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Analysis of information integration benefit drivers and implementation hindrances

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ABSTRACT

This paper presents an analysis of benefits and hindrances for specific information integration implementations in the industrial construction sector. A tool, developed by a Construction Industry Institute research team, detailed 37 benefit drivers and 34 hindrances that affect information integration implementation efforts. The tool was applied to 16 test cases. Scores from the cases allow analysis of the importance and consistency of factors. Findings reveal that benefit drivers have a certain degree of consistency, particularly around justification to enhance work process benefits rather than broader benefits to project outcomes. On the other hand, there is a much wider range of important implementation hindrances. These findings suggest that each implementation requires a customized approach to address hindrances rather than reliance on generic methods. More broadly, the set of specific benefit drivers and hindrances extends and generalizes the literature on information integration implementation in construction, particularly with respect to the industrial sector.

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1. Introduction

Information integration has been widely implemented in the capital projects industry in various forms. For example, a recent broad industry survey found that 49% of respondents answered they use Building Information Modeling (BIM) or BIM-related tools [1]. Similarly, 48% of engineering and construction firms are reported to use Enterprise-Resource Planning (ERP) packages [2]. Although very different technologies, both BIM and ERP systems advance the integration and management of business information.

Despite increasing levels of information technology adoption, implementation success varies. It is argued that firms tend to focus on technical challenges to the detriment of cultural and organizational factors when they design and implement information technology, which may limit benefits [3]. O'Brien [4] argued that sociological issues are important to consider for successful use of project web sites. Factors related to organization, process, people, and legal context have been reported to influence successful technology implementation [5–7].

This paper builds on previous research to explore in more detail factors driving and hindering implementation of specific information integration opportunities. In particular, this paper explores the results of 16 applications of an Integration Opportunity Assessment Tool (IOP Tool) designed and validated by Construction Industry Institute Research Team 258. The team defined information integration as "the sharing of information between project participants or melding of information sourced from separate systems." [8]. The tool assesses the benefits and hindrances of specific information integration opportunities identified by firms for potential implementation. Specific information integration opportunities can be small or large (for example, application of commercial CAD tools that leverage limited data sets to enterprise wide information tools). The tool walks users through 37 benefit driver questions and 34 implementation hindrance questions, which are grouped into categories of market/legal, organization and process, and people/roles/training, and provides a score that summarizes relative driver/hindrance weights. Trends and variations across answers to these 16 applications are explored and compared to the extant literature. The authors find some consistency among rankings of important benefit drivers but considerable variation in hindrances, suggesting a more tailored approach to integration is needed for each implementation.

This paper follows with several sections. Section 2 makes a brief review of the literature relating to implementation of information integration implementations and discusses its shortcomings with respect to generality beyond specific technologies and sectors. In particular, much of the construction literature is not based in the industrial sector, which is the focus of this paper. Section 3 provides a brief introduction to the IOP Tool which was used to generate the data for this study. Building from the previous sections, Section 4 discusses the research objectives and methods to explore two research questions relating first to generality and expansion of the literature and second to consistency of applicability of factors affecting

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implementation. Section 5 presents an initial analysis of the research teams' scoring of the relative importance of the benefit driver and implementation hindrance questions described in the IOP Tool. Section 5 also serves as an introduction to the detailed questions contained in the tool. Detailed findings are presented in Section 6, which reviews the application of the IOP Tool to 16 cases in the industrial sector. Section 7 summarizes the discussion in Sections 5 and 6 to present three specific contributions of the paper. Section 8 presents the summarized conclusions and outlines future research directions.

2. Literature review

There have been many studies investigating various benefits and obstacles to implementing information integration technology within the construction industry. An early study of challenges to CAD adoption with AEC firms by Tatum et al. found a range of issues from technical to legal to behavioral [9]; less emphasis was placed on organizational or process implications as the firms interviewed had experience largely with implementation of specific CAD systems and broader integration with work processes was not yet underway. Since that study, numerous studies within the construction industry as well as the broader business literature have investigated information integration implementations. Apart from technical issues which are often system specific, there are three generally agreed broad categories of factors influencing integration: market and legal factors, organization and process factors, and people-related factors. Each category is briefly discussed below.

