Coordinating virtual building design teams

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Abstract

Most research in design project management support systems treats the subject as an isolated objective problem. The goals to be met are defined in terms of a supposed universal view of the project, and now outside concerns are taken into account. While such approaches, including project simulation, may yield excellent results, they ignore what, for many projects, are the real difficulties. Design projects are not isolated. All participants have other obligations that compete with the given project for attention and resources. The various participants in the design process have different goals. For these reasons it is proposed that design project management can be best facilitated by tools which assist the participating actors to share suitable management information in order to make better co-ordination possible, while allowing the resource balancing between projects to occur in private. Such a tool represents the design project management task as a negotiation task that spans both projects and firms; the management of one project is the management of all.

The model of design collaboration upon which the ***Design Coordination System*** *(DeCo) is built was developed from 1) a heuristic case study used to gain insight into the ways in which designers co-ordinate their efforts, and 2) the application of the theory of the social contract as developed by John Rawls to the problem of design project management. The key innovation in the DeCo system is the shaping of the project management system around existing practices of collaborative project design management and planning. DeCo takes advantage of how designers already co-ordinate their work with each other and resolve disputes over deadlines and time lines. The advantage of DeCo is that it formalises these existing practices in order to accommodate both the increasing co-ordination burden and the difficulties brought about by the internationalisation of design practice.*

DeCo, the design project management system proposed here, provides a representation, a communications protocol, and a game theoretical decision structure. The combination of these three units provides users with the ability to exchange structured pictures of the project as seen from the points of view of

individual actors. Further, it suggests a mechanism based on a specific principle of fairness for arriving at mutually acceptable project plans.
The DeCo system permits the users freedom to manage their design processes as they will, while providing a basic compatibility between practices of design team members which supports their collaborative efforts to co-ordinate their design work.

Keywords

Design collaboration, Design coordination, Project management

1. Introduction

The profession of architecture and the production of building designs have undergone dramatic changes in this century. Perhaps the single most important change in the profession, however, is the degree to which the coordination of design activities has become a central and essential activity of building designers. The design of buildings is the result of an intense collaboration between many ***actors*****:** architects, engineers, the client, financiers, inspectors and others. Architects and their partners have found it necessary to devote increasing amounts of time to coordinating their activities. While legal and contractual regulations do address design coordination, they do not, in fact, determine the behaviour of the actors. The informal relationships and conventions are much more important in determining the behaviour of designers. Thus the means of design coordination have remained mainly intuitive and informal. The research presented here is based on the proposal that the formalisation of the coordination process and the introduction of more explicit project planning techniques will improve the quality of coordination, while at the same time reducing the time required for it.
It is essential to understand that design actors are autonomous. Actors have individual goals and criteria for success that may be in conflict, and are independent of any central authority. Actors also have conflicting commitments to other projects. The assignment of resources to one project most therefore be balanced by considerations having nothing to do with that project. Thus each actor has both private and public interests in shaping the arrangements they come to with their collaborators. I will compare collaborative design team is compared to a 'society' engaged in a particular practice: collaborative building design. I will then use the Social Contract theory of John Rawls to show how such autonomous actors will bargain with each other. It will then become clear that it is in the individual interests of the actors to ensure the success of the other actors as well. This provides a clear model of the way in which collaboration arises out of a collection of heterogeneous actors.
The ***Design Coordination System*** (DeCo) proposed here is a tool for achieving this more explicit and effective form of design coordination. The DeCo system is composed of two elements: the ***collaborative design project network***

(CDPN) and a series of coordination games (one of which is described below). The DeCo system is immediately applicable as a set of procedures for improved design collaboration; it is also a computational theory for a system of software agents that will act on behalf of the actors to facilitate the coordination of their design activities.

2. Design Collaboration

2.1. Case study

The Case

The design of the tool is based on the results of a case study. The case chosen was the design of a public library in the Netherlands. The architectural firm is an internationally recognised firm, well known for ambitions to both design excellence and attention to the client's business imperatives. The architects refuse to work with a project manager between themselves and the client, preferring both direct contact with the client and a more active role in managing the design process. The other design firms in the project, structural engineers, services engineers, and technical advisors, are all known for their competency and their willingness to entertain the ideas of the architects they work with. A more complete description of the case study and its results is given in my dissertation (Heintz 1999).

