Emerging Technology to Model Dynamic Knowledge Creation and Flow among Construction Industry Stakeholders during the Critical Feasibility-Entitlements Phase

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Abstract

Managing facility development is challenging for several reasons. For instance, the developer's organizational structure differs over multiple workflow processes, and changes over different development phases. As another instance, individuals and organizations become affiliated on a temporary—or even virtual—basis, yet they must learn quickly how to work together as a coherent team. Managing the development of affordable housing is even more challenging, for financing regulatory requirements add burden to an already complex management task, and little organizational learning—through the flow of knowledge—appears to manifest itself from one challenging project to the next. Supporting this challenging management and learning task motivates us to employ agent-based simulation technology to model and analyze the development process—before the project begins—and thereby seek to improve project performance through enhanced owner-design-construction coordination. Further, such new technology can support the dynamic process of knowledge creation and flow among temporary stakeholders, who do not belong to the project sponsor's organization, but whose combined decisions during the entitlements-feasibility phase impact the facility's overall implementation time and cost. We model the pre-construction activities of an affordable housing project in California, as a particularly challenging case, to illustrate how an agent-based organization simulation tool can be used to analyze dynamic knowledge creation and flow. Despite the challenge associated with modeling the affordable housing case, however, the technology and approach articulated in the paper remain quite general, and should also apply well to more-conventional construction projects and organizations, across all project phases.

Introduction

There is no such thing as a typical facility development project. No two projects are ever the same. This makes management of facility development challenging for several reasons. For instance, the developer's organizational structure differs over multiple workflow processes, and changes over different development phases; just compare the work activities, skills and interactions of owners, managers, architects and engineers during early stages of the facility development life cycle with those of managers and various construction subcontractors later on. As another instance, individuals and organizations become affiliated on a temporary—or even virtual—basis, yet they must learn quickly how to work together as a coherent team. Managing the development of affordable housing is even more challenging, for financing regulatory requirements add burden to an already complex management task, and little organizational learning—through the flow of knowledge—appears to manifest itself from one challenging project to the next. The need to manage exceptions throughout the development of a facility life cycle requires a modeling tool that can support knowledge creation and flow among the stakeholders.

Developers divide the development life cycle process into five phases: *Feasibility, Entitlements, Building Permit, Construction,* and *Property Management Phases* (Ibrahim 2001). The most critical is during the integrated feasibility-entitlements phase. This early phase starts when a parcel of land becomes available for consideration, and continues until the development proposal receives its entitlements. Currently, the essential knowledge often remains clumped within specific stakeholders and organizations, as explicit mechanisms such as design specifications and building documents have yet to be developed in this early phase. Thus, the challenges of managing facility development also include organizational learning, which is not understood well in the construction domain. Moreover, people are rationally bounded (March and Simon 1958) and limited in their individual and collective abilities to share such knowledge through current means, such as conversations, documents, diagrams, and others.

Such dearth of understanding is particularly acute in situations where individuals and organizations become affiliated on a temporary basis—which is the norm for facility development projects—and this contributes toward the lack of IT support among construction industry stakeholders. Supporting this challenging management and learning task motivates us to employ agent-based simulation technology to model and analyze the development process—before the project begins—and thereby seek to improve project performance through enhanced owner-design-construction coordination. We model the pre-construction activities of an affordable housing project in California, as a particularly challenging case, to illustrate how an agent-based simulation tool can be used to analyze dynamic knowledge creation and flow.

This paper describes and reports the results of our case study modeling experience. The following section explains facility development's equivocal environment and organizational climate. We then detail how knowledge flows are modeled for an affordable housing project. Results and analyses of organizational simulations are presented subsequently, which we follow with discussion of the case to highlight the key points and implications of the results, including issues and areas for future research.

Background

There is evidence that knowledge on how to enhance performance does not transfer readily within firms (Pfeffer and Sutton 1999). In addition, the success of most interventions designed to improve organizational performance depends largely on implementing what is already known, rather than inventing previously unknown ways of doing things (ibid.). As such, understanding the operating environment of the real estate development may pave the way for better and appropriate technology implementation during the feasibility-entitlements phase. Based on data collected from one of the largest affordable housing developers in the San Francisco Bay Area, we find the real estate development process displays two strong characteristics. First, the process activities (i.e., workflows) are generally sequential yet highly interdependent. Second, stakeholders and participants in the process reveal a dynamic organizational structure that varies across different development life cycle phases. We posit that the dynamic nature of the developer's organizational structure can cause knowledge flow breakdown despite the sequential work processes involved. We also posit that the high interdependency of tasks in concurrent workflow processes compound such breakdown.

