whose tasks are stalled as a result.

4.2 Technology Scenario for Design Coordination

To illustrate the requirements and constraints discussed in the previous section, we now discuss a technology scenario that is based on familiar PERT and Gantt charts. Our goal is not to propose a system in any detail, but rather to illustrate how the requirements of the previous section could be achieved in a system that would be perceived by designers to be simple, compatible with existing practice, easy to experiment with and likely to yield a direct benefit to them. At the same time, the scenario is intended to show how the cultural constraints that we have discussed can be observed .

Figure 1 shows mockups of three screens or windows. Access to information about the project is through a schedule, where a user selects a timeframe. This view shows all milestones within that time frame. All design releases -- a conventional design product consisting of the completed drawings to this point -- are identified on the schedule. This facilitates retrieval of the current and any prior release documentation and thus ties the schedule to the design artifacts with which the designer is familiar.

The privacy gradient is supported by having separate public and private window. A Public Window is available to all team members. It shows the interactions and dependencies with the user's organization for the selected timeframe. A Private Window is available to all members within an organization, for their internal collaboration and

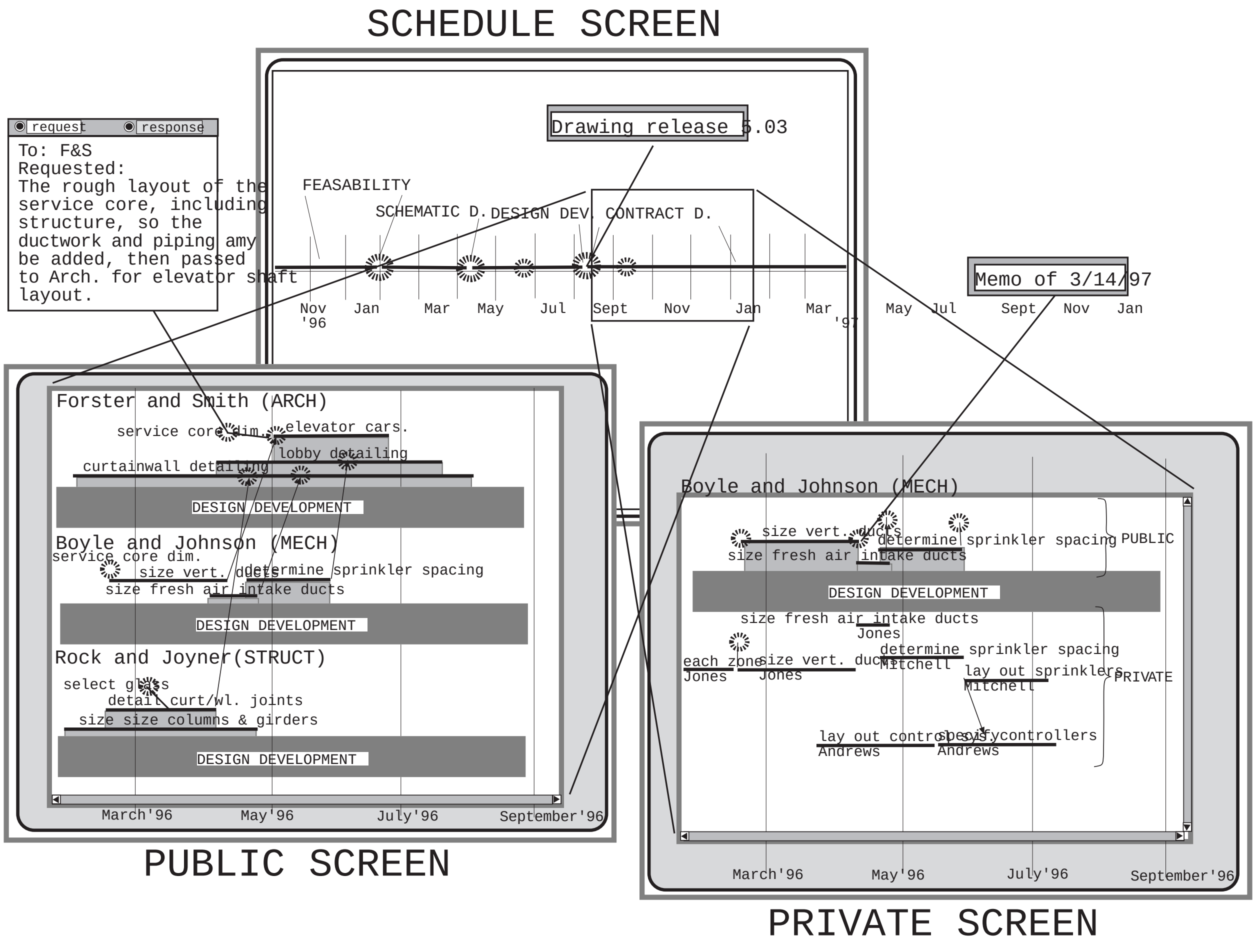

Figure 1: Mockup of screens of technology scenario

coordination. Each organization's Private Window is different.

As work is laid out in the Private Window, inputs or dependencies for the organization's tasks required from external team organizations are identified. When such a dependency is identified, the person or organization must first communicate the request. By default it is made to an organization. It may be by any medium. The form and date of the request is logged. After making the request, the request is posted, making it visible to the sending and receiving organization. By default, the organization makes the request, but if desired, the person needing the information can be identified.

Requests and responses are logged. If the information is in digital format, the information itself is logged so that any future change to it will be announced to the requestor. The Private Window identifies all dependencies with outside groups: both requests to the organization and by the organization.

By querying a past exchange, noted by arrows or a starburst, the document, fax or telephone call that carried the request, and the information responding to the request can be identified. If the exchange was in a digital format, it can be accessed by either the sending or receiving organization.

