ALIGNING INNOVATIONS TO DESIGN AND CONSTRUCTION NETWORKS[1]

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ABSTRACT

Innovation research to date has predominantly focused on hierarchically-organized bureaucratic organizations competing within single markets. Meanwhile, researchers report a proliferation in the use of interorganizational networks within and across industries. Researchers have debated whether the evolution to interorganizational networks promotes or stifles innovation. We argue that these contradictory findings result from a failure to link innovation implementation processes to diffusion outcomes. In this paper, we resolve this contradiction by inducing a new model for innovation in project networks that integrates dual perspectives. The model is based on cross-national diffusion data from three technological innovations in 3D CAD and related implementation data from 82 design and construction firms.

KEYWORDS: 3D CAD, Innovation, Construction Networks, Technology Implementation

INTRODUCTION

For a quarter of a century, network researchers have studied the economic (Eccles 1981; Williamson 1985) and sociological (Granovetter 1985; Powell 1990) foundations of the network form of organization. Though there is general agreement among researchers that organizing into project networks leads to improved performance, only a handful of studies discuss the implications of the networked organizational form for innovation; and none of those that do link network processes to innovation outcomes.

One group of researchers focuses on the ability of a network of firms to produce novelty. In an investigation of biotechnology project networks, Powell and his colleagues (1996) concluded that the project network itself could be viewed as the locus for innovation and learning. In contrast, other researchers identify concomitant issues for innovation associated with learning in project networks. Lampel and Shamsie (2003, p.2206) caution strongly against the use of project-based networks, finding an "evolutionary stagnation in the craft of making movies" associated with the adoption of the project network form of organization in the Hollywood motion picture industry. To develop a theoretical model for innovation in project networks and to resolve the identified paradoxical perspectives, researchers need to link project network implementation processes to innovation outcomes. This paper provides such an integrated perspective of implementation processes and diffusion outcomes.

In this paper we investigate the implementation processes for three comparable innovations in three-dimensional computer-aided design (3D CAD) software through networks of design and construction firms. We link the observed implementation processes in design and construction firms to market level diffusion outcomes in the U.S. and Finland. We use the

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findings to induce a grounded theoretical model for understanding innovation in the context of project networks.

3D CAD TECHNOLOGICAL INNOVATIONS INVESTIGATED

We identified three comparable technological innovations in the construction industry on which to focus our data collection. Software vendors in the industry recently introduced a three-dimensional, object-based modeling version of computer-aided design software that enables architects, engineers, contractors, subcontractors, and fabricators to work together to build shared, three-dimensional computational models of buildings with intelligent objects. We will refer to this new generation of software as 3D CAD software. In the 1980s, early CAD software enabled the digital representation of a building through two-dimensional line drawings on personal computers. By the 1990s, some vendors began introducing CAD software packages that allowed for sophisticated design and representation of three-dimensional geometries and related data. Only recently, however, have mainstream CAD software vendors begun marketing object-oriented building information modeling systems that seamlessly integrate 3D geometry at the building component level with a wide variety of data.

The recent evolution from three-dimensional CAD geometries to three-dimensional building information models creates new interdependencies and collaboration requirements for firms in the construction network without greatly altering the end product (e.g., a set of blueprints). These systemic innovations have been described by researchers as potentially leading to significant increases in productivity while being particularly difficult to implement in project networks (Taylor & Levitt 2004), particularly when technologies span organizational boundaries (Taylor 2006). We chose to focus on the implementation of a systemic innovation, 3D CAD, in project networks.

In our study, we focus on three comparable 3D CAD applications. Our expectation was that the implementation findings for the three 3D CAD applications would not vary significantly within a single market. This enabled us to focus on the variances introduced by different market structures while maintaining consistency across the technologies introduced. By incorporating replication logic strategies in our research design, we increase the external validity of our findings (Yin 1989).

The first innovation we studied, which we will refer to as Building Modeler, was developed by a global software firm based in the United States that has sales and development offices in Europe. They focus their marketing and development efforts largely on the needs of architects. The second 3D CAD application in our study, which we will refer to as Structural Modeler, is produced by a global software development firm based in Finland that focuses its product development and marketing on structural engineers. This firm also has offices in the United States. We refer to the third application included in our study as the Home Modeler. The company that created Home Modeler operates in the United States through a subsidiary but is based in Finland. Its 3D CAD application targets the homebuilding market.

