Paper to be presented at the DRUID 2012

on

June 19 to June 21

at

CBS, Copenhagen, Denmark,

Modular Components, Integrated Practices: Managing Complexity and Interdependence in Temporary Organizations

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Abstract

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"Modular Components, Integrated Practices: Managing Complexity and Interdependence in Temporary Organizations"

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ABSTRACT

This paper investigates how firms manage complexity and interdependence through an in-depth analysis of a temporary organization, Heathrow Airport's Terminal 5 (T5) project. It highlights how firms manage interdependencies by complementing modular product designs (e.g. standardized components, prefab/offsite construction, interface compliance) with integrated practices (e.g. co-located teams, strong team identities, incentive alignment). Our study extends existing work on managing interdependence and complexity in several ways. First, our study underlines how modular designs and integrated practices might be mutually reinforcing, rather than opposites. Second, we point to the role of information transparency to aid coordination and the challenges in achieving such transparency. Third, it underlines recent work that has emphasized the importance of "tacit" coordination mechanisms for firms that integrate tasks among geographically distributed sites.

INTRODUCTION

In organizational contexts, interdependence refers to the degree to which two or more activities interact to jointly determine an outcome (Sorensen, 2003). As such, managing interdependencies constitutes a primary function for any organization. Several streams of literature have addressed how organizations might manage interdependence, including work on organizational design (March and Simon, 1958; Thompson, 1967; Galbraith, 1977), contingency theory (Burns and Stalker, 1961; Woodward, 1958; Lawrence and Lorsch, 1967) and, more recently, modular designs (Ulrich, 1995; Baldwin and Clark, 2000; Baldwin, 2008).

A large-scale survey among European firms has highlighted the increasing complexity faced by managers in contemporary organizations, in terms of the number of horizontal inter-firm linkages. In turn, this rising complexity appears to be associated with an increase in the number of temporary organizations (Whittington et al., 1999). Temporary organizations allow firms to flexibly recombine and reconfigure resources (Shenhar and Dvir, 1996; Shenhar, 2001; Hobday, 2000; Davies and Hobday, 2005; Gil, 2007; Janowicz-Panjaitan et al., 2009; Cattani et al., 2011). For instance, based on an in-depth study of the film industry, role-based coordination facilitates effective collaboration among heterogeneous groups of teams or individuals in temporary organizations (Bechky, 2006). Davies et al. (2011) emphasize how these organizations allow for economies of recombination through reuse of products, services and other replicable components. Temporary organizations are, of course, not a new phenomenon and project-based forms of organizing have been investigated in a variety of settings, including theater productions (Goodman and Goodman, 1976), construction (Eccles, 1981), oil production (Stinchcombe and Heimer, 1985) and biotechnology (Powell et al., 1996), and.

While temporary organizations may allow firms to deal with rising complexity, these organizational forms themselves also create additional levels of complexity, in particular those involving multiple firms (Janowicz-Panjaitan et al., 2009). This is not only due to inherent time constraints, but also because of frequently diverging stakeholder interests. The complexity engendered by large scale multi-stakeholder projects is often witnessed in the protracted processes (in terms of e.g. delays, cost overruns) associated with these endeavors. As such, temporary organizations appear to be a suitable setting to understand how firms might manage complexity, in particular how they resolve increasing interdependence. This issue ties into recent work that has focused on coordination mechanisms used to manage interdependence across geographic sites or organizational boundaries (Staudenmayer et al., 2005; Jones and Lichtenstein, 2008; Srikanth and Puranam, 2011).

Our paper investigates the question of how firms might manage complexity and interdependence through an in-depth analysis of a temporary organization, i.e. the construction of Heathrow Airport's Terminal 5 (T5), built in the UK between 2002 and 2008. Given the scale of this project, as well as additional challenges given the need to integrate the new terminal within an existing airport, the case appears to be a suitable setting to investigate how firms manage interdependencies in temporary organizations.[1]

Overall, our study emphasizes the importance of combining modular components with integrated practices. In particular, it highlights how firms manage interdependencies by complementing modular product designs (e.g. standardized components, prefab/offsite construction, interface compliance) with integrated practices (e.g. co-located teams, strong team identities, incentive alignment). Therefore,

[1] Following Shenhar and Dvir (1996), the Heathrow Terminal 5 construction can be considered as a system of systems project, therefore constituting a very high level of complexity.

modularity is not a “technological fix”. The study draws attention to the organizational practices required to implement modular design principles, highlights the formation of these practices and the challenges surrounding their maintenance. Our study extends existing work on managing interdependence and complexity as follows. First, our study underlines how modular designs and integrated practices might be mutually reinforcing, rather than opposites Second, the case points to the role of information transparency to aid coordination, as well as the challenges in achieving such transparency. Third, our findings resonate with recent work that has emphasized the importance of "tacit" coordination mechanisms for firms that integrate tasks among geographically distributed sites.

This paper is built up as follows. The next section briefly discusses relevant background literature on how firms manage complexity and interdependence in relation to modular designs. We then describe our empirical setting, focusing on several key components used to manage interdependence. Next we discuss our findings in light of existing work on organizational interdependence and coordination mechanisms, followed by concluding remarks.

BACKGROUND LITERATURE

A variety of literatures has dealt with the way organizations manage complexity; here, we focus in particular on the issue of interdependence among organizational subsystems. Organizations can be conceptualized as vehicles to manage interdependence, given the need to integrate subtasks created by the division of labor among actors comprising the organization (Galbraith, 1974; Victor and Blackburn, 1987). In turn, organizations need to integrate these subtasks, requiring coordination mechanisms such as plans, procedures, standards or schedules (Perrow, 1967; Galbraith, 1977; Van de Ven et al., 1976). Depending on the complexity of the organization, these coordination mechanisms are more or less elaborate. For example, Thompson (1967) distinguishes between various types of interdependence (in ascending order of complexity: pooled, sequential, and reciprocal) and proposes several coordination strategies to resolve these forms of interdependence (standardization, planning and mutual adjustment respectively). Organizational complexity increases as the number of interdependencies between actors or tasks rises. As they grow, organizations usually create sub-units (e.g. divisions) to manage these interdependencies. However, divisionalization in turn creates additional interdependence between these newly formed sub-units, reflecting a general challenge faced by organization designers.

Related work by Simon (1962) on the architecture of complex systems has emphasized two features of these systems: a nested hierarchy of subsystems, and an overall architecture that is *nearly* (as opposed to *fully*) decomposable. A normative implication for designers of social systems is to concentrate interdependencies among elements within individual subsystems, such that each subsystem is relatively independent. Interdependence between the various tasks or subsystems can be mapped onto a matrix, where the goal will typically be to concentrate tasks within subsystems. Since complex systems are nearly-decomposable, "residual" interdependencies (or, from a visual point of view, the "off diagonals") will occur, which can be considered both the “bane and raison d'être” of any organization (Levinthal, 2010).

Drawing on Simon's work on near-decomposability (1962, 2002), more recent studies on modularity have further highlighted how modular designs can alleviate the issue of interdependence (Ulrich, 1995; Baldwin and Clark, 2000). Here, existing research has pointed to several issues in relation to the question of how firms manage complexity in the context of modular designs. Research on systems integration has highlighted the importance of the "systems integrator" firm, which needs to integrate disparate knowledge bases, in particular when interdependencies are unpredictable or when rates of technological development are uneven (Brusoni et al., 2001; Prencipe et al. 2003; Hobday et al., 2005).