Consider first the point that real estate development workflows are generally sequential yet highly interdependent. Contingency factors describe the operating environment as one of having high complexity, high uncertainty, and high equivocality (Burton and Obel 2003). It has high complexity because, despite having a functional organizational configuration, the facility development organization also reflects a strong matrix configuration. For example, it is common for a single project manager to handle several development projects concurrently. There are also many interdependencies between workflow processes in a development project. For example, the development team needs to work with its finance and property management teams internally, while working with external design consultants and regulatory agencies to complete the development project. A development project has high uncertainty because, despite having a general sequential development activity schedule, each development project is unique. Project Managers cannot accurately predetermine which workflow path they need to concentrate on at any given time. For example, developers cannot be sure which program will fund a particular development project, and each funding program has different requirements and application procedures. The environment has high equivocality, because there exist multiple and conflicting interpretations, confusion, and lack of understanding among the stakeholders. These are apparent especially when dealing with regulatory agencies, city officials, and the public.

Consider next the point that stakeholders and participants in real estate development join together to form a dynamic organizational structure. The specific structure of such dynamic organization varies across different phases of the development life cycle. First, there are different teams working over different workflow processes. Second, there are different teams working over the same functional workflow process that transgresses over several development life cycle phases. In addition, it relies more on external environmental information and is responsive to them in order to determine the direction of how developers will proceed. Developers commonly have multiple functional departments where project managers will lead the interdisciplinary or interdepartmental teams for each development project.

The purpose of our modeling exercise is to build a model that represents the high uncertainty, high equivocality, and high complexity of the real estate development operating environment. We require such a model before we can proceed with our research on knowledge-flow among the stakeholders involved during early development phase. We expect our model to reflect the unforeseen exceptions that would cause developers to redirect their resources and attention during the development process.

Modeling Knowledge-Flow In Equivocal Environments

Carley and Lin indicate that the environment poses a set of problems for the organization's performance, and research has yet to agree as to what the salient environment features are (Carley and Lin 1997). Their study shows that task environment characteristics have more effect on performance than information distortion and the organization design. In this section we detail how we model the real estate development process and environment. We follow Thomsen et al. to validate the model, both by analyzing a toy problem and conducting intellective experiments (Thomsen et al. 1998).

Organizational behavior assumptions. We set up the workflow and organizational structure dynamic characteristics in accordance with Burton's and Obel's *Contigency Theory* (Burton and Obel 2003). We base the high level organizational behaviors of the real estate development organization on the following assumptions. The development life cycle reflects the need for multiple bosses from different functional departments--internal and external--to come together in a multi-disciplinary project team in order to enable the organization to work more efficiently. Such groupings are *matrix* organizations (ibid., Davis and Lawrence 1977). We divide key responsible stakeholders into three high-level matrix groups: City Matrix, Building Matrix, and Owner Matrix. City Matrix consolidates public and financing support from the local jurisdictions. The Building Matrix consolidates the planning, design, and technical aspects to ensure compliance to build, while the Owner Matrix coordinates the Owner's activities pertaining to the development proposal. The limitation to Davis's and Lawrence's matrix organizational structure theory is that the organizational structure is fixed throughout the project's duration. In order to model the dynamic knowledge-flow during pre-construction phases, we must incorporate the inter-changeable aspect of the matrices over the development life cycle processes and phases.

The Contingency Theory states that a high complexity, high uncertainty, and high equivocality organization tends to have low formalization, low organizational complexity, and low centralization (Burton and Obel 2003). There is also tendency of organizational managers to get overloaded. In such dynamic operating environments, Burton and Obel propose *Ad Hoc* or *Matrix* configurations as the best organizational structures to manage the workflow processes. It conforms to the preceding assumption. Their Contingency Theory states that a d*evelopmental* climate organization, such as the real estate development organization, should be medium in complexity, low in vertical differentiation and formalization, and low/medium in centralization. Its best coordination methods are via planning, integrators, meetings, use of rich media, while its best motivation is to provide result-based incentives.

Knowledge-flow assumptions. Rapid knowledge conversion processes between tacit and explicit knowledge between individuals, organizations, and combined organizations cause the dynamic knowledge-flow so evident during the feasibility and entitlements phases. Tacit knowledge (Polanyi 1967; Nonaka 1994) is deeply rooted in action, commitment, and involvement in a specific context, while explicit knowledge refers to knowledge that is transmittable in formal, systematic language. There is an abundance of explicit knowledge in the real estate context such as published general plans and funding program applications. There is an equal abundance of tacit knowledge within the same context. Developers obtain tacit knowledge by socializing and internalizing the actions and sayings of the local elected officials, and the public who supports them. Nissen's *Vertical and Horizontal Processes Model* characterizes the powerful interaction between the flow of work and the flow of knowledge in an enterprise (Nissen 2002). The horizontal sequential process represents the flow of work, and the vertical process represents the flow of knowledge through time and space. However, Nissen's dynamic knowledge-flow model stops at conveying the interdependencies of information processing requirements between some tasks in different workflow processes. It assumes that vertical knowledge flow only occurs at the end of a horizontal process, and is independent of other workflow processes.