DATA COLLECTION AND ANALYSIS

Researchers suggest that grounded theory building research include multiple case studies and multiple data collection methods (Eisenhardt 1989) in order to increase the validity of the constructs identified. In this paper we investigate three innovation cases diffusing through project networks in the United States and Finland. We employ multiple data collection methods; including, ethnographic interviews, direct observation, and review of primary and secondary documentation. By triangulating our findings across these different data collection methods we strengthen the validity of our findings (Eisenhardt 1989).

The data collection effort for this paper took place over a period of 9 months. Three months were spent collecting data in Finland and the remaining six months were spent collecting data in the United States. We conducted over 200 hours of interviews in 82 discussions with owners, architects, engineers, general contractors, subcontractors and fabricators. Of the interview discussions, 31 were with project network specialist firms in Finland and the remaining 51 were within the United States. In most cases we interviewed the individual in the organization most involved in managing the company's utilization of CAD products. This individual was typically referred to as the "CAD Manager" or the "CAD Director." In all cases we focused the interview discussion on project's employing 3D CAD applications.

In addition to interview discussions, direct observations were made within and across specialist firms to observe the changes in process associated with implementing 3D CAD applications. We were invited to attend company meetings and project discussions, to visit project sites both under construction and recently completed, and to generally observe the interactions between specialists in the network relating to the implementation of 3D CAD. We took extensive notes during this process and took digital photographs for use in our data analysis. Interview discussions and observations were recorded in a numbered set of field research notebooks. Interview discussions were also.

Whenever possible, we requested hard copies of materials discussed during interviews and observations. Data collected included contract documents, process flow diagrams, construction schedules, 3D CAD models, bills of materials, project decision schedules, animations of building information models, and any other information that might lend insight into the internal and inter-organizational practices of the project network in implementing 3D CAD applications. This primary documentation was attached to our field notebooks and often elucidated concepts that were not entirely clear when reviewing the notes from an interview or observation. Data from the interviews, observation, documentation, and photographs were coded and systematically analyzed for patterns. Memo notations were used to develop concepts and constructs. Constructs were grouped into propositions that explain the implementation process in project networks. Finally, a set of propositions was developed to provide the foundation for a grounded theoretical model for innovation in project networks.

ALLOCATION OF WORK TO SPECIALISTS IN NETWORKS

During our data collection effort in Finland, we were surprised to learn that work in the construction project network is allocated in a fundamentally different way from networks in the United States. In one interview we sought to understand how the firms in one Finnish network used the Home Modeler 3D CAD application. We were specifically trying to understand whether or not the architect did the final detailing of the design or whether it was handled by the contractor, subcontractor or fabricator. However, we were having a great deal of difficulty getting the interviewee to understand the concept of "detailing."

To resolve the situation, the interviewee firm invited a professional translator into the meeting. After some deliberation, the translator suggested that the problem in communication was due to the fact that a single verb, suunnitella, describes both the designing and detailing process in the Finnish language. Furthermore, there is no separate verb to describe the act of designing or detailing. In Finnish work practice, the designer always does the detailing work. Therefore, the architect using the Home Modeler application both designs and details the model.

In the United States, the architect is only expected to provide schematic designs. The downstream partners in the network detail the design provided by the architect. One architecture firm in the United States describes architectural designs as follows: "design professionals don't use exact dimensions. Contractors interpret these (refers to the architect's drawings) and create shop drawings with actual dimensions … if a dimension is wrong, it's the contractor's fault."

To confirm the generality of this work allocation practice, we posed similar questions to construction networks in Finland and the United States implementing the Building Modeler and Structural Modeler applications. The work practice of architects providing schematic designs in the United States and "detailed" designs in Finland was also true for the networks using the Building Modeler application. However, we were surprised to learn that users of the Structural Modeler application could be observed to allocate work in similar ways even though no architect was involved. A Finnish structural engineer described the process in Finland as: "The structural engineer is responsible for the structural analysis. You check the codes and if everything is okay you do all the connection details, slot holes, connectors..."