2.1. Market and legal factors

Market and legal forces significantly shape information implementation efforts. Market expectation can be a driver for investment. For example, a survey conducted by McGraw-Hill Construction revealed that owners' demand for Building Information Modeling (BIM), is the second highest reason influencing the use of BIM [10]. Contractual arrangements also may drive (or restrict) adoption of integration technologies [5,11]. Taylor [6] argued that new contractual arrangements in interorganizational networks are an antecedent for successful 3D CAD implementation. The legal environment creates the pathways for information to flow. Beyond contracts, significant characteristics include data and information security [12,13], data ownership [14,15], and intellectual property [13]. Other forces can restrict or support implementation. In particular, the labor market can affect implementation depending on both available skills and legal restrictions (for example union agreements can restrict the ability to substitute information technologies for labor via anti-automation clauses [16]).

2.2. Organization and process factors

Information system resources play an interdependent role with other organizational resources [17–19]. Many researchers have observed that adoption of new technology leads to profound organizational shift, facilitating changes in policies, rules, organizational structure, work practices, and organizational culture [20–24]. Since a significant portion of capital project processes requires interorganizational cooperation, external integration is important. For this reason, the IT resources of an organization's trading partners are important consideration when designing and implementing integrated processes [16,25]. Indeed, an early paper by Ahmad et al. argues that for capital project processes, technology needs to be implemented to facilitate complex interrelationships among various participating entities [26].

Several supporting factors have been identified as necessary for implementation success. Alignment between organizational strategy and information technology strategy is also generally thought to improve performance [27–29]. Top management commitment is another important organizational factor identified by academic literature as a substantial portion of IT investment is determined by top management's 'gut feeling' or instinct [18,30–35].

Specific to capital projects, various studies have investigated the benefits of information technology. Some statistical studies have shown that application of integration technologies lower project costs [36,37] and result in schedule reduction [38,39]. In a study of 3D CAD implementation, Taylor [6] argued that using new technology leads to changes of work scope and pattern and that through these changes there are beneficial results to project outcomes. Similarly, Anumba et al. [40] argued that higher level of concurrency in processes requires a higher level of coordination and communication, which in turn increases the importance of information technology to support a range of processes. In particular, version control [40–42] and process compatibility [12] can be strong drivers for information integration.

2.3. People-related factors

A factor cited by many research studies as a key to the successful implementation of information integration is the level of innovation encouraged in the existing culture and the degree of cooperativeness [18,24,43]. Davis and Songer [7] argued that cultural issues are a major hindrance in implementing IT in the architectural, engineering, and construction (AEC) industry. Yet beyond observations about the importance of culture, specific issues have often been understudied compared to other factors [16]; this is somewhat surprising because IT can generate competitive value only if it leverages preexisting human resources in the organization [44]. One area that has received some study is the need for training on technologies and processes to assure successful implementation [11,16,33]. Barki and Pinsonneault [29] discussed the need to jointly consider training, compensation, and personnel development in a holistic manner to leverage investments in information integration.

2.4. Discussion

Since the paper by Tatum et al. [9], there has been considerable progress in documenting information integration implementation efforts. Discussion of both benefits from and hindrances to implementation continues and our understanding is incomplete. Most of the construction literature is based in the AEC or commercial sector and it is unclear to what extent is can be generalized to other sectors. Similarly, the general business literature on IT adoption has many observations, but their application to construction is unclear.

Within construction, much research remains focused around case studies (for example, [6]) or surveys of specific technologies (for example, market reports on BIM usage [1,10,45]). For both drivers and hindrances, some papers have sought to generalize and bring together lists, but it is difficult to know which benefit/hindrance is appropriate in a particular context. For example, Fischer et al. list a range of benefits of 3D CAD [46–49], but translating these benefits to a specific project is difficult. Quantification of benefits in terms of dollar savings remains an open goal; reports here are generally presented as case studies with little ability to be generalized. Few papers report benefits to work processes rather than benefits to project outcomes, although in the general business literature there is a stream of research suggesting benefits from IT are derived from changes to work processes [22,33,50]. An exception is the work of Nitithamyong and Skibniewski [5] who report on a survey of professionals with respect to web-based construction management systems, listing and ranking a number of process related factors; it is unclear that these results can be generalized as they are about a specific technology.