Nonaka's dynamic theory of organizational knowledge creation posits that knowledge-flow processes--i.e. transformation of tacit knowledge to explicit knowledge--occur through socialization, internalization, externalization, and combination within the individuals of the development team with others, internal and external, of the organization (Nonaka 1994). Although the integration of this concept is yet to be validated, we can explicitly bring it out in future studies, because Nissen builds his model on Nonaka's dynamic knowledge-flow model theory at task level in a workflow process (Nissen 2002). We will further research this notion upon the success of modeling the real estate development environment.

Framework For Tracking Dynamic Knowledge-Flow

A Knowledge Group Set (KGS) is a group of processes that requires a team or several matrix teams to accomplish a common goal within a time frame. Each process is independent, but contains several interdependent tasks from another concurrent process within the same time frame. Referring to Figure 1, we build a KGS unit model in three steps: Nissen's horizontal workflow process is represented by arranging several sequential tasks (e.g., T1 to T5) for a Workflow Process 1; it culminates with a goal (e.g., G1) at the end of the horizontal sequence; and finally, the knowledge goal of each horizontal workflow flows vertically to the next time frame as other workflow processes continue to their next time frames.

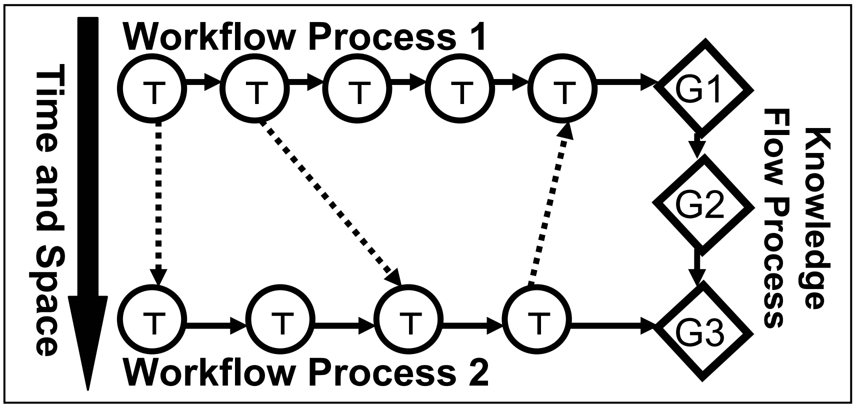

Figure 1. Knowledge Group Set Model showing typical task interdependencies between different workflow processes during a knowledge life cycle period (adapted and revised from Nissen's Horizontal and Vertical Processes Model (2002, Fig. 3))