Recent work invoking the notion of "mirroring" (Colfer and Baldwin, 2010; MacCormack et al., 2008; Cabigiosu and Camuffo, forthcoming) has emphasized that modular product designs are not necessarily associated with modular organizations. This contrasts with earlier work on modular designs that implicitly (Henderson and Clark, 1990) or explicitly (Sanchez and Mahoney, 1996) assumed isomorphism between the architecture of the product and the organization.

While existing research has made important progress for our understanding of the ways in which organizations can manage complexity and organizational interdependence, important questions remain. In particular, while modular designs appear to help control interdependence, it is unclear which organizational coordination mechanisms are required to make use of these modular product designs. On the one hand, existing work has suggested that modular designs reduce complexity, thereby facilitating or even substituting for organizational coordination (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Langlois, 2002; Sturgeon, 2002). On the other hand, modular designs may also be an imperfect substitute for organizational coordination (Staudenmayer et al., 2005; Zirpoli and Becker, 2011; Tiwana, 2008). The latter line of work has emphasized the ongoing need for organizational actors to manage the various interdependencies that occur, in spite of the use of modular designs. Therefore, this paper investigates what organizational practices are required to manage modular product designs, focusing in particular on the issue of managing complexity and organizational interdependence.

We will investigate this question in the context of a temporary organization. In terms of managing interdependence, temporary organizations are not fundamentally different from "regular" organizations, though the issue of interdependence and complexity may be exacerbated due to the transitory nature of the endeavor. Drawing on existing work on temporary organizations and related coordination mechanisms (Cattani et al., 2011; Bechky, 2006; Jones and Lichtenstein, 2008), this paper focuses on the organizational practices and coordination mechanisms used to resolve organizational complexity and interdependence. As described in further detail in the next section, an advantage of analyzing a temporary organization is that the various phenomena of interest (complexity, interdependence, coordination mechanisms) are strongly manifested in large-scale, capital intensive temporary organizations. Therefore, this facilitates analysis of how these processes unfold, allowing us to draw implications for our overall question of how firms manage organizational interdependence and complexity using modular product designs.

METHODS, DATA ANALYSIS, EMPIRICAL SETTING

This section highlights the empirical setting investigated in this paper, and the methods we used to analyze our data.

Methods, data sources and analysis

Given our goal of understanding *how* firms use modular designs to manage interdependence and complexity, we adopted a qualitative single-case design (Yin, 2003). This allowed for an in-depth analysis of the various processes used by the firms involved in the T5 project. We used combination of primary and secondary sources to ground our analysis. In terms of primary sources, we conducted 39 interviews, focusing on senior decision makers relevant to our setting. The interviews were done in two separate rounds, the first taking place in 2005/2006 and the second one in 2009. The first round occurred during the construction stage, while the second round took place after delivery of the project. This allowed us to gain insight both during the construction period itself (to reduce post-hoc rationalization), while also gaining additional reflection upon completion. The interviews were typically conducted by a team of two researchers. All informants agreed to have the interview recorded, which were transcribed afterwards by a specialized firm. Prior to each interview we sent our informants a short description of the research project and an overview of themes for discussion. The interviews followed a semi-structured approach, with more or less emphasis on each topic depending on the informant's background. Secondary sources consisted of written reports including documents used by T5 stakeholders themselves (e.g. the T5 Agreement and T5 Handbook), as well as other materials such as books and trade journals. Table 1 contains an overview of our data gathering stages and data sources.

INSERT TABLE 1 ABOUT HERE

As an inductive study, we iterated between our data collection and theoretical framing, which is further reflected in our data analysis. After our initial interview round, we coded the interview transcriptions using several general categories. Following Van de Ven (2007), we tried to engage closely with our informants where possible. As such, we summarized our initial findings in an interim report, which was shared with our informants for corrections to our interpretations. We then conducted the second round of interviews, both to refine our initial understanding of the case and get additional reflection. When conflicting accounts of a particular issue were given, we attempted to discuss this with multiple informants from different firms. We then coded the transcripts from our second round of interviews, adjusting our initial set of codes where relevant. We also sent out a final case summary to our informants, to further check our interpretations with the informants. This case summary also served as the main input to our empirical data (see section 3.3).

Heathrow Terminal 5 (T5): overview and case selection

Before describing our empirical data in further detail, a brief overview of our setting. Our case focuses on the construction of Heathrow airport's Terminal 5 building, located near London, UK. Terminal 5 opened in March 2008, following a 6 year construction period starting in 2002.[2] In contrast to many other large-scale infrastructure projects, the T5 project was completed within budget and ahead of time.[3] Overall, the construction of T5 has been considered a success by the key stakeholders involved in its delivery, in particular BAA (British Airports Authority, the main project sponsor and client), Laing O'Rourke (LOR, one of the main contractors in the T5 project), and BA (British Airways, the main operator of T5 upon delivery). Further details of the various stakeholders and sub-projects are provided in the Appendix.

There are several reasons for selecting the T5 case to improve our understanding of how organizations manage interdependence and complexity using modular designs. First, T5 constitutes a large-scale project (with a final cost of £4.2 billion) comprising a great number of subprojects and therefore interdependencies; the overall project consisted of 16 main projects, 147 sub-projects, and used over 11000 pre-assembled modules. In terms of the size of the project, considering T5 as "just" a terminal building could be misleading, since its handling capacity is equivalent to Europe's fifth largest airport. Second, the delivery of T5 also involved an additional integration challenge, given its location within an existing airport. T5 is situated between two runways, in an area previously occupied by a sewage works (see Figure 1 in the Appendix). Working next to live runways posed additional challenges, for instance regarding safety, security and logistics. Third, airport buildings benefit from modular designs, as highlighted by one interviewee: *"Airport owners and operators have to be very agile in terms of being able to reconfigure their infrastructure to meet the changes in operational requirements and airline requirements and so on. And therefore you have to design with flexibility."* As such, this setting appears

[2] The construction of T5 was preceded by a protracted planning process involving the longest public inquiry in UK history; however the issues during this pre-construction phase are largely beyond the scope of our empirical analysis.

[3] However, the successful delivery of the project was initially overshadowed by problems with the operation of the luggage handling system, briefly referred to in the empirical section.

to be well-suited to enhance our understanding of the ways in which organizations manage complexity and interdependence using modular designs.

Empirical data: key elements for managing interdependence in T5

Moving on to our empirical data, this section highlights two key elements used to manage interdependence and complexity in the delivery of the T5 project: A) the T5 agreement, a legal document codifying a set of behaviors for T5 project participants. This agreement stimulated a particular way of collaboration, focused on "integrated teams", which emphasized team identities, incentive alignment and co-location. B) The single model environment (SME), a common repository for sharing design information and updates for project participants. The SME facilitated the use of modular designs, which focused on standard components, interface compliance, and pre-fabricated (pre-fab), off-site construction. We discuss these two elements in more detail below. Table 2 summarizes the main elements and uses illustrative quotes to describe these topics.