In contrast, fabricators complete the final detailing of schematic designs provided by structural engineers in the United States. They are then able to adjust the connection details to match their operations and available inventory. For example, a design may require a certain member sizing and connection detail, but in order to save time and costs in the fabrication process, the fabricator might suggest using a slightly larger member and bolt size to divest themselves of inventory surpluses. In the Finnish construction networks, this practice is much less likely since fabricators fabricate structural materials to the exact, detailed specification of the engineer.

Our finding of how work is allocated to specialists was consistent within each national market structure and across the three innovations included in the study. Given this corroboration across the data set, we consider the finding that work is consistently allocated differently — designers complete "detailing" work in Finland but not in the United States — across markets to be significant. In the case of each technological innovation studied, alignment of the innovation to the work breakdown of the country led to faster diffusion. This leads to our first proposition:

PROPOSITION 1. *If an innovation aligns to the allocation of work in a design and construction network, then it will diffuse more rapidly than if it is misaligned to the allocation of work.*

MISALIGNMENT AND PROJECT NETWORK DYNAMICS

Building Modeler provided a unique case in which the innovation aligned to the allocation of work in Finnish construction industry project networks. However, the Building Modeler in the United States and the Structural and Home Modeler in both the United States and Finland were misaligned to the allocation of work. The impact of the misalignment on implementation processes innovation outcomes varied significantly between the United States and the Finnish project networks. In the following sections we describe a set of constructs relating to implementation in networks that moderated innovation outcomes.

Relational Stability

In Eccles' (1981) 25-year old study of the construction industry, he identified that construction firms operated in networks with long-term relationships and only contracted with one to two specialists of each type. These longer-term relationships were not based on choosing partners offering the lowest price. Interestingly, in our study, we found that Finnish construction networks currently contract very much along the lines described by Eccles, with firms engaging in tight partnership relationships with one to three firms for each specialist type in the network. In contrast, construction networks in the United States currently tend to adopt shorter-term relationships than those identified in Eccles' study. Interviewees in United States construction firm networks disclosed that they contract with five to six different firms for each specialist firm type. Many firms cited cost pressure as a rationale for adopting a more arms-length approach to contracting. In the 25 years since the Eccles' investigation of the quasi-firm, the construction network has evolved to a larger set of partner firms in the United States.

We describe the degree of stability in network role relations as relational stability. Networks in the Finnish construction industry exhibited strong relational stability by choosing to work with only one to three firms for each specialist type. As predicted by the Hall and Soskice (2001) work on varieties of capitalism, members of networks in this coordinated economy tended to choose partners based on previous working relations. In contrast, construction networks in the United States exhibited weak relational stability due to the fact that members tended to choose from among five or six firms for each specialist type.

Each of the three innovations achieved unexpectedly slow rates of diffusion in the United States. In each of these cases the innovation was misaligned with the allocation of work in the U.S. project networks. Weak relational stability in those networks created difficulties for firms implementing these innovations because learning from one project failed to carry forward to the next project when membership in the project networks shifted significantly from project to project. Learning occurred more slowly within firms because the weak relational stability limited the number of times they would be exposed to the innovation. However, much more insidious is the fact that inter-firm learning — the development of interorganizational routines — failed to accumulate as a result of the limited opportunities for specific specialist firm pairs to work together. The impact of this has been explored in computational simulation models (Taylor, Levitt & Villarroel 2006). Since each of these innovations required firm networks to shift the allocation of work and to resolve new kinds of interdependencies, the weak relational stability exacerbated problems associated with implementing the application in the network and led to much slower diffusion than expected.

In contrast, the strong relational stability in the Finnish networks mitigated the impact of misalignment on diffusion for the Structural Modeler and Home Modeler innovations. Both of these innovations diffused rapidly through the Finnish market — and through the French and German markets — in the case of the Structural Modeler innovation. Because the Building Modeler innovation actually aligned to the allocation of work in the network, the relational stability between firms was not an issue and the diffusion for that particular innovation far exceeded diffusion expectations.