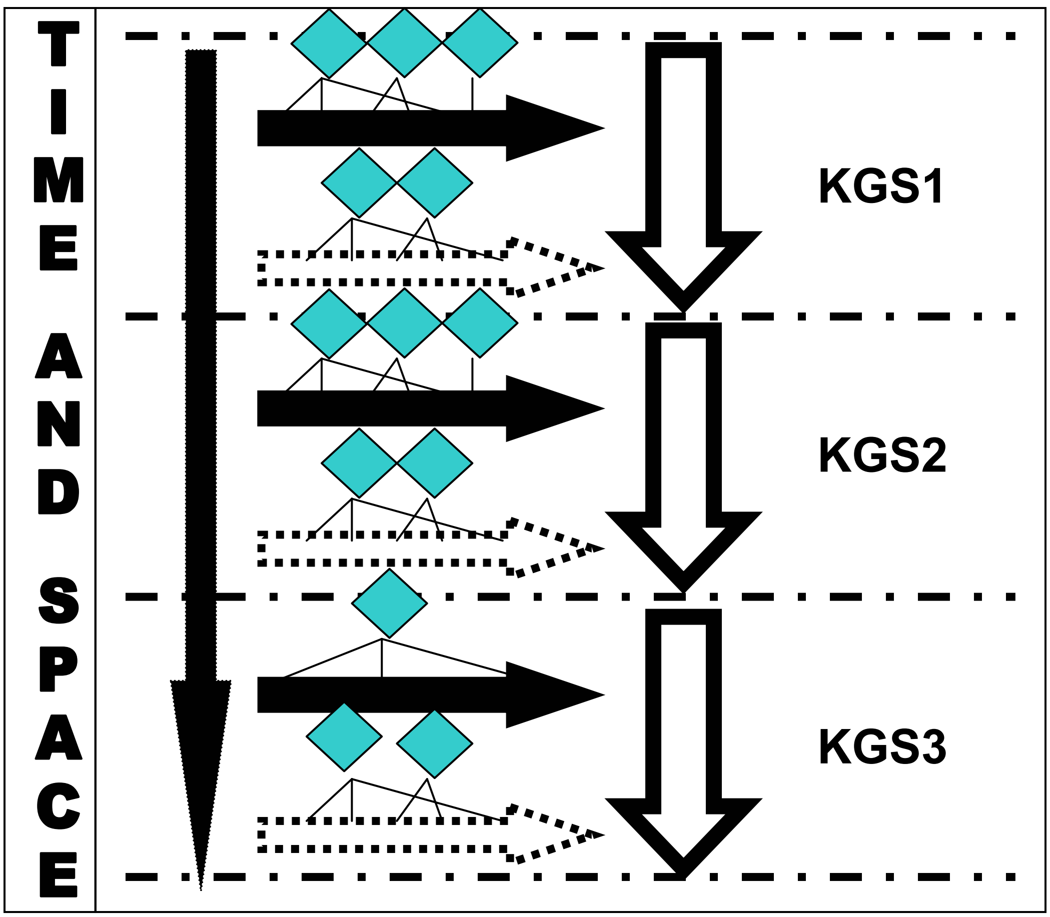

Figure 2. Knowledge Group Set Flow Model during Knowledge Life Cycle of a real estate development life cycle

One KGS unit represents a real estate development life cycle phase. Figure 2 illustrates the sequential combination of several KGSs, which forms the Knowledge Group Set Flow Model. As noted above, different workflow processes in a KGS unit (e.g., KGS1 to KGS3) have similar or different combinations of matrix teams working over them. These are represented by the different squares shown above each workflow. Each KGS unit represents the vertical knowledge-flow goals represented in Nissen's model.

In the real estate development case, KGS1 represents the Feasibility Phase, KGS2 represents the Entitlements Phase, and KGS3 represents the Building Permit Phase. A workflow in a KGS unit continues to the succeeding KGS unit. As it transits into the next phase, the matrix team combination may change. The goal for Feasibility, Entitlements, and Building Permit Phases are submission for development permit, receipt of the development permit, and construction start respectively. Developers achieve these goals as the project progresses through time and space.

Model

We use SimVision® to model the pre-construction activities of an affordable housing project. This paper assumes reader familiarity with agent-based modeling in general and SimVision® in particular. Background information can be obtained from Jin and Levitt (1996). In this case study, we represent all such pre-construction activities as one KGS unit. SimVision® is an agent-based representation (Cohen 1992; Kunz et al. 1998) that reflects well-accepted theory of micro-level organizational behaviors (Levitt et al. 1999). The development tasks we model are high-level development processes.

Our case study is a 43-unit, affordable family housing development for farm workers located in Watsonville, California. We obtain data through interviews and documents from the owner's representatives. The owner is a subsidiary of a premier affordable housing developer in the Bay Area, which owns and operates 73 affordable housing projects. The Watsonville development has been in operation since June, 2001, but has been plagued with civil and wastewater related problems since the construction phase began. The case study we examine is the first design-build development for the developer. It is currently operating in negative cash flow due to the overwhelmingly high maintenance cost of its septic tank and leach field failure. We expect the model to identify causes during the pre-construction activities that lead to its current predicament (see Figures 3 and 4).

Baseline Model. The Baseline Model represents a KGS unit, which will guide us to build a string of KGSs to form the KGS Flow Model. We model the pre-construction activities of the case study with a different organizational structure for each project. At the program level, there are two projects running concurrently: the Design-Construction (Des-Cons) and the Finance-Asset Management (Fin-Assm) projects. They consist of 39 tasks with twelve milestones in both projects. The Des-Cons project has three company staff and six external consultants, while the Fin-Assm project has four company staff and two external consultants.