With respect to implementation challenges, studies similarly tend to focus on specific cases or technologies (see the BIM market reports

[1,10,45]). Some reviews seek generalization. For example, a recent paper by Erdogan, et al. [3] reviews the literature and suggests implementations of collaborative environments need to be planned with respect to both technical issues and changes in work process, and hence must be introduced to the organization as such for the technology to yield its intended benefits. Several common challenges are listed and the authors state the need for a systems approach to planning and managing implementation, but do not otherwise assert which factors may be more relevant than others in specific contexts. Nitithamyong and Skibniewski [5] in their survey of web systems do list a range of factors affecting implementation and from their survey rank them, although as with benefits generality of the findings beyond the technology is unclear.

Overall, while there is considerable knowledge in the literature about both benefits and hindrances to information technology implementation, much of that knowledge remains tied to individual technologies as well as industry sectors (in particular, the commercial or AEC sector). Generalization of specific factors is unclear, as is knowledge about the relative importance of those factors.

3. Information integration opportunity assessment tool (IOP tool)

The literature reviewed above identifies a number of factors that affect both drivers and hindrances to information integration implementation. However, this knowledge is broadly distributed and provides little guidance about how a firm should leverage the knowledge for assessment of specific implementations. In response to this, CII Research Team 258 (RT258), Information Integration to Improve Capital Project Performance, was chartered to review the state of information integration in the capital projects industry (namely, the industrial construction sector that CII membership represents) and help provide a path forward. The team conducted its research from fall 2007 to winter 2009/2010.

A specific product developed by RT258 is the Information Integration Opportunity Assessment Tool (IOP Tool), which is a spreadsheet based application that asks users to assess applicability of benefit drivers and implementation hindrances for their specific integration opportunity. The tool takes users through 37 driver questions and 34 hindrance questions where they rate each question as High, Medium High, Medium Low, Low, or None/Not Applicable. These user assessed answers are normalized and weighted in a scoring algorithm that provides a (benefit driver, hindrance) pair expressed as a percent for each measure. The purpose of this simplified scoring pair is to allow firms to make comparisons between opportunities as well as make an overall evaluation the likely success of a given opportunity. Scores are plotted against a chart divided into red/yellow/green zones of implementation success (Fig. 1 shows a sample IOP Tool score plotted on the chart). Details of the IOP tool, its validation, and recommended uses are provided in [8] and [51].

The 37 benefit driver and 34 implementation hindrance questions in the IOP Tool comprise the collective experience of the research team, which had four members from owner organizations and eight members from contractor organizations. The driver and hindrance questions were developed by the team in an iterative process under the guidance of the academic team members. Initial creation of questions was performed in brainstorming sessions with the team. The questions were later refined through multiple, iterative review sessions to remove duplicates, add questions where influences were missed, and to add precision. As part of this process, the academic team reviewed the questions against the existing literature to identify any missing items as well as help add clarity. However, the primary source and screen for the questions was the team members and their experience, and thus the questions can fairly be said to reflect the contemporary experience of the industrial construction sector.

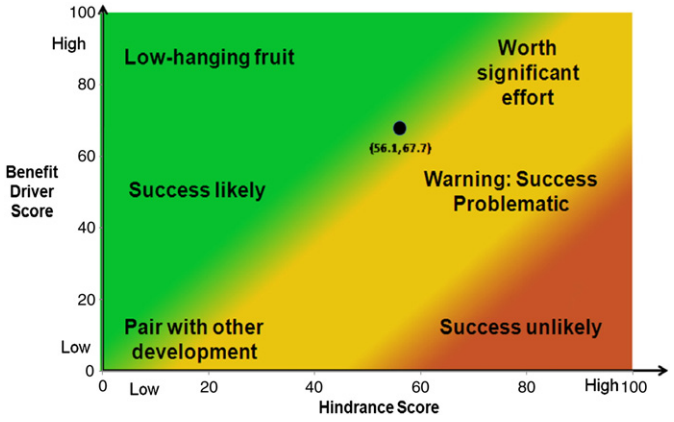

Fig. 1. Example of IOP Tool score plotted on the chart.