Users of the Private Window can zoom in to see more detail. Tasks may be broken down. If a task is broken down that has inputs or outputs, then these can be re-allocated to the more detailed tasks. These changes make no automatic change to the Public Window.

If an organization requests information be obtained by a second organization as a conduit to a third organization (for example, one of its subcontractors), this is shown as a small task the second organization is requested to undertake.

Not shown in this scenario is how a request for information could be initiated from a CAD tool, nor how a response to such a request could be attached to the appropriate CAD model as an annotation. Nor have we shown the posting of meta-level process issues. However, further detail could take us beyond the description of a scenario for illustrative purposes into a design proposal. The points that the scenario illustrate are as follows:

- It is possible to provide meaningful and design-relevant coordination support as an extension to familiar coordination and planning representations.

- Information dependencies are the principal objects of design coordination and are manifested as requests for information and notifications about changes.
- The details of a task structure do not have to be known by other participants in a multi-organization project for them to coordinate technically in detail.

5 Discussion and Conclusion

5.1 Related Research

5.1.1 Virtual Organizations

Virtual organizations [4] are those in which boundaries between business functions and rigid processes are less important than flexibility and responsiveness to business needs. Typical of virtual organizations are alliances among companies, their suppliers and customers to produce configurable products rapidly. A property that virtual organizations and multi-organization projects share is the existence of a common objective that coheres several organizations and renders problematic any attempted adherence to their individual standard ways of working.

5.1.2 Coordination Models and Technology

Model-based research studies have proceeded through the construction of formal descriptions of normative coordination practices and the development of tools to support these practices. Such research include process programming in its early [14] and recent [8] manifestations. Such models stem from earlier and parallel (e.g. Joosten [11]) research into workflow automation and business process modeling in which the coordination processes under consideration were activities such as student loan management or hiring decisions. While any coordination technology must necessarily have at its heart some model of the process being coordinated, these models should share two characteristics that are not readily apparent in model-based coordination theories: the basic idea should be very simple and familiar, and the details or elaborations should be purely in the user's language.

5.1.3 Coordination in Other Design Fields

We are not aware of other studies of coordination in architecture. Other areas of design, however, have received some attention, especially software design. Many problems that software projects face are coordination-related. For example, Curtis, Krasner and Iscoe [3] interviewed representatives of software development projects to summarize the categories of problems that such projects encountered. A key result of their study was the importance to successful projects of a single person (a "superdesigner") who could relate the overall picture of the emerging design to detailed design decisions and who therefore served a vital coordination role by managing design dependencies.

There have been few longitudinal studies of system development projects. Potts and Catledge [15] observed one project for several months during its conceptual design phase, and report that many of the problems encountered by that project concerned the lack of convergence on a design vision. These were less coordination problems than they were conceptual misunderstandings of alternative designs and their consequences, although like coordination problems they did involve the consolidation and management of multiple viewpoints. Accordingly, Potts and Catledge [15] conclude that the most valuable interventions in such projects are likely to be low-tech procedures, including the standardized recording of open issues during design meetings.

5.1.4 Empirical Research on Architecture

There have been only a few serious attempts to monitor and study large scale design processes. While there has been a large number of protocol studies that address how a single design or small group manages design within a short time period (a few hours) [5,6], larger scale studies have been only a few. An early overall study was reported by Krauss and Myer [12]. Akin reviews the literature as of the middle 1980s [1]. Recently, further protocol studies of design activity have been undertaken by Cross et al [2].

5.2 Conclusions

Design coordination is a challenging problem for any project, but for large, heterogeneous projects of the kind exemplified by the Shanghai project, it is particularly so. Several factors affected the quality and timeliness of coordination in this project. Participants occasionally exhibited misunderstandings about who was responsible for what task and, more importantly, who was depending on information that they were responsible for providing. These information dependencies cut across the formal structure of the project. There are cultural and professional reasons for keeping some information about a design under wraps until the organization responsible for it is confident that it is ready for release. This can lead to other project participants relying on partial or tentative information. This information was nearly always consumed in the production of another design artifact: an object's dimensions is reflected in the design of a dependent space; an analysis from the energy analysis results in the selection of a building material. Messages requesting such information and replies to such requests were generally free-form faxes, however, and were not therefore obviously tied to the part of the design in question. The process followed by project participants to coordinate their work was not pre-specified and was itself the subject of much discussion in writing and at meetings. Finally, different participants had differing expectations about the need for formality in the coordination process, differences that at least in part reflected different practices among the design and construction professions.

Any large project is unique, and so it is risky to generalize from one project to all projects with a similar, heterogeneous make-up. Indeed, with qualitatively rich case studies such as this the goal is not to treat the data as average and to generalize to all projects, but rather to explore its extrema and to argue what there implications are for the general case. Several factors made the Shanghai project especially notable. Most obviously, the project is large and visible: the tower will be among the tallest ten buildings in the world when complete. It is an international venture, involving participants on two continents. There are language differences and differences of national culture among the participants. JPA is in the vanguard of adoption of CAD technology among architecture firms, and yet there is little support in available commercial tools for coordination. Given that the other project participants were far less committed to CAD technology, this led to the universal use of general-purpose office technology for most communication. We take this heterogeneity to be intrinsic to situations of technological change and not a temporary blip that will disappear when the less technologically committed organizations catch up.

We conclude that design coordination is an intractable problem that can be facilitated but not automated. Coordination technology is necessarily intertwined with the management of cultural and professional differences among project participants. As our technology scenario shows, however, coordination support is possible that respects these social factors and which goes beyond traditional project scheduling tools.

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