INSERT TABLE 2 ABOUT HERE

A) The T5 Agreement: codifying behaviors focused on incentive alignment

The T5 Agreement represented a new type of partnering and non-adversarial approach to project management. Rather than transfer risk on to its contractors, BAA (British Airports Authority, the main project sponsor and client) held all the risk on the project. By removing that burden from the supply chain, suppliers could work as part of an integrated team and focus on creating innovative solutions to any problems encountered during the project. Table 3 provides a summary of the differences between traditional contracting and the T5 approach.

INSERT TABLE 3 ABOUT HERE

One interviewee reflects on the impetus to find new ways to partnering in temporary organizations as follows: *"(…) I remember when I first got involved in the project, and with the team we carried out a piece of research which was against UK delivery norms from the National Audit Office and lots of other, you know, learning bodies. And the conclusion that that presented was if you did it the way that the UK always delivers projects with this degree of complexity, it would be a year late, it would a billion pounds more than we could have afforded and we would have killed six people. So from the outset it made it quite clear that a conventional way simply wasn't an option.* We had to find a smarter way of delivering a program of this type*"* [4]

BAA's previous involvement in the Heathrow Express project (a high-speed rail link between Heathrow airport and central London) laid the foundations for a new way of collaboration:
"(…) don't forget, prior to Terminal 5 we'd had a very successful experience of this with our Heathrow express rail project"

The usual solution to project failures is for the client to sue the contractor for breach of contract. At one point the Heathrow express project was 24 months behind schedule. BAA then recognized that *'there are two ways to get major problems sorted out. You either get people round the table with clearly*

[4] All emphases in quotations are added by the authors.

aligned objectives or you take them to court. And when you take them to court you're likely to be there for years and years and no one wins'.

Codifying the T5 handbook: risk and incentive alignment. The T5 Agreement, a legal document, was based on processes outlined in a more informal document called the T5 Handbook. The T5 agreement was devised to create a new set of behaviors that allowed project members to work under a new set of rules based on integrated project team working approach and partnering. The Agreement attempted to end the traditional pattern based on *'the client sitting on this side of the table and you are the contractor'*. Instead, the Agreement assumed that the client holds the risk all the time and is designed to achieve the desired outcome for the client and to '*fundamentally influence the behaviors that you then get to enable people to want to come together, rather than the reality: the minute anything goes wrong, that they're all going to take their positions and draw their pistols'*. BAA's use of the integrated team working in the Heathrow Express project *'was proof of concept that the agreement could work'*.

One informant further reflects on this as follows: *"It was a long and drawn out debate as a Board of Directors and we concluded that ultimately we [i.e. BAA] held all the risk all of the time, and therefore* what we wanted to do was to create a form of contract, the T5 Agreement, that actually converted risk into being a positive, *converted risk into being the area where people applied their most capable individuals to understand the dimensions of risk and then how you would mitigate it, you know, how you would manage that risk away. And that's the fundamental shift in this regard."*

In addition to changing the way the main sponsor managed risk and uncertainties, an additional element involved changing the different incentives of the various stakeholders involved. Focusing on the roles of different firms collaborating in a particular sub-project, one interviewee summarizes the incentive issue as follows: *"Firstly to do their own piece of the work against the benchmark cost.* But also they're incentivized on the performance of the integrated team; i.e. the completion of all the work. *So every time that they delivered at… beneath the agreed cost, the savings were shared three ways. So we shared, one part went to the supplier, one part went to BAA and one part was put in the incentive fund and these ratios varied in different areas."*

The T5 agreement in practice: integrated team working

While the T5 agreement laid the foundation for changes in the way different stakeholders collaborated, it remained limited to a formal agreement. Whether the formal contract translated to behavioral changes in the day-to-day practices of the different actors could not be taken for granted. While implementing the T5 agreement in practice, the T5 project management put a large emphasis on the use of "integrated teams" (focused on team identities, co-location, and shared incentives).

Project roles and firm capabilities BAA's main role in the T5 project *'has been to create an environment within which our suppliers can actually find the solutions'*. Integrated project teams had been formed to run every sub-project on T5. No organization within T5 worked as a sole participant – or prime contractor – within a team. In some teams, BAA was the project team leader, while in others it was the largest contractor (with the strongest capability) that performed this role. The formation of each integrated project team was driven by the T5 needs for capability: the people with the right skills and previous experience were brought together to carry out particular project tasks. The capability could be provided by organizations ranging from large corporate suppliers to small specialist firms and individual consultants. The selection of integrated project team members was based on an assessment of their capability, which included a judgment about their ability to behave 'constructively' rather than 'subversively' on a project. One example where the benefits of using integrated teams came to light was in the construction of the roof of the T5 building: in order to better understand and minimize the risks of erecting such a large roof, the T5 roof team – including designers, suppliers and fabricators – pre-erected the main roof structure off-site in Yorkshire (about 200 miles north of Heathrow), making large gains in terms of delivering this task ahead of schedule.[5]

Challenges in shifting to integrated team working. While the shift to integrated teams paid off to the T5 project as a whole, stakeholders faced challenges in changing their existing ways of work to these new practices. Collaboration between Laing O'Rourke (LOR), one of the main contractors in the T5 project, and Mott McDonald (a technical consultancy) provides an illustration of the challenges faced.

LOR's made frequent use of digital prototyping, which was driven in part by the need to solve a specific problem encountered by one of its integrated project teams. It wanted to use sub-assemblies for concrete reinforcements, rather than the standard practice of using loose bar.

Working as the designers in a team led by LOR, Mott McDonald was responsible for creating reinforcement design drawings for the production of sub-assemblies. However, LOR believed that Mott

[5] The roof of the main terminal building is 156 m long and was assembled in prefabricated elements. Each 156m steel beam is made up of 30m-long sections, which had to be transported by lorry to the Heathrow site and bolted together. When Hathaway, T5's roofing contractor, started working on the project in June 2000, it assumed that the roof would have to be assembled on site. However, Hathaway was encouraged by the architect in the team to adopt off-site prefabrication techniques and came up with the solution of fabricating the roof in 'lumps'. Pre-assembled roof cassettes of a standard size (3 x 6m) were developed for efficient transportation so that 10 cassettes could fit on a lorry at once. Hathaway built 12 prototype cassettes using different materials and tested their acoustic performance. A specially constructed factory produced over 3,000 cassettes for the main terminal and 950 cassettes for the satellite building. The pilot test produced lessons about how to mitigate the risk. The main roof contains 22 steel box rafter sections which were assembled and pre-fabricated into the largest pieces that could be transported to the site. This reduced the amount of work that had to be done onsite under hazardous conditions. This minimized any disruption to airport operations, reduced the number of vehicles moving on and offsite, and increased safety and project reliability. The central 117m arch section of the roof was assembled at ground level and jacked up 40m into its final position. Overall, the project team estimates that at least three months were saved by this pre-emptive risk management approach.