It is important to note that the scoring algorithm for the benefit driver/hindrance pairs is drawn from two data sources. The first is the IOP Tool user answers to the questions for the specific integration opportunity being evaluated. The second data source is research team assessment of the general importance of the questions. This general importance was derived without specific reference to projects and in the scoring algorithm acts as a normalizing function to facilitate comparison between scores for different integration opportunities. (Details of the algorithm can be found in [8]). For the purposes of this paper, the general importance assessment serves as a basis of comparison between what a representative group broadly thinks of each question with the results from actual implementations.

4. Research objectives and methodology

As described in the Literature review, although there is considerable knowledge about implementation of information integration in the literature, it is unclear how well it can be applied beyond its specific contexts, nor is it clear among the many factors that drive or hinder implementation if there are any factors that are more important or more consistently experienced. The generation and validation of the IOP Tool by RT258 provides an opportunity to extend existing literature in the context of the industrial construction sector with respect to these two research questions: (1) To what extent can we generalize (and enlarge) the existing literature with respect to benefit drivers and hindrances affecting implementation? (2) Within the factors identified, are there consistent factors which are more important or more prevalent during implementation?

To validate the scoring algorithm in the IOP Tool, RT 258 generated 16 test cases of actual implementations. These were performed by the academic team members in concert with industry team members and company personnel responsible for implementation. Use of these 16 cases for calibration of the scoring mechanism is provided in [8]. Independently of this calibration, the 16 cases represent a wide cross-section of information integration implementations in the industrial sector. As such, they can be used to address both research questions. First, they can be used as good evidence of the general applicability of the benefit driver/hindrance factors identified in the IOP Tool (which are developed from industry experience and literature review). Second, the cases are a large enough sample to draw observations about the consistency with which factors apply.

As data, this paper utilizes the 16 IOP tool test cases as well as the general importance assessments made by the research team to examine both research questions. With respect to importance scores that were generated by the team, analysis is given that shows both the specific scoring and relative ranking for each benefit driver and hindrance question detailed in the IOP Tool. The ranking, together with

the standard deviation, gives a measure of a question's importance as well as the consistency of that measure within the research team. Analysis of the 16 test cases is extended to show the consistency of responses across actual implementations. This gives a measure of both how important questions are as well as how consistent the scoring is for each question. In addition, the application to actual scenarios serves as evidence of the generality of the factors as worded in the tool. Analysis methods are described in more detail below.

5. Results from importance scores

The RT 258 team developed 37 questions for benefit drivers and 34 questions for hindrances. As noted above, separately from case specific application, the team made a general assessment of the importance of each question on a high/medium/low scale. The list of benefit drivers and associated importance assessment is shown in Table 1. Table 2 shows the same information for hindrances. We consider these assessments of general importance of interest as this ranking was done without specific reference to sample implementations (although each team member of course was drawing from their experience). Thus the scoring discussed below provides a point of comparison to assessment of specific integration implementations.

Questions were scored by each of the research team members. A mean score was calculated along with the standard deviation. Scoring weights for high, medium or low were explicit so that team members could make an accurate and consistent judgment for each question. High scorers were determined to count as nine points, medium scores as six points, and low scores as three points. (In three cases, a team member was unable to decide on an importance for the question as they thought assessment was too context specific to assign a general importance. In these cases, that ranking is shown as "D" in Tables 1

Table 1
List of benefit drivers and importance scores.

Higher mean rank indicates greater mean value.	Importance score						
	Count				Mean		St. dev
Higher st.dev rank indicates smaller st.dev value.	H	M	L	D	Value	Rank	
Market/legal benefit drivers							
1