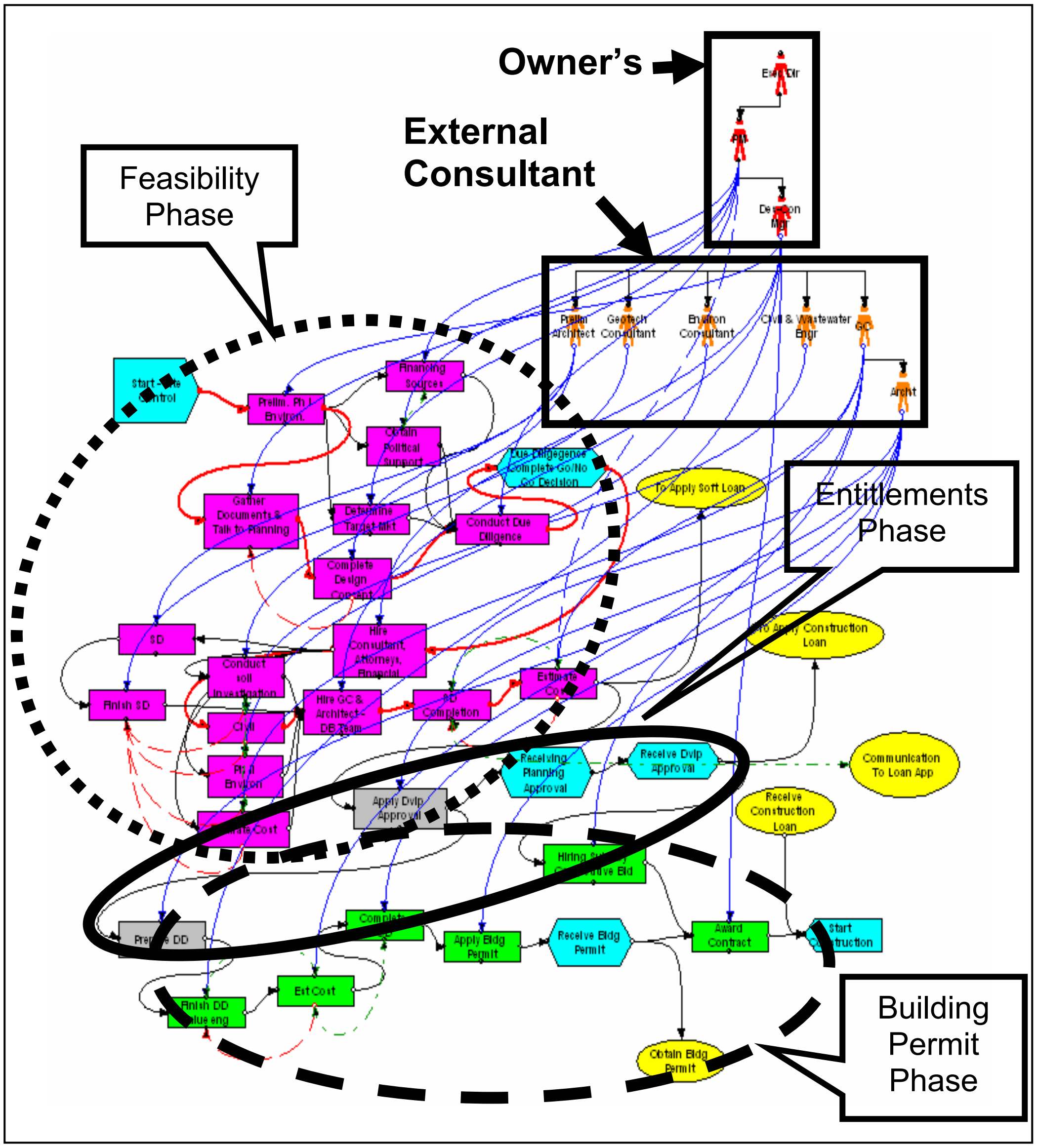

Figure 3. Network diagram of Design-Construction Project in Baseline Model

The start date is shown as June 1, 1997, when the developer obtains site control. In parameterizing the SimVision® model, we set the variable *centralization* to low; the variables *team experience, formalization,* and *matrix strength* are all set to medium based on the case study. *Information exchange probability* is set to 0.7, *noise probability* to 0.2, and both *functional and project error probabilities* to 0.05. These parameter settings reflect well-established norms for specifying SimVision® models (e.g., see Jin and Levitt 1996).