McDonald was making insufficient progress with the delivery of designs. At one point, designs produced by Mott McDonald for the reinforcement of structural elements were only 7% ahead of schedule, when they should have been 20% ahead of schedule to ensure that bulk materials could be ordered in time. The process was inefficient because there were many unnecessary feedback loops between the designers and the constructors. Consequently, as team leader LOR faced the possibility of being unable to meet its objectives for T5. The LOR team met with BAA and explained that the project would fail unless Mott Macdonald was told to accelerate the delivery of detailed designs. BAA responded by asking LOR (as the leader of the integrated team and working in the spirit of the T5 Agreement) to take responsibility for the project. LOR subsequently worked with Mott McDonald to solve the problem by using 3-D modeling. Rather than building physical prototypes, the team created digital prototype designs for rebar concrete.

The team worked together to carry out the detail design in the digital model. However, it was a cultural shift for both companies: LOR and Mott Macdonald both had to learn the new co-operative behaviors required by the T5 integrated team project working approach. Efforts to work more closely were met by considerable resistance from both Mott MacDonald side and LOR. Overcoming this inertia was a huge leadership challenge for both firms, which was achieved by continuously communicating and reinforcing the importance of the new behaviors. As highlighted by one interviewee: *“This is the way we’re going forward. We are going to use digital prototyping, and this is why and this is what it gives us. We are going to go to sub-assemblies and we are going to optimize reinforcement fabrication to drive down labor costs and labor levels on the project. And we are going to use ProjectFlow and you are going to plan your work and be held accountable for delivering it. And here are the reasons why.”*

The Mott MacDonald team ultimately recognized the benefits of this approach and worked closely with LOR to implement it. As a result, the process of producing detail design drawings of reinforcement sub-assemblies was reduced from six weeks to five days.

Co-location and team identities. Another aspect of integrated team working constituted the focus on the team identity, as opposed to the traditional emphasis on the firm identity. Several quotations below illustrate this focus on emphasizing the team (or sub-project) identity: *"But if you look at all of our people you can, you can't tell, distinguish between, you know, who are the, which company you work for generally."* Another informant: (the goal was) *"not to have people overtly identified with their own company. This created a much better team atmosphere…"* A further interviewee adds: *"If you walked onto the architectural fore plate for instance you wouldn't be able to tell who was being paid by me and who was being paid by them."* From another informant: *"… if you went into any part of the offices, either on site or off site, there were completely integrated teams. So you had people from any of the disciplines, professional disciplines, including the constructors. They also engaged down, right down at the work front where we brought some of our supervisors in to advise for instance engineers doing detailing around steel and stuff like that, how to actually assemble so that they could actually effect it in the site that more readily."*

The breakdown of the project helped to create sub-project teams that were focused on delivering specific tasks. However, in some cases the "sub-project identity became so strong that they were inward-looking and lost focus on the interfaces with the other projects…*and so for a period we really struggled at managing those interfaces."* BAA recognized that the sub-projects have to manage their own tasks as well as the dependencies with other projects in the overall program. Figure 2 provides a visual illustration of the contrast between the traditional and new way of organizing teams in inter-firm projects.

INSERT FIGURE 2 ABOUT HERE

B) Single Model Environment (SME): facilitating information transparency

Besides the T5 agreement and its emphasis on integrated teams, the second element for managing complexity was the use of the Single Model Environment (SME). The SME aimed to provide a central data repository for digital data relating to the project. This ensured that the work undertaken by different teams was coordinated to fit within the overall T5 program objectives. The SME aimed to prevent inaccuracies when information was shared between partners in the integrated project teams who needed to view it in the various design, production and construction phases of the project.[6]

BAA developed the SME during the early T5 planning period, which helped to meet the Public Inquiry requirement that the design had to be done up-front. The use of the SME in T5 was laid out in an early BAA IT strategy document as: capturing volume of information in a way that was manageable; controlling change; and assisting life-cost implications. Overall, BAA's vision for using the SME on the T5 project was *'to make it possible for all of the companies involved in the project to have access to a single design model, to be able to interrogate it, to be able to take a section from it, do their work and plug it back in'*.

[6] BAA developed the SME not only to assist design coordination and drawing production, but also to help plan T5's construction and future maintenance.

The creation of the SME was partly inspired by innovations outside of the construction industry, in particular the automobile sector. The car industry was able to achieve efficiencies in design through the use of standardized components: at the time, between 60-70% of car components were standardized and could be re-used across different products. Sir John Egan (BAA's Chairman during the initial stage of the T5 project) wanted to transfer this component-led design approach to the construction industry so that buildings could be created by *'mixing and matching Lego-like components'*.

SME: coordination, complexity and informational transparency. A key function of the SME was to facilitate coordination among actors that were dispersed in different parts of the country: *"The single model environment, it's primary intent was to coordinate the designs of all parties and a design integration and a design review process so that there was one view of the truth, one absolute statement design and that when each team developed their design, they could publish change in a coordinated manner and ensure therefore that when construction occurred there was very little chance of rework due to designs that didn't come together."*

Another interviewee explicitly highlights the role of the SME in relation to rising complexity:
"So you always need in any project, when it gets to a certain level of scale and complexity, some coordinating activity. The single model environment is the mechanism through which that sort of activity occurs."

Finally, a key role of the SME was to develop informational transparency for stakeholders working on interdependent subsystems: *"(…) the benefit of a single model was that everybody could see it. And although we had all the major design teams working in a co-located environment, other than some very key and specialist members of the supply chain, the others were dispersed around the country."*

Challenges implementing the SME (1): incompatible standards. BAA attempted to accommodate the numerous processes used by the designers and supply chain so that T5 could be based on a single model using standardized rather than bespoke software solutions. However, many of the companies involved in T5 continued to use their own design software (such as MicroStation and AutoCAD). As one informant explained, it would have been better if the suppliers involved all used the same software: *"If I were doing the same project again, or any other project for that matter, I would insist on everybody using the same software. Because it's very complicated trying to adapt people's designs which are done under one sort of software umbrella and to fit into a single model."*

Challenges implementing the SME (2): cultural shifts and capability gap. As the SME became used during T5, it was regarded as a useful tool for macro-level co-ordination of space layout and planning. However, there were difficulties getting design data input into appropriate formats. BAA realized that co-location or at least face-to-face interaction was vital for dissemination of design practices that are conducive to the SME. As one manager explained: *"Part of that is making them come and do it here, and saying, right guys we are going to set it up at Heathrow, we want your main men at Heathrow and we want them to understand how it's going to be done.* Because at the end of the day we want a single model back, we don't want cupboards full of drawings which are all different; *we want a single model back."*

The main reason why the SME could not be fully implemented and used effectively on T5 was that the UK construction industry did not have the 1200 designers with the level of capability needed to understand the benefit of using and exploiting the full potential of the tool. Many of the CAD designers employed on T5 came from other industries. As a result of this, the software used in the original SME had to be downgraded (from AutoCAD MAP to AutoCAD plus X-referencing) to match the capabilities of designers, and use became locally organized, per sub project. Here, success depended on the complexity of the work; the level of capability of people in the team; and their behavioral attitudes towards integrated team working. Informants reflect on the latter issue as follows: *"The important thing is the process for the coordination of design. So building the set of procedures of how we work together and embedding those as elements of the commercial relationships."* Another interviewee emphasizes: "But it’s not about the software, it’s about the culture, how people want to operate."