PROPOSITION 2a. *The weaker the relational stability in a network, the greater the difficulty to achieve network-level learning. This contributes to slower innovation diffusion rates.*

PROPOSITION 2b. *The stronger the relational stability in a network, the lesser the difficulty to achieve network level learning. This contributes to faster innovation diffusion rates.*

Interests

A second contrasting construct between the Finnish and United States network implementation processes related to firm-level versus project-level interests. In the United States, firms in construction networks were focused on the interests of their own firm. In one illustrative case, an architecture firm in the United States opted not to inform its customers or network partners that it was using the Building Modeler application even though its managers acknowledged that sharing such information and files would greatly reduce downstream workload and reduce errors. They stated clearly that they wanted the benefits of the new technology to accrue only within their own firm.

In the Finnish case, firms were much more inclined to share the benefits of 3D CAD with their network partners. In the case of the Structural Modeler application, structural designers in construction networks in Finland chose to share models with downstream fabricators to obviate the fabricator's need to produce its own electronic CAD files for manufacturing. In the case of the Home Modeler innovation, one Finnish contractor described how it brought all of its impacted network partners to sit around a table and discuss how the change would impact each firm, so that the costs and benefits of the innovation could be equitably distributed across the network.

When interests accumulated at the level of the firm, as was the case for the U.S. networks studied, the effect was to exacerbate the impact of misalignment on diffusion. By considering only their own interests and not attempting to share the benefits of the innovation with their trading partners, firms in U.S. networks restricted the rate of diffusion of the innovation. In contrast, in the Finnish networks the interests were defined at the network level, alleviating fears of opportunism and increasing firms' willingness to share the benefits of innovation with their partners. In these networks, the network level accrual of interests mitigated the impact of misalignment on diffusion.

PROPOSITION 3a. *If interests are centered on the firm in a network, the network will adopt misaligned innovations more slowly. This contributes to slower innovation diffusion rates.*

PROPOSITION 3b. *If interests extend to the network in a network, the network will adopt misaligned innovations more quickly. This contributes to faster innovation diffusion rates.*

Boundary Permeability

The permeability of organizational boundaries played a critical role in how networks adapted to misaligned innovations. In the United States the boundaries between firms in a project network were comparatively impermeable. In the adoption of the Building Modeler innovation in the United States, several firms vertically integrated into a single firm when attempts at redistributing work in the network failed. Each of the 3D CAD innovations required the designer to increase his or her knowledge of the objects they were designing. An example observed many times in the data collection was the situation where the wall of a room meets the ceiling. In 2D CAD it sufficed for the architect to simply draw a line where the wall meets the ceiling. However, with 3D CAD modeling, the designer must define the way in which the wall object is connected to the ceiling object. This requires increased knowledge of how the structure will be constructed in the field. In U.S. networks architects generally refused to take on this additional responsibility since it did not fit with a standard interpretation of their role in the network. In contrast, Finnish firms adopting the Home Modeler application redrew the organizational boundaries separating the firms in the network without losing their firm identity. The firm network was quickly able to use permeable boundaries to benefit from the misaligned innovation.

In the case of the networks we investigated, the boundaries in the U.S. networks were impermeable. Because they continued to work with so many different network partners across projects, firms in the United States found it more difficult to negotiate changes in their organizational boundaries with other firms in the network to accommodate the misaligned innovation. This contributed to a reduction in the rate of diffusion. Interestingly, in the case of one project network, the boundaries separating firms in the network were removed when the contractor in the network decided to vertically integrate a set of specialist firms from the network into its own organization. This led to tremendous productivity improvements as it reduced the impact of the weak relational stability and the firm level interests. However, it did not positively influence the diffusion outcome because not many others in the industry followed the same strategy of integration. In the case of the Finnish project networks, the organizational boundary was permeable, enabling the distribution of work to ebb and flow. Finnish firms were able to reallocate work across organizational boundaries as necessary to accommodate a misaligned innovation. This dynamic capability mitigated the impact of misalignment on the diffusion rate.