Consensus decision making

The first of the observations made was that the project team made collective decisions through consensus rather than through the decision of a 'chief' designer. In the minutes of design meetings, decisions were always represented as conclusions of the whole, and individual voices were suppressed. This indicates that the importance of the individual person who may have been the active agent behind a decision was not of significance to the design team. Decisions were made by consensus and adopted as the unanimous opinion of the design team members.

In the context of such level social structures it is important not to impose artificial hierarchical structures. The fact that the existing contractual hierarchy is never mentioned or invoked is evidence that the informal practice culture of collaborative building design is at odds with the official contractual structures. It is therefore important that the design of a tool intended to support collaboration should facilitate the informal practices rather than the formal organisational structure.

Planning at the extremes

The second observation is that designers are poor planners (of their own work that is). The planning visible in the case study occurred at the two extremes of scale without any connection between them. Either dates were given for the completion of standard ‘phases’ of design (sketch design, concept design, design development, working drawings), or plans were made to perform small tasks such as making single telephone calls. There was very little planning or coodination of activities between these two scales. Fires were put out, but the crucial middle level planning which could have permitted the anticipation and control of problems was not observed.

Moral persuasion

Perhaps the most interesting observation was than when a member of the design team failed to deliver promised information or documents on time, the only tool used to attempt to hasten the delivery was moral persuasion. Neither penalty fees nor litigation were threatened despite considerable delays in the performance of one actor. The team members made clear their dependence on the work of the slower actor, highlighting the fact that without his contribution they too would fail to live up to their promises. The rhetorical strategies used made appeals to professionalism, pride and a sense of obligation. In essence, the actors attempted to remind their slower collaborator of his moral obligations.

2.2. Collaboration and Coordination

Collaboration

Collaborative building design (CBD) as a ***shared collaborative activity*** (Bratman 1992). As such, the actors in CBD are in constant communication, and their activities depend on the results of the activities of their collaborators. Further, the actors are modelled as autonomous and competitive – they seek to realise their own goals and have no *altruistic* interest in the goals of other actors. The only interest actors have in each other’s success is that their tasks and goals are mutually interdependent. Their collaboration is based solely on enlightened self-interest.

In particular, architects and services engineers have particular ways of accomplishing their goals, ‘discrete working practices’, and need a degree of autonomy from others (Harper and Carter 1994). Design collaboration is less about doing design with other people or firms, and more about dividing the design task into subtasks to be undertaken by the different actors, within a structured set of precedent and dependency relationships. “Collaboration consist[s] of a subtle arrangement whereby two groups of people negotiated about their shared work.” “... organis[ing] themselves to ‘solve’ the ‘problem’ of getting the work done.” (Harper and Carter 1994). All this requires coordination.

Design coordination

Thomas Malone and Kevin Crowston (Malone and Crowston 1994) have given the following widely accepted definition of coordination:

“Coordination is managing dependencies between activities.”

To coordinate its actions with those of other actors, an actor must have a

representation of both its one activities and those of the others.
CBD team meetings between these groups were less about sharing knowledge, than about obtaining the upper hand over the other group, both in terms of specific design decisions and about the organisation of the work to be done (Harper and Carter 1994). Actors will often argue about the precedent order of design tasks -- who should complete their work first, the engineers or the architects?
This new model will make use of game theory as a structure that allows the modelling of the outcomes likely to arise from the different combinations of actions the actors may choose from. The principle advantage of this approach is that it permits a decentralised model to be constructed. Such a decentralised approach better models the social behaviour of building design team members, who are, after all, tied together only by bonds of mutual interest, and not through any central authority.
In any decision-making setting where there are multiple actors whose decisions will impact on the outcome of the decisions of others the accepted technique for modelling the decision making process is game theory. The advantage of using game theory as a model of coordination in CBD is only increased by the lack of coercive powers among the actors. In making coordination decisions, actors must always realise that without the active cooperation of their partners, or in game theory terms 'opponents', their own goals cannot be realised. In order to enlist the cooperation of the other agents to realise their individual goals, each agent must be prepared to accommodate the needs of the other agents.
Game theory offers a uniquely well-suited tool for the study of negotiation methods, and in particular for methods where there is little or no overall control. Game theory has a long prehistory, but is normally said to begin with the work of John von Neumann and Oscar Morgenstern (Von Neumann and Morgenstern 1944). It arose out of an interest in the economic behaviour of individuals who take into account the actions of other individuals around them.