Challenges implementing SME (3): constraints and regulations. BAA’s efforts to improve project performance were aided by the use of the SME. BAA wanted the numerous designers and suppliers involved in T5 to have access to an SME based on a standardized software solution, rather than bespoke system. When concept design for T5 began in January 2000, BAA inherited AutoCAD MAP as the platform for computer-aided design and Documentum as document management platform. As the project grew in scale and complexity, the SME was upgraded using more advanced technologies and applications, such as a T5 Windows Explorer environment and Architectural Desktop. However, the SME only worked when the designers adhered to the same set of standards and processes, which was not always possible because many suppliers on T5 continued to use their own design software, such as MicroStation and AutoCAD. One informant emphasizes the need for continued emphasis on using common standards where possible: *"You’ve still got to have lots of rules and regulations, and* somebody has got to be in charge of this bloody model otherwise the whole thing will become a complete mess."

Modular designs: standard components, pre-fab construction, interface compliance

The previous section highlighted the use of the Single Model Environment (SME) to reduce interdependence and complexity, as well as the challenges in implementing and using the SME.

Generally, the SME facilitated usage of modular designs, focusing on standardized components, off-site construction, and interface compliance. Modular designs helped manage the great levels of complexity and interdependence encountered in a large-scale project as the T5 construction, described in further detail below.

Standardized components to manage costs and complexity. One aspect of T5's emphasis on modular designs involved the usage of standardized components. Here, mature technologies were emphasized, to avoid uncertainties in integrating these. Standard components further reduced the risk of rework, thereby suppressing costs. Several informants describe the use of standardized components as follows: *"When you're talking about large scale projects, levels of complexity multiply enormously.* And just to handle the complexity, having something that is standardized, *whose dimensions you know, whose weight you know, whose ability to be moved around a construction site, you know, for example, whose safety implications you know, is an advantage. You're trying to narrow all your variables on a big construction project, risk and managing risk is a significant element of the process. And the more you can understand and know about and measure in general terms, and plan as groups, and integrate together, the greater certainty you can generate."*

"So there's modularization of building fabric and there's modularization and standardization of enormous amount of context which is not necessarily basic shell, but is stuff that passengers always interface with. Whether it be balustrading, whether it be staircases, whether it be escalators, whether it be seating, whether it be information screens, they're all standard components."

"And rework is phenomenally expensive. Normally it's very cheap to change what's on a CAD drawing but when you're having to do changes in concrete and steel, it becomes phenomenally expensive. So

when we looked at other large projects, particularly projects which have very many interfaces and very many suppliers, we found that the percentage of rework in some areas was quite high. It could be 10 or 20% for some disciplines. That would involve on a project of £4.3 billion, that would be a lot of money."

Just as the T5 agreement emerged gradually based on knowledge developed in previous projects, the emphasis on standardized components similarly arose from earlier experiences. An important part of BAA's strategy to improve its project processes was implemented in 1995 when a new standardized process for delivering capital projects was developed called 'Continuous Improvement Project Process' (CIPP). The CIPP process was embodied in a BAA Project guide book, which provided a set of guidelines for delivering *'cost effective and profitable projects through the consistent application of best practice'* (BAA Project Guide, 1995). As well as improving processes, BAA's CIPP approach was devised to achieve efficiencies based on the principle 'design it once, build it multiple times'. This component-led design approach could be achieved by creating standardized and replicable products and components, ranging from whole buildings to specific modules such as standardized toilets.

In contrast to these standard components, in other areas the complexity of the project increased due to the number of systems and operators in the Terminal 5 building. Some of the largest and most complex systems that were integrated into T5 included the £239m – the world's largest at the time – baggage handling system, the building management system and the fire alarm system supplied by Honeywell. The value of using mature technologies was further highlighted in the problems associated with the operation of the luggage system during the opening period of T5.

Off-site, prefab construction and just-in-time development. In addition to using standardized components, another element of modular designs is reflected in the use of off-site and prefabricated construction, based on just-in-time development techniques. Several informants reflect on this as follows: *"We built part of the structure in Yorkshire with the architects, with the structural engineer, with the crane driver, to make sure that the lessons [and associated problems] we learnt in Yorkshire were not repeated on the job site. We took all of our systems and our system integration in an interface test facility so that from an IT perspective we designed things simply, that could be enhanced in the first few years of operation, but that we didn't import any of the IT risks to site through that important period of configuration management and interface testing."*

"We had to take that thinking into Terminal 5 context which, in itself, was a major civil engineering project with very, very large components and not a lot of which were how we described off the shelf components. So we set about managing the whole construction methodology around offsite fabrication, modularization, building sub-assemblies, creating a facility which was about a mile away from the site where these sub-assemblies could be brought together and assembled into a larger sub-assemblies, and then transport it to the site on adjusting time basis."

"Another part of the challenge was to do Just In Time prefabrication. So we used to pull data out of the single model environment in the evenings, transmit it over to a steel bending plant that we set up just across the other side of the M25 in our logistics center, steel would be delivered off the rail head that we had there, it'd be bent, welded and shipped across the site in the evening and arrive in the morning from designs that were only fixed the night before, yeah."

Design preparation and interface compliance. Finally, another element of modular designs involved the emphasis on managing interfaces between subsystems and its importance during the design phase. In preparing for the construction of T5, it was recognized that many projects failed because of insufficient investment in the design phase of the project: *“The importance of the design phase is that is when you achieve your biggest wins. You’re never going to achieve them during the construction phase.”*

Another informant emphasizes the importance of managing interfaces upfront where possible:
"I built a thing called the interface test center. For any electronic system to be installed in the terminal it had to prove all its dependences and interfaces offsite in the test center before it was allowed to be installed in site. So that way rework and misconfiguration and misbuilds were dramatically reduced. So this technique of taking work off the site extended well beyond just prefabricating some large steel plant."

In summary, our empirical data highlight two key elements used in the T5 project to manage complexity by reducing interdependencies. First, the T5 Agreement codified a specific set of behaviors that emphasized incentive alignment to manage the risks inherent in a project of the scale of the T5 endeavor. In practice, the agreements laid down in the T5 Agreement worked out by an approach focused on integrated team working. This approach emphasized team identities, co-location, and shared risk and reward structures. Second, a set of technologies complemented these behaviors in the form of the Single Model Environment (SME), a tool facilitating coordination by increasing informational transparency. Our data also emphasize the challenges in making such a tool work in practice, in particular the challenges caused by incompatible standards, capability gaps and other constraints; more generally the importance of stimulating or enforcing the usage of the tool is emphasized, highlighting the behavioral element of making the technology work. Further, the SME facilitated the use of modular product designs, which focused on standardized components, off-site and prefab construction, and interface compliance.

Overall, the T5 Agreement and the SME appear to act as complementary components, whose combined usage reinforces the benefits from each element individually. A temporary organization that focuses solely on integrated practices would appear to be penalized in terms of economies of scale (e.g. due to lack of standardized components) and costs more generally (e.g. increased coordination costs between teams). In turn, projects that depend solely on modular designs lack the practices required to integrate these various modules (which still requires interface compliance where standards differ, and stimulation and enforcement to increase informational transparency). Therefore, it appears to be the joint usage of these two elements that constitutes the overall template to manage complexity and reduce interdependence. Figure 3 provides a visual overview of the key elements described in our setting.