PROPOSITION 4a. *If the organizational boundary between firms in a project network is impermeable and work redistribution is impeded, then networks will have significant difficulty adapting to misaligned innovations. This contributes to slower innovation diffusion rates.*

PROPOSITION 4b. *If the organizational boundary between firms in a project network is permeable and work redistribution is enabled, then networks will have less difficulty adapting to misaligned innovations. This contributes to faster innovation diffusion rates.*

Agent for Network Change

A final construct identified in comparing Finnish and United States construction networks was the presence of an agent for network change. In the liberal market economy context of the United States, firm networks must be self-organizing in the face of pressures for network-level change. The knowledge of an innovation among firms in the network can be distributed unevenly across multiple firms in networks. Moreover, discussions among groups of firms to assess needed changes can easily contravene tough U.S. anti-trust laws and be viewed internally or externally as illegal collusion. Thus, rational self-organization among firms in the United States networks may not lead to the most rational solution for the entire network.

In Finland, TEKES, the national technology funding agency, promotes network level productivity enhancing changes by organizing firms into partnership networks to adopt innovations it regards as promising and by directly subsidizing the costs such a change may have on individual firms in the network. It subsidizes these costs by funding the applied research on issues associated with early adoption of the innovations. In doing so, the national technology funding agency fulfills the role of an agent for network change.

PROPOSITION 5a. *In the absence of an agent for network change, firms in networks will have difficulty self-organizing to adopt misaligned innovations. This contributes to slower diffusion rates.*

PROPOSITION 5b. *In the presence of an agent for network change, firms in networks will benefit from orchestrated change. This contributes to faster innovation diffusion rates.*

TWO STAGE MODEL FOR INNOVATION IN CONSTRUCTION NETWORKS

Network Structure

Before we can understand the impact and outcomes of technological innovation on a network or a population of networks, we must understand the pre-existing network structure. One key aspect of the network structure identified in this paper is the allocation of work to specialists in the network. Because firms in the network must work together to complete some overarching task (e.g., the design and construction of a building, the production and distribution of a motion picture, or the testing and development of a new drug) certain task interdependencies exist that structure the flow of work between firms in the network (Thompson 1967). The current technology used by firms in the network is an important element of the network structure.

In this paper, we illustrate how the allocation of work can vary across markets. However, one would expect allocations of work to vary within some markets, in particular as innovations spread from one industry segment to another. When an innovation is introduced into the network, the alignment of that innovation to the allocation of work in the current network structure must be ascertained before the network dynamics can be predicted. Alignment then becomes the moderating construct of the first stage of a model for innovation in project networks (see Figure 1 below). Innovations that align to the allocation of work will circumvent the difficulties associated with implementing innovations across design and construction networks. These innovations can be understood applying current innovation theoretical frameworks of organizational innovation (Rogers 1962). However, innovations misaligned to the allocation of work in the network will undergo an implementation process unique to project networks. These innovations do not fall within the confines of existing innovation theory.