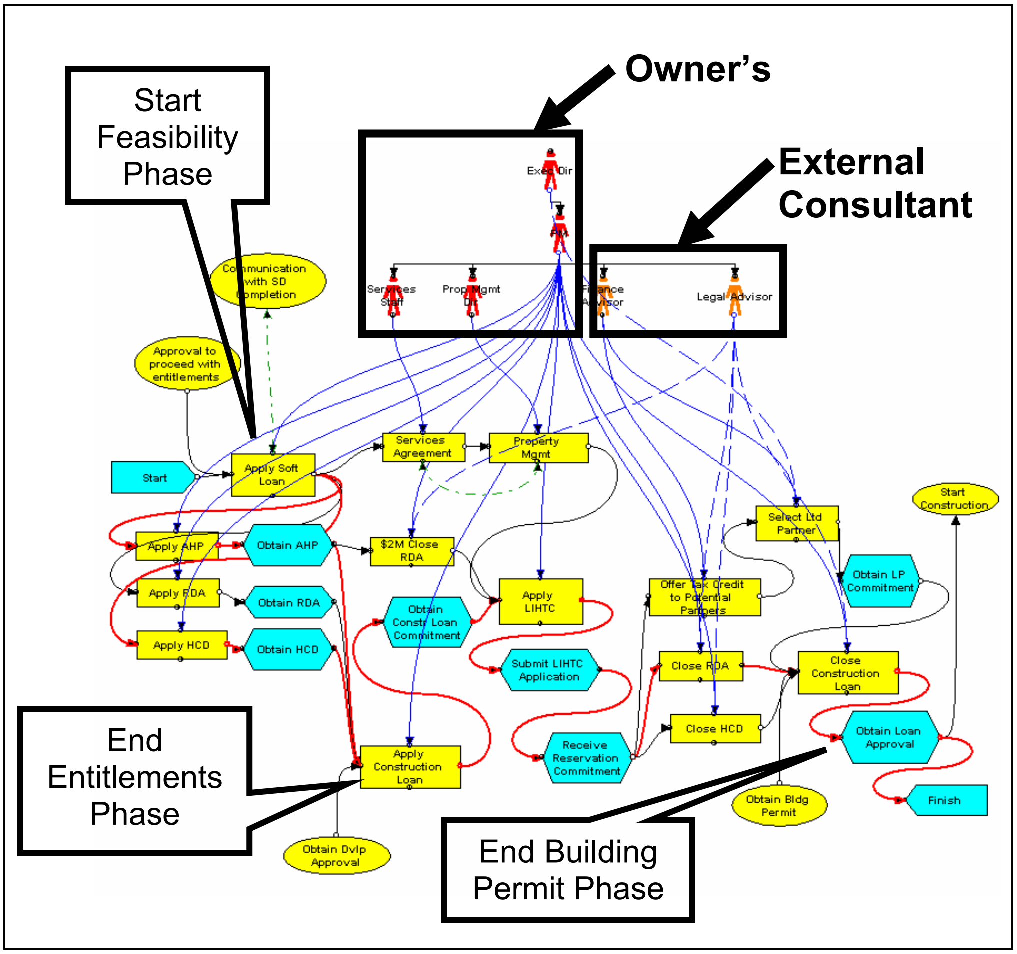

Figure 4. Network diagram of Finance-Asset Management Project in Baseline Model

The Des-Cons project includes architectural, engineering, developer's due-diligence tasks, and others, which occur during the feasibility, entitlements, and building permit phases. Some milestones in the workflow process represent explicit knowledge that the Project Manager must transfer to another workflow process for the program to continue. In the Baseline Model, we represent the organizational actors through attributes and parameters reflecting characteristics of the people actually involved in the development project. We do not model specific individuals as actors in the projects' position, however; specific individuals change frequently, but the nature of the roles they play does not. We specify the Baseline Model schedule to include indirect work (i.e., coordination, rework, and waiting period) based on the actual schedule and related documents the Project Manager provides. These steps give our model considerable accuracy in terms of representing the organization and process under study in the field. The Fin-Assm project captures a very complex set of financial activities that include three "soft loan" applications, one permanent/equity financing, and one construction loan application processes. We parameterize this model in similar fashion.

Matrix Model. The SimVision® modeling environment enforces an explicit method for examining different models. First, one represents the baseline case, which we describe above. Then, one develops one or more new cases, each of which is used to examine some aspect of the organization and process. Our first such new case is called "Matrix Model." The key representational difference with the baseline model above is, we represent organizational actors according to specific individuals in the development firm. Specifically, the Executive Director, the Project Manager, the Design-Construction Manager, the Architect, and the General Contractor is each represented according to the person occupying the corresponding position in the field organization, and to represent how they distribute their time and energy across projects. Each organizational actor is modeled by distributing their responsibility across two or three matrices. For example, the Project Manager's position actor is staffed with a total of 0.4 full-time-equivalent people (FTE) in the Des-Cons project and 0.3 FTE in the Fin-Assm project respectively; the FTE does not total 1.0 in this case, because the Project Manager is handling several concurrent development projects. The Des-Cons project reflects a higher FTE allocation, because it has three matrix teams (i.e., City, Building, and Owner Matrices) working on it, while the Fin-Assm project has only two matrix teams (i.e., City and Owner Matrices). We utilize the *department* in SimVision® to represent each matrix.

Tasks interdependencies. The model illustrates the close interdependencies between the Des-Cons and Fin-Assm projects by having four *ghost connectors* between the two projects. The *ghost connectors* reflect the flow of knowledge from a preceding task in one project to a succeeding task in another project. We use these ghost connectors to represent explicit knowledge exchange. There is a *ghost communication* link that reflects communication between Des-Cons and Fin-Assm teams. It represents tacit knowledge exchange. The Fin-Assm project starts out with a soft loan application after obtaining a first-order cost estimate from the Des-Cons project.

Results and Analyses

We run Monte Carlo simulations of 100 cases for both the Baseline and Matrix Models in SimVision®. The Baseline Model reflects the actual schedule of the case study. In both models, the Project Manager's, Civil Engineer's, and Architect's tasks are the top five tasks for schedule growth risks. The Matrix Model gives interesting results comparatively. Despite a 6-month delay in meeting the tax credit application deadline, the Des-Cons schedule shows a 4-month delay to start construction. Due to the delay, the developer has to postpone the application to March 2000 application (i.e., an 8-month delay). The Matrix Model's duration indicates that the matrix configuration actually helps reduce the schedule extension, which the Fin-Assm project causes. The schedule growth chart shows that all the Project Manager's tasks in the Fin-Assm project are at risk of being extended, because the Project Manager has a 60-day backlog. Unlike the Fin-Assm project, there are improvements to position backlogs of the Project Manager, the Architect and Civil Engineer in the Des-Cons project. There is a slight improvement of three days to the Project

Manager in the Des-Cons project, but 26 backlog days is still too much for one person to handle.