INSERT FIGURE 3 ABOUT HERE

DISCUSSION

The dynamics observed in the T5 case contain a number of implications for our understanding of how organizations might use modular designs to manage interdependence in temporary organizations. In particular, the case highlights the importance of complementing modular designs (e.g. standardized components emphasizing informational transparency) with *behavioral coordination mechanisms focused on integration* (e.g. incentive alignment, shared identities, co-located teams). As such, our findings point to several implications for existing literature on how firms manage complexity and the underlying mechanisms involved in managing organizational interdependence.

First, our data underline the importance of complementing modular designs with integrated practices. As such, this contrasts with existing work that has suggested that modular product designs pose a substitute, or minimize the need for organizational coordination (Sturgeon, 2002; Langlois, 2002). Instead, in this setting modular designs need to be complemented by practices emphasizing integration (co-location, strong team identity). As such, our findings are more in line with work that has underscored the importance of organizational coordination, in spite of the use of modular product designs (e.g. Brusoni et al., 2001; Staudenmayer et al., 2005; Zirpoli and Becker 2011). Our study extends these existing studies by analyzing the various organizational practices needed to complement modular product designs. Therefore, our findings also speak to recent work that has investigated under what conditions modular products are produced by modular organizations (Hoetker, 2006; Colfer and Baldwin, 2010). This study departs from existing work by pointing to the behavioral elements needed to make modular designs function in practice. Modularity is not a technological fix; instead, a set of practices is needed to integrate the various modules. Paradoxically, these practices emphasize coordination mechanisms emphasizing integration (e.g. co-location, strong team identities, incentive alignment), as opposed to modularity (e.g. arms-length contracts, virtual collaboration).

Second, the case points to the importance of information transparency to aid coordination, as well as the challenges in achieving such transparency. The single model environment used in this setting served as a way to help geographically dispersed actors coordinate subsystems that need to be integrated over time. The importance of information transparency is similar to what Colfer and Baldwin (2010) referred to as "actionable transparency", referring to the shared representations (i.e. software source code) used in open-source based software development. However, what is different in physical infrastructure projects such as this setting is that the representations are *not* equivalent to the artifact (in contrast to the source code example). Rather, in construction projects it is crucial that the shared representations (in our case embodied in the Single Model Environment, SME) matched, to the extent possible, the physical reality constructed on the work sites. The key challenge then, is to ensure that the shared model does not become de-coupled from the physical artifacts. As such, maximizing information transparency becomes the overall goal, highlighting the importance of stimulating maintenance of the model (which may be helped by e.g. incentive alignment). The importance of the notion of information transparency further adds to earlier work on information richness as a way to facilitate coordination (Daft and Lengel, 1984). Their study introduced an ordinal scale (with face-to-face interaction as the highest degree of information richness, and numeric computer output as the lowest) of information richness vis-à-vis particular tasks. Information transparency can be considered orthogonal to this scale, as it may apply to both information-rich and information-poor environments. Our findings further underline Adler’s (1995) emphasis on “analyzability” as a critical dimension for managing interdependence. In our study, the SME can be regarded as an empirical example of a tool that increases analyzability for project participants, thereby aiding coordination and decreasing interdependence.

Third, our findings also resonate with recent work that has pointed to the importance of "tacit" coordination mechanisms for firms that integrate tasks among geographically distributed sites (e.g. Srikanth and Puranam, 2011). These studies have highlighted the importance of establishing "common ground" (Clark, 1996), which is built through several means, including enabling actions to be transparent across different locations and having knowledge of individual idiosyncrasies through shared work experiences. The data from our setting reinforce this idea, while suggesting that some of these mechanisms may not be limited to geographically distributed work teams. In our case, information transparency (facilitated through the SME) allowed teams to collaborate as if they were co-located, though this mechanism applied both to remote *as well as* closely collaborating teams. Further, for all teams, incentive alignment and shared identities were emphasized, thereby strengthening "common ground" the various teams could draw upon. More generally, as highlighted earlier, the data emphasize the importance of behavioral elements to facilitate the use of modular product designs. It also shows the challenges of changing existing patterns and roles (Bechky, 2006; Jones and Lichtenstein, 2008). These organizational patterns appear to be maintained by a combination of formal and informal practices. Formally, codified agreements help shape behavior, in particular when care is taken to make sure incentives are aligned to the greatest degree possible. Informally, where formal procedures are not in place, individual actors need to stimulate desired behaviors (such as maintenance of shared information repositories) to aid coordination and reduce interdependence.

CONCLUDING REMARKS

Building on recent work that has argued for a more contingent understanding of how product and organizational architectures are related (Colfer and Baldwin, 2010), our study has highlighted how firms might manage complexity and interdependence by combining modular product designs with integrated organizational practices. At the product level, modular designs help reduce interdependence. In turn, integrated practices allow coordination to manage unforeseen or residual interdependencies that invariably arise in complex temporary organizations as the one observed in our setting. Therefore, our study highlights how modular designs and integrated practices might be mutually reinforcing, as opposed to the traditional conceptualization as being opposing ends of a continuum.

As such, our work attempts to contribute to existing research on how firms manage complexity and interdependence in several ways. First, the findings in our case underline the importance of complementing modular designs with integrated practices. In this setting, they act as complements, mutually reinforcing the value of the individual elements. Second, the case points to the importance of informational transparency to aid coordination, which ties into existing work on information richness to reduce interdependence. However, in contrast to existing work that has looked at information-based settings (e.g. software), our setting also points to the challenges in achieving such transparency. Third, our findings resonate with recent work that has emphasized the importance of "tacit" coordination mechanisms for firms that integrate tasks among geographically distributed sites. Our results suggest that these mechanisms may also be relevant to co-located teams, and more generally emphasizes the importance of behavioral elements to facilitate the use of modular product designs.

Our study may also have implications for practitioners. In particular, the combination of modular product components and practices emphasizing integration appear to be a potent way to manage the complexities that invariably arise in temporary organizations. While the overall approach to managing interdependence may also work in other settings, it is crucial to keep in mind the idiosyncrasies of this setting that may complicate its implementation in other areas. This is an important limitation to our current study. Further research might further look into how this approach works out in other settings.

APPENDIX

Overview of Heathrow Terminal 5 sub-projects and stakeholders

BAA (the British Airports Authority) built the £4.2bn fifth terminal to increase Heathrow's capacity from 67 million to 95 million passengers a year. On completion, BA (British Airways) transferred their entire Heathrow operation (which before that was split between Terminals 1 and 4) to T5. The project built a large array of airport infrastructure including:

- Two terminal buildings: Concourse A, the main terminal building, is 396m long, 176m wide and 39m high and Concourse B, the satellite building, adjoining the T5 building is 442m long, 42m wide and 19.5m high
- A network of over 13km of bored tunnels
- Two river diversions
- A new M25 spur road
- A new air traffic control tower
- Airfield infrastructure
- A 4,000 space multi-story car park
- A 600-bed hotel

Some of the major organizations in the T5 project supply chain included:

- BAA: T5 project sponsor, client, airport owner and operator, T5 project manager and systems integrator
- British Airways: main project customer; user of the T5 campus.
- Richard Rogers Partnership: lead architect
- 60 first tier suppliers covering diverse areas such as construction (e.g. LOR Civil Engineering Ltd and Balfour Beatty), design (e.g. Arup), technical consultancy (e.g. Mott MacDonald), IT (e.g. Alcatel Telecom) and transportation systems (e.g. Thyssenkrupp Airport Systems).