3. DeCo System: Collaborative Design Project Networks

3.1. DeCo Architecture

The CDPN permits actors in the design process to define their participation in the project as they see it and then knits these ***partial plans*** together to show how the work must be coordinated. Individual actors may coordinate the partial plans of several projects to achieve improved resource balancing without fear that their internal business decisions will be subject to outside scrutiny.
The second element of the DeCo system, the coordination games, are proposed to facilitate the resolution conflicts, which may emerge in the formation of the project network. An example is proposed: an N-person scheduling game. This tool aids in reaching a ***feasible*** project plan, and an ***acceptable*** schedule.
3.2. Collaborative design project network
The CDPN is composed of tasks, infotems, and the links between them. Each actor builds its own partial plan independently, using whatever planning tools it

desires. The partial plans are shown between the horizontal lines. The circles represent infotems. Those infotems that are exported to other actors lie on the boundaries between actors.

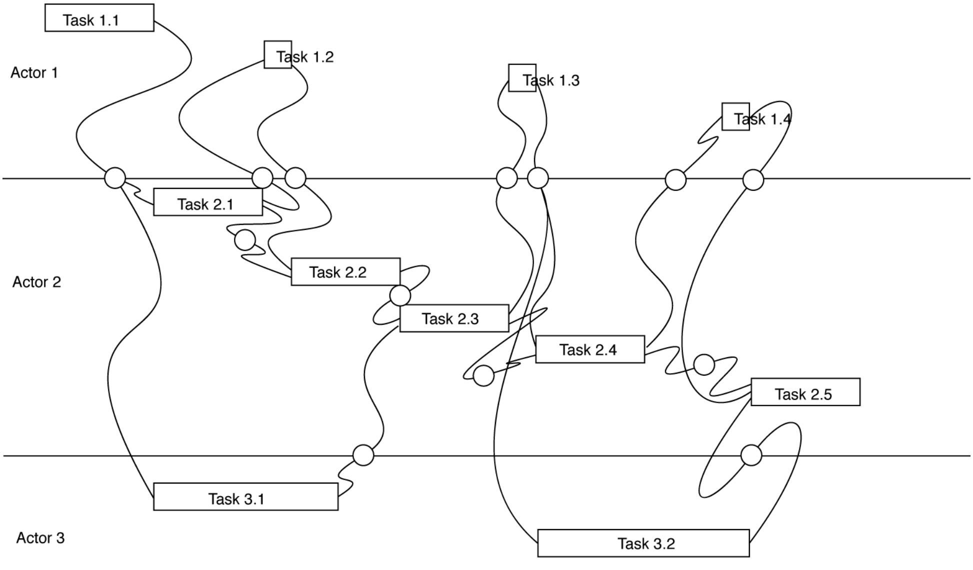

Figure 1: A CDPN for a small project.

The use of the conventions of Gantt charts makes the CDPN easily legible. The horizontal dimension represents time. This dimension may or may not be scaled according to the preference of the user. The ADePT system uses a similar network representation (Austin, Baldwin et al. 1996; Baldwin, Austin et al. 1998), but, where as the diagrams generated by the ADePT system represent the output of a simulated design process, CDPN's are constructed by concatenating the partial plans of the individual actors. These partial plans remain under the control of the actors. CDPN's permit a decomposition of tasks and documents, which allows information produced before the completion of the entire task to be identified and delivered to waiting tasks more quickly.

3.2. Infotems

An infotem is any specifiable item of information. It has no specific scale, and can be a document or a message (thus the neologism). Infotems may be a variety of types of information, including but not limited to: drawings, specifications, product information, site information, programmatic information, approvals, and comments and feedback. Like tasks, infotems may be decomposed. The infotems link tasks, and their existence makes it possible to represent many types of task dependencies as structural features of the CDPN.

3.3. Partial and global plans

To use the DeCo system, actors begin by constructing lists of tasks they intended to undertake and infotems they would be generating. These would be assembled in ***a partial project plan***. The actors would then assign durations to their tasks as they saw fit. These partial plans would then be exchanged. Each actor constructs a CDPN by locating coincident infotems and linking the partial plans together. Any infotems not linked to both producing and consuming tasks are be flagged as representing a missing link in the design process requiring further discussion. The sharing of partial plans and the construction of global plans is now also done during design team meetings. The DeCo system would allow junior staff to accomplish this in advance of the meeting.

The construction of the CDPN reflects a more realistic approach to collaborative project planning. All actors must agree to come to an agreement over a project plan, and must commit themselves to the plans developed, and not merely be handed a global schedule developed by another actor, and told 'this is what you will do'. Having completed the CDPN, there remains, however, the development of an acceptable schedule.