The work breakdown for the top ten tasks shows 0.5 to 2.5 days improvements to indirect work durations in the Fin-Assm project, and 2 to 3 days in the Des-Cons project respectively. This indicates the matrix configuration does improve their task deliveries, but the Project Manager's backlogs are causing several of her tasks to change status from "non-critical" to "critical." Less available FTE allocation, i.e. from 0.4 FTE to 0.3 FTE, is the cause; there is simply not enough of the Project Manager to go around. Consequently, the Fin-Assm tasks that the Project Manager handles are causing more delays and putting interdependent tasks in the Des-Cons project at risk. We validate this assumption through intellective experiment: adding 1 FTE to the Project Manager's staff improves project performance by reducing the duration by 2.5 months. Indeed, this case shows a construction start date that is earlier than the actual schedule date; hence the matrix case represents an improved plan for managing this affordable housing development project. Our analysis finds the inability of the Project Manager to cope with internal and external coordination and error exceptions--on top of her own workload--is causing the overall schedule delay in a Matrix Model as the development project progresses.

Discussion

Modeling the case study provides insights on how we can further investigate the knowledge-creation and flow among different construction stakeholders in the real estate development domain. As presented above, real estate development displays two strong characteristics. First, the workflow processes are generally sequential yet highly interdependent. Second, the process has a dynamic organizational structure that varies across development life cycle phases. We posit above that the dynamic nature of the developer's organizational structure is the cause for knowledge flow breakdown despite the sequential work processes involved. We also posit above that the high interdependency of tasks in concurrent workflow processes is compounding this breakdown.

Through analysis of the agent-based simulation data, we find the critical path in the real estate development process very sensitive to how the process is planned and managed, and we describe it as turbulent (Fyall 2002). It changes within less than a few days of duration difference. This chaos puts the tasks in both Fin-Assm and Des-Cons projects at schedule growth risk when developers make appropriate changes to handle exceptions throughout the development life cycle process. One functional project's urgency is not obvious to another functional project's team members. It becomes noticeable only when work along the critical path of one project stops in the middle of the workflow process and appears in the middle of a different project. Among the causes for critical path flow change are extending/reducing the duration of a task or a lag, and adding/deleting new task to the existing workflow process. The Matrix Model exhibits the same chaotic nature, because it produces similar critical path changes during simulation. However, the amount of available FTE's is affecting the total direct and indirect work volume of a task, which in turn affects the critical path in both projects.

The critical path reflects the tasks' sequencing priority among the workflow processes within a project. It also reflects the interdependency needs between several projects within a time frame. Since each workflow utilizes a different organizational structure in different development life cycle phases, it can facilitate the understanding of knowledge-flow priorities among the functional groups in the dynamic operating environment. Further investigation into the critical path changes due to change in organizational configuration is a good starting point on how knowledge flow breaks down among different construction stakeholders.

The pre-construction activities in the affordable housing developer's process do not consist of a lot of reworking with sequential tasks compared to typical construction projects. The whole process is quite sequential within a project. The key issue has to do more on "go/no-go" decisions among the stakeholders, such as waiting for planning or development approvals, and obtaining loans. The total process has several milestones, which if missed, can cause additional delay in the overall program. A typical example is, if the developer has yet to receive its development approval, it cannot proceed to apply for tax credit funding. The delay can cause developers to miss the targeted application deadline.

There are several limitations to current SimVision® application. First, it does not allow two primary actors assigned to one task, hence, limiting the flexibility to model the City and Building Matrices into the organizational structure at project level. To resolve the issue, we use departments to explain the matrix composition. Second, when SimVision® simulates the model, it does not consider the hierarchical structure in the departmental level unless organizational actors are represented as specific individuals (i.e., not just roles) at the project level. Therefore, although the simulated results come close to actual outcomes, we note the inclusion of indirect work--rework, coordination, and waiting period--taken by non-assigned actors in the overall schedule. Third, we can only assign one primary skill to a shared task. Such task example is "close construction loan" where both finance and legal actors play equal roles. We attribute this difficulty to our decision on not breaking certain tasks into smaller tasks (i.e., modeling granularity). This fact points to a secondary team working within the project's organizational structure. It is an area we can investigate further about knowledge-flow dynamics of a team within a larger team configuration. This also suggests future extension to the SimVision® application may be warranted to allow secondary skill assignments at the task level.

Inadequate support for the team leaders in affordable housing projects makes their tasks riskier and consequently puts the whole program at higher risk. It is common for a single Project Manager to be in charged of multiple concurrent development projects. Although there is no significant cost effect on the affordable housing developers—i.e., since they are nonprofit in nature—decreases in workflow process efficiency can cause long term financial loss to the state or federal funding programs. The organizational matrix configuration improves coordination, rework, and waiting period for critical position's task. However, any time savings can cause a project's critical path to change, for example, when different tasks will emerge more critical for the Project Manager to concentrate on.