The four major groups were broken down into 16 projects and 147 sub projects (ranging from small projects valued at £1 million to much larger projects, such as the Heathrow Express station which alone represented a £300 million investment). For example, the Infrastructure group ran a single airfield project which is broken down into about 12 sub-projects. The sub-project is the level at which work was organized. As one interviewee remarked: *'what that meant was that people were managing things on a scale that they could comprehend, that actually probably matched the scale of things they had delivered before and therefore allowed them to relate their experiences before'*. The project workload varied over time. For example, Rails and Tunnels started out with about 17 projects, but by 2006 this had reduced to four main projects – the Heathrow Express extension, the Piccadilly Line extension, the Track Transit System and the Airside Road Tunnel.

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FIGURES AND TABLES

Characteristics of Stage	**Stage 1: Oct 2005 – June 2006**	**Stage 2: July-Oct 2009**
Objectives	Explore general dynamics in T5 project focused on 1) usage of digital technologies to manage risk and complexity, 2) capabilities and learning	Focus on the interaction between digital technologies (e.g. SME) and behavioral mechanisms (e.g. T5 Agreement)
Primary sources: interviews	Interviews (total 30) LOR (19), BAA (10), BA (1)	Interviews (total 9) LOR (3), BA (1), BBM (1), GO Ltd (1), Severn Trust (1), Rogers Stirk Harbour & Partners (1), Volkswagen (1)
Secondary sources	Business press and trade journals Internal documents (e.g. T5 Agreement and Handbook)	Business press and trade journals Internal documents (e.g. T5 Agreement and Handbook) Research papers and books on T5

Table 1: overview of data gathering stages and data sources

A: T5 Agreement	
Key objective T5 agreement: codifying behaviors focused on incentive alignment	
Topic	**Description / illustrative quote(s)**
T5 agreement origins: Impetus for changing behaviors	*"(…) if you did it the way that the UK always delivers projects with this degree of complexity, it would be a year late, it would a billion pounds more than we could have afforded and we would have killed six people. So from the outset it made it quite clear that a conventional way simply wasn't an option. We had to find a smarter way of delivering a program of this type."*

Codifying the T5 handbook: Risk and incentive alignment	*“what we wanted to do was to create a form of contract, the T5 Agreement, that actually converted risk into being a positive”* *“But also they’re incentivized (i.e. T5 project participants) on the performance of the integrated team; i.e. the completion of all the work.”*
The T5 agreement in practice: integrated team working	
Project roles and firm capabilities	BAA’s main role in the T5 project *‘has been to create an environment within which our suppliers can actually find the solutions’*. Integrated project teams had been formed to run every sub-project on T5. No organization within T5 worked as a sole participant – or prime contractor – within a team
Challenges in shifting to integrated team working	Efforts to work more closely were met by considerable resistance from both Mott MacDonald side and LOR. Overcoming this inertia was a huge leadership challenge for both organizations, which was achieved by continuously communicating and reinforcing the importance of the new behaviors. *“This is the way we’re going forward. We are going to use digital prototyping, and this is why and this is what it gives us. We are going to go to sub-assemblies and we are going to optimize reinforcement fabrication to drive down labor costs and labor levels on the project. And we are going to use ProjectFlow and you are going to plan your work and be held accountable for delivering it. And here are the reasons why.”*
Co-location and team identities	*"But if you look at all of our people you can, you can’t tell, distinguish between, you know, who are the, which company you work for generally."*
B: Single Model Environment (SME)	
Key objective SME: facilitating information transparency	
SME drivers and vision	Overall, BAA’s vision for using the SME on the T5 project was *‘to make it possible for all of the companies involved in the project to have access to a single design model, to be able to interrogate it, to be able to take a section from it, do their work and plug it back in’*.
Coordination, complexity and informational transparency	A key function of the SME was to facilitate coordination among actors that were often dispersed in different parts of the country: *"The single model environment, it’s primary intent was to coordinate the designs of all parties and a design integration and a design review process so that there was one view of the truth, one absolute statement design*
Challenges implementing the SME (1): incompatible standards	*“If I were doing the same project again, or any other project for that matter, I would insist on everybody using the same software. Because it’s very complicated trying to adapt people’s designs which are done under one sort of software umbrella and to fit into a single model.”*
Challenges implementing the SME (2): cultural shifts and capability gap	BAA realized that co-location or at least face-to-face interaction was vital for dissemination of design practices that are conducive to the SME. As one manager explained: *“Part of that is making them come and do it here, and saying, right guys we are going to set it up at Heathrow, we want your main men at Heathrow and we want them to understand how it’s going to be done. Because at the end of the day we want a single model back, we don’t want cupboards full of drawings which are all different; we want a single model back.”*
Challenges implementing SME (3): constraints and regulations	However, the SME only worked when the designers adhered to the same set of standards and processes, which was not always possible because many suppliers on T5 continued to use their own design software, such as MicroStation and AutoCAD. One informant emphasizes the need for continued emphasis on using common standards

	where possible: *"You've still got to have lots of rules and regulations, and somebody has got to be in charge of this bloody model otherwise the whole thing will become a complete mess."*
Modular designs: standard components, pre-fab construction, interface compliance	
Standardized components to manage costs and complexity	*"So there's modularization of building fabric and there's modularization and standardization of enormous amount of context which is not necessarily basic shell, but is stuff that passengers always interface with. Whether it be balustrading, whether it be staircases, whether it be escalators, whether it be seating, whether it be information screens, they're all standard components."*
Off-site, prefab construction and just-in-time development	*"We built part of the structure in Yorkshire with the architects, with the structural engineer, with the crane driver, to make sure that the 120 lessons [and associated problems] we learnt in Yorkshire were not repeated on the job site. We took all of our systems and our system integration in an interface test facility so that from an IT perspective we designed things simply, that could be enhanced in the first few years of operation, but that we didn't import any of the IT risks to site through that important period of configuration management and interface testing."*
Design preparation and interface compliance	*"I built a thing called the interface test center. For any electronic system to be installed in the terminal it had to prove all its dependences and interfaces offsite in the test center before it was allowed to be installed in site. So that way rework and misconfiguration and misbuilds were dramatically reduced. So this technique of taking work off the site extended well beyond just prefabricating some large steel plant."*

Table 2: Key elements for managing complexity and interdependence in T5 Project

Contracting approach	
Traditional contracting	**T5 contracting**
Transfer of risk	BAA manages the risk
Price in advance	Reimburse properly incurred costs
Profit at risk	Profit levels pre-agreed
Penalties	Success driven
Silos	Integrated teams
Best practice	Exceptional performance