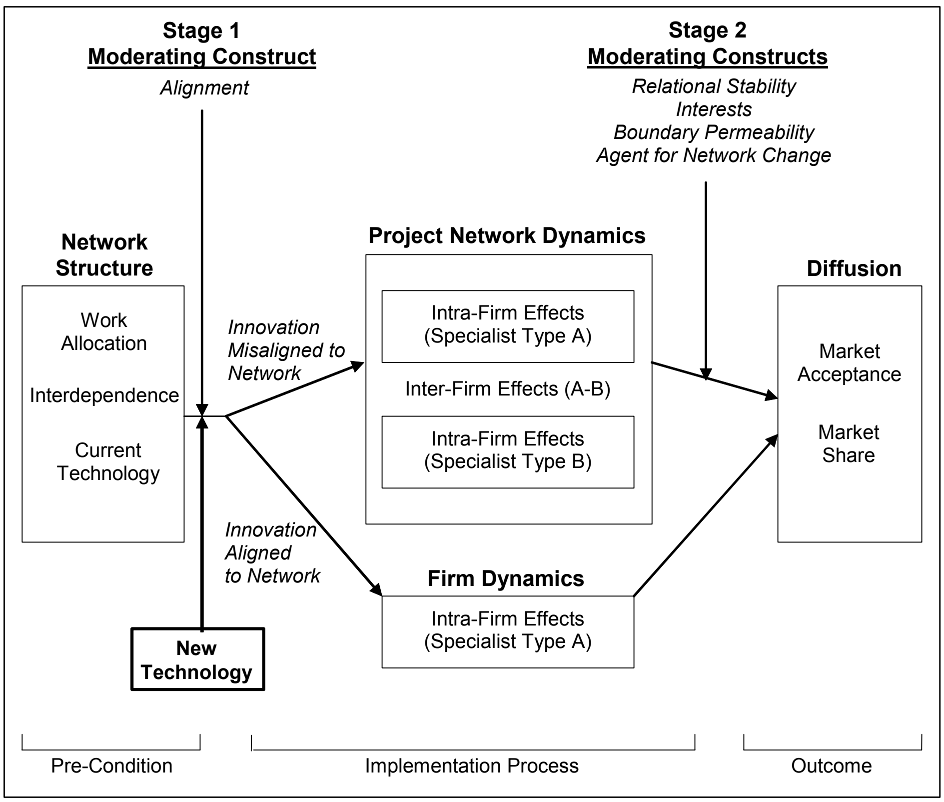

Figure 1. Two Stage Model for Innovation in Design and Construction Networks

Network Dynamics and Diffusion Outcomes

Innovations that are misaligned with the allocation of work in the network will require multiple, interdependent types of specialist firms to mutually adapt to changes introduced by the innovation. Therefore, there is a set of firm effects that can be understood using existing innovation theory as in the case of aligned innovations. However, in the case of misaligned innovations more than one type of specialist firm population must adapt to the change. This impacts the rate at which the network can adapt to the change. Network dynamics caused by the inter-firm effects, however, have a far greater impact on the diffusion outcomes. The inter-firm effects invoke a second set of moderating constructs (see Figure 1). The degree to which diffusion outcomes are impacted by innovation misalignment is determined in this second stage of our grounded theoretical model for innovation in project networks. The values for the four moderating construct dimensions determine the degree to which misalignment effects are mitigated or exacerbated. Strong relational stability, network-level interests, permeable boundaries, and the existence of an agent for network change will mitigate the impact of misalignment on diffusion. Conversely, weak relational stability, firm-level interests, impermeable boundaries, and the absence of an agent for network change will exacerbate the impact of misalignment on diffusion.

CONCLUSIONS

The findings from the implementation and diffusion of three innovations in 3D CAD demonstrate that an alignment of innovations to project networks greatly increases the rate of market acceptance for innovations. Data from construction networks in Finland and the United States illustrate that in cases of misalignment of innovations to the allocation of work in networks, stronger relational stability in the network can mitigate the impact of misalignment on diffusion. In addition, we find evidence that permeable boundaries between firms, network-level accrual of firm interests and the presence of an agent for network change can all serve to mitigate the effects of misaligned innovations diffusing through project networks. These constructs and a set of related propositions are used to build a grounded two-stage theoretical model for innovation in project networks. This research, therefore, contributes to a fuller understanding of innovation by extending previous organizational innovation theories to include innovation in construction networks.

This research contains limitations that should be addressed in future research on the subject of innovation in construction networks. We attempted to access precise time-series diffusion data for the different 3D CAD software applications included in this study. However, we were unable to gain access to such detailed quantitative diffusion data and, necessarily, had to rely on vendor supplied market data points. In this paper we describe each of the induced constructs in detail, however, the qualitative nature of our analyses makes it difficult to unbundle and discern the relative impact of each construct on the diffusion of misaligned innovations. Further research should be conducted to determine the contribution of each of the constructs in our model on diffusion.

This research has important implications for firms operating in design and construction networks, particularly those firms experiencing difficulty with innovation. The theoretical model presented in this paper suggests that networks contemplating introducing technological innovations should first understand the alignment of that innovation to the allocation of work in their network. In the case that the innovation being implemented in the network is misaligned with the current allocation of work, firms in project networks should strengthen relational stability, realize shared interests, enable the permeable redistribution of work across organizational boundaries, and work with an agent for project network change if one exists. Addressing these factors will enable construction networks to more seamlessly implement technological innovations and more quickly realize productivity improvements.

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