4. DeCo System: Scheduling Game

4.1. Fairness in design scheduling

The principle issue in designing a schedule for a collaborative design project is fairness. A schedule is a compromise between the desire to allow an adequate amount of time for the completion of each task in its proper order, and the desire to complete the design quickly. The need for fairness arises from the need to obtain commitment to the schedule (Heintz 2000).

We can begin to discuss fairness by asking what would be an ideal schedule for a design project? Ideally, actors will have "enough" time to complete their tasks*****. If these are the conditions are met in the schedule, then the project is planned to occur under ideal conditions. If these conditions are met during the course of the project, the project is (was) carried out under ideal conditions. However, there is generally not enough time, so some compromises must be made. Therefore, one may think of scheduling as a bargaining game. However, unlike financial bargaining, it takes time to keep a schedule, and there are no ways to enforce a bargain once it is agreed upon.

A schedule should also be reliable. Clients are often more interested in obtaining a reliable forecast of the completion date of the project than they are in attempting to meet an overly ambitious completion date (Coxe 1987). Designers too appreciate the timely arrival of the inputs required for the completion of their tasks.

The decision mechanism proposed here takes the form of a game. The actors in CBD have no means of coercing each other to behave in desired ways. The actors are not even able to see all the factors (payoffs) that lead their partners to make coordination decisions.

*** Although one must always beware of Parkinson's law: Work expands to fill the time allotted.**

However, in settings where the actors belong to different organizations and where they must balance their interests in one project against their interests in other projects, conventional decision making processes cannot be applied. In these settings the decision making process of each actor must take into account that there are other actors who are also making decisions and whose decisions will effect the outcome. Game theory was developed for decision making in precisely these sorts of environments.

“A game is a strategic interaction that includes the constraints on the actions that the players can take and the players interests, but does not specify the actions that the players do task.” (Osborne and Rubinstein 1994).

4.2. The scheduling game

The game proposed here is modelled closely on the game John Rawls proposes in his book ***A Theory of Justice*** (Rawls 1971), but has two important differences. The first is that, following Ken Binmore’s heretical formulation (Binmore 1994; Binmore 1998); the original (starting) position will not be assumed to be a hypothetical position but to be the status quo. At the start of the project, the status quo will be taken to be no contract. Later in the project, the status quo will be take to be the existing schedule incorporating any delays with no re-planning. At any time, an actor may opt to a return to this position, taking all other actors with it. Since, however, this position will be substantially sub-optimal, it seems that there will be considerable room for the actors to move forward into. Second, there is no veil of ignorance, at least not as Rawls describes it. The actors on CBD all know exactly what role they will have in the society they form. What they do not know is the future course of events that will lead to the profit or loss resulting from inefficiencies in the design process.

This is an extensive game. That is players do not make a decision hat captures the entire game, rather they make individual moves towards an outcome. Extensive games can be represented as decision trees (Osborne and Rubinstein 1994). These trees can be interpreted as the paths which players may make through a space of possibilities, each path representing a possible play of the game. However, there the Scheduling game is not finite, and cannot be completely analyzed. Further multi-player game theory does not reliably provide solutions to large games (Binmore 1994). It is therefore necessary that actors attempt to use informal reasoning in order to arrive at a solution.

4.3. Moving in the game

Starting with the CDPN and the task durations provided by the individual actors, the actors take turns proposing a project schedule, and the others declare if they find it acceptable or not. A schedule is only accepted if everyone is in accord.

move number	move action
1	The first player makes a proposal.
2	It is rejected.
3	Next player learns from previous proposals and makes a new one.
4	Next player learns from previous proposals and makes a new one.
5	The proposal is either accepted or rejected.
6	If rejected, repeat steps 3-5.
7	If accepted, adopt schedule.

Table 1: Moves in the Scheduling Game

The first actor would begin by making an assumption about how the burden of bringing the project duration within the deadline should be distributed among the actors. He would then design a schedule which achieves the required reduction of project duration by distributing the reductions among his own tasks in the way he sees best, and among the tasks of the others with only the constraint being that the distribution does indeed achieve the required reduction. Since the payoff functions associated with the other projects each actors will have are unknown, only the most general assumptions can be made, that each actors will prefer as little variation from their first proposal as possible. However, each actor, in making a proposal is offering information about which compromises it finds most acceptable. The mechanism works because the actors can learn from each other's proposals how to shape mutually acceptable compromises.