Table 3: Traditional vs. T5 contracting approach

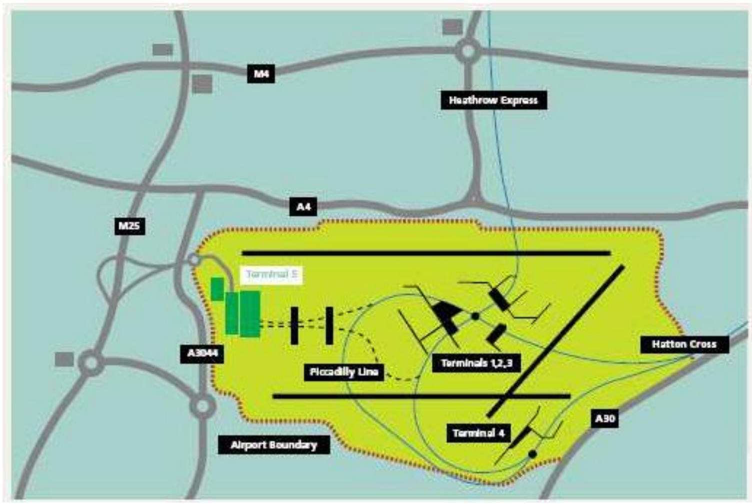

Figure 1: geographical location of T5 terminal (highlighted in dark green on left side)

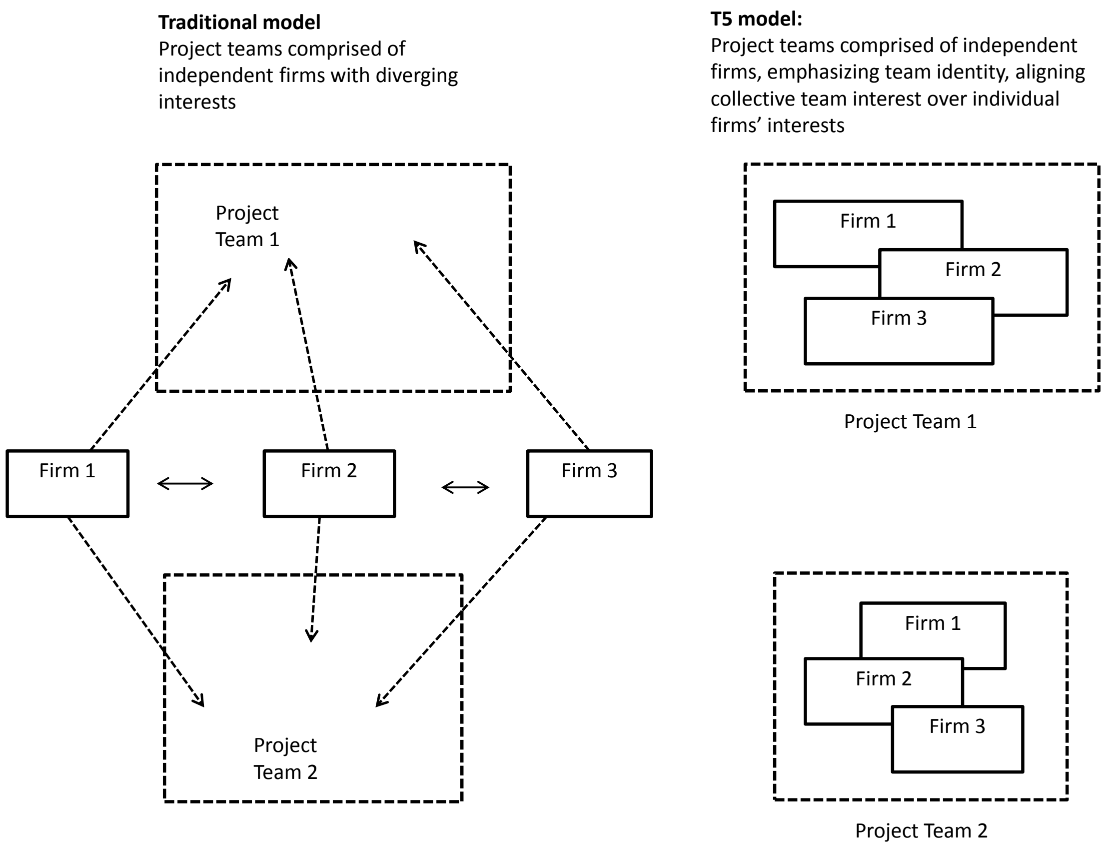

Figure 2: traditional vs. new ways of collaborating

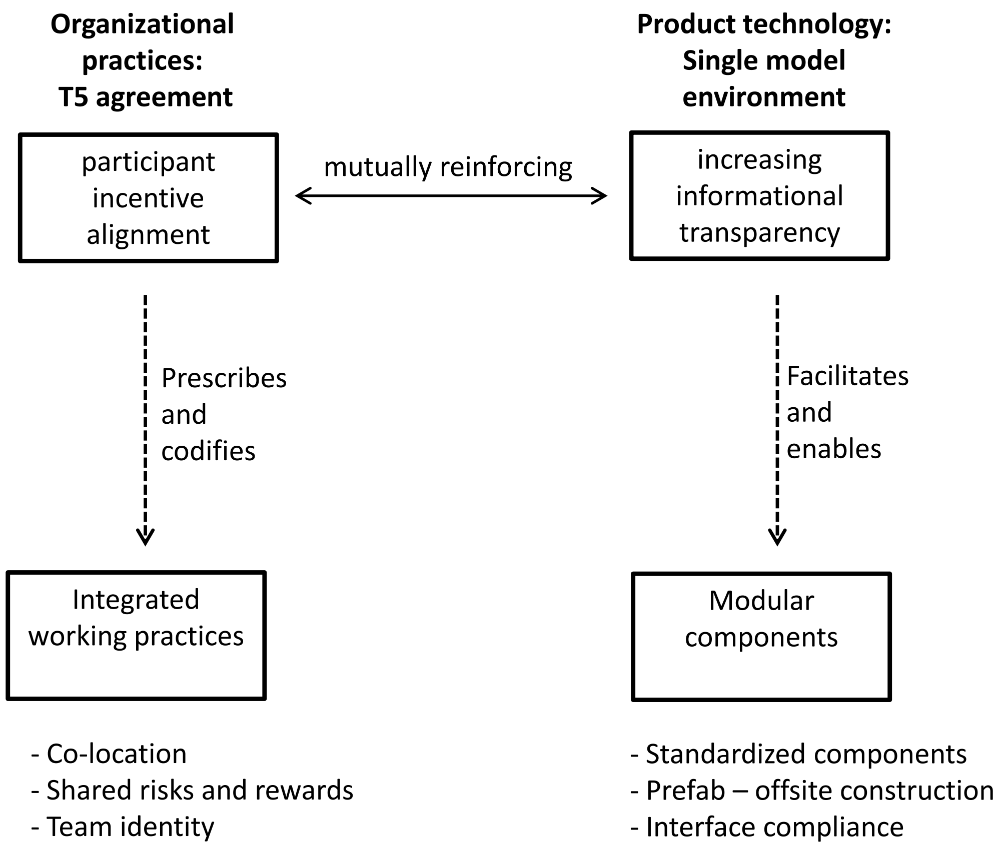

Figure 3: Managing complexity and interdependence in temporary organizations