Having a matrix configuration increases the project and functional risks, because it increases the interdependencies of tasks between different workflow processes. Project Managers wear many hats and work in at least three matrices in one development project. As Burton and Obel posit, the head of the team will tend to be overloaded. For instance, the Project Manager in the case study allows the Civil Engineer to maintain a low level performance rather than firing him and instructing the General Contractor to hire another. This non-action has long term financial impact on the operational costs. We recommend further investigation to review the Project Manager's work volume definition, since the case study shows a higher amount of indirect work as opposed to direct work volume in a SimVision®'s work volume calculation. We suspect that the micro-behaviors of a real estate development organization may be different, and we recommend an empirical study to verify such suspicion. We also recommend further software development to incorporate some flexibility in SimVision® to include departmental hierarchical reporting structure in the work volume equation.

The overall results support our base assumptions in building a model that reflects the challenging dynamics of the real estate development operating environment and climate. This case study is successful in representing a KGS set model that represents the two characteristics of the real estate development life cycle: sequential yet interdependent workflow processes, and dynamic organizational structure over different workflow processes and phases. Among the uncertainty and equivocality causes that impact the chaotic information processing nature of the development life cycle process are adding/deleting tasks in a workflow sequence, extending/reducing task or lag durations, and changes due to dynamic organizational structure. These exceptions impact the duration and interdependencies of tasks in different workflow processes. Without a modeling tool to explain the impacts of changing the critical path of pre-construction activities, it is not surprising that only highly experienced developers have the tacit knowledge to act accordingly when exceptions occur. Unfortunately, even highly experienced people make some decisions that are unwise, as shown in the case study. The KGS set model is successful in representing the real estate development characteristics. Therefore, we can extend the SimVision® tool to support future research on computational simulation of dynamic knowledge creation and flow to the affordable housing domain.

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References

Burton, R. M. and B. Obel. (2003). *Strategic Organizational Diagnosis and Design: Developing Theory for Application.* Kluwer Academic Publishers, Boston.

Carley, K. M. and Z. Lin. (1997). "A Theoretical Study of Organizational Performance Under Information Distortion." *Management Science.* Vol. 43 (7), July, 976-997.

Cohen, G.P.. (1992). *The Virtual Dsign Team: An Object-Oriented Model of Information Sharing in Project Team.* PhD dissertation, Stanford University, Stanford.

Davis, S. and P. Lawrence. (1977). *Matrix*, Addison Wesley, Reading, MA.

Fyall, M.. (2002). "When Project Information Flow Becomes Turbulent: Toward an Organizational Reynolds Number." CIFE Technical Report #138.

Jin, Y. and R. E. Levitt. (1996). "The Virtural Design Team: A Computational Model of Project Organizations." *Computational and Mathematical Organizational Theory*. 2(3), 171-196.

Ibrahim, R. (2001). *Feasibility of 4D CAD during Design Development and Approval Process for Affordable Housing.* Degree of Engineer dissertation, Stanford University, Stanford.

Kunz, J.C., R. E. Levitt, and Y. Jin. (1998). "The Virtual Design Team: A Computational Simulation Model of Project Organizations." *Communications of the Association for Computing Machinery.* 41:11, 84-92.

Levitt, R. E., J. Thomsen, T. R. Christiansen, et al.. (1999). "Simulating Project Work Processes and Organizations: Towards A Micro-Contigency Theory of Organizational Design," *Management Science*. 45, 1479-1495.

March, J. G. and H. A. Simon. (1958). *Organizations.* New York: John Wiley & Sons, Inc., Chapter 6.

Nissen, M. E.. (2002). "An Extended Model of Knowledge-Flow Dynamics." *Communications of the Association for Information Systems*. Vol. 8, 251-266.

Nonaka, I.. (1994). "A Dynamic Theory of Organizational Knowledge Creation." *Organization Science.* 5:1, 14-37.

Paulson, B.. (1976). "Designing to Reduce Construction Costs." *Journal of the Construction Division.* ASCE, Vol. 1, No. CO4, Proc. Paper 12600, Dec, 587-592.

Pfeffer, J. and R. Sutton. (1999). "Knowing "What" to Do is Not Enough: Turning Knowledge into Action." *California Management Review*. Vol. 42, No. 1, Fall, 83-108.

Polanyi, M.. (1967). "The Tacit Dimension," Routledge and Keoan Paul: London (1967).

Thomsen, J., R. E. Levitt, J. C. Kunz, C. I. Nass, and D. B. Fridsma. (1999). "A Trajectory for Validating Computational Emulation Models of Organizations." *Journal of Computational & Mathematical Organiztion Theory.* 5, (4), Dec, 385-401.