This first proposal would most likely be refused by one or more of the other actors. However, in shaping his proposal the next actor would take into account how the first had distributed the reductions in task duration among his tasks. Thus, while not any more likely to be acceptable to the other actors, the 2nd actor's proposal should be more acceptable to the first actor than an arbitrary set of reductions in task duration. Following this process, the proposed schedules will continue to converge until a schedule deemed satisfactory by all actors is reached.

The game procedure described mitigates the advantages actors seek when beginning with a so-called bargaining position. Such a strategy will only increase the cost of arriving at an acceptable schedule without significantly changing the result. Acceptability is judged by the actors on the basis of their true criteria and not on the basis of publicly announced criteria or on how far they have managed to get another actor to deviate from its initial proposition.

5. DeCo in Action

5.1. DeCo system implementation

The DeCo system described above was developed as a concept for a software agent system. However, a guiding principle was the notion that the model upon which the DeCo system is based, and the procedures that it incorporates are applicable by people without the use of software agents. Thus, there are several procedures and techniques that are directly applicable to the management of the building design process. Among these are the CDPN representation and the scheduling game.
The use of the CDPN representation, while not as yet incorporated into any existing project management software, can be applied today to the paper based, rather than computer based, management of projects.

The DeCo system is:

1. A set of representational conventions and protocols***** which can be used to build partial and global plans of CBD projects,
2. A set of game theoretic procedures for resolving coordination conflicts in CBD,
3. A design for a system of software agents.

As a system of software agents, Design Coordination system is a tool that will assist and support architects and their partners in planning and coordinating architectural design projects. DeCo is a system of independent software agents who use a specific protocol to communicate between each other in order to accomplish the task of planning and coordinating a concurrent architecture project. Each agent represents its corresponding actor (usually a firm, company, organisation, department of government, etc.) in a round table planning process. The agents conduct automated project scheduling negotiations for the actors in an architectural design project. These schedules are then used (subject to confirmation by the principals associated with each actor) in managing the progress in the design project. As the actors are free to instruct their agents in how to conduct themselves the system as a whole permits a high degree of autonomy and self-interest among the actors.
DeCo will arrive at preliminary schedules and plans that the actors will be free to re-negotiate among themselves. DeCo is not intended to replace human interaction in face-to-face meetings, but to provide the maximum *mutual* preparation possible for such negotiations.

*** There are two common definitions of protocol. In some contexts protocols are conventions with which to represent observed behavior, in this text the term is used to designate normative rules constraining actors will or should behave.**

5.2. Rolling planning

The DeCo system makes use of rolling planning, that is a planning practice in which the fineness of grain of the plan decreases with distance into the future. The initial partial plans would be very generalised. Perhaps not much more detailed than the Plan of Work, but with a few smaller tasks to be carried out in the immediate future. However, in response to the construction of the global plan, more detailed partial plans would begin to emerge. As the project advanced, and design decisions were made, the nature of the design tasks to be accomplished would become clearer. This time dependence of the grain of planning is a natural feature of building design processes. The design process itself is dependent on the design decisions made during its course (Donker 1999). Thus, unless one wants to build the universal design model that Austin, Baldwin et al team hope to establish the design cannot be planned in complete detail from the outset.

5.3. Finer grain planning

Some scheduling efficiencies can be realised by making information available between formally defined project phases. This is indeed common practice, but it is rarely planned for. By formally describing the infotems required for the initiation of each task, the actors have informed each other of precisely what is needed. The dependence on contract documents or preconceptions of how one's partners do their work blinds the actors to the opportunity to build synergistically upon each other. By learning precisely the nature of the inputs required by one's partners one can liberate information already generated but not yet reported to the team.

6. Conclusions

The DeCo system continues to be developed, and trials of aspects of the tool in practical design situations are being prepared. The use of game theory as a basis for the scheduling process provides support for the belief that the tool will be effective in practice (Heintz 1999). Similarly, the use of familiar conventions drawn from Gantt and CPM charts, will ensure that the project schedules will be useable by the intended audience: architects, engineers and their clients. The contentious question is whether the effort to make the scheduling process, and therefore the process of continuous re-scheduling during the course of the project, explicit will be repaid by a more successful project outcome, typically to be measured in terms of the total project duration and in invested labour. One might also hope to see improved building quality as an outcome of a better coordinated design process. These benefits cannot be measured easily, and certainly cannot be predicted with confidence without field testing the DeCo system. It is hoped that there will be an opportunity to report the results of such field tests in the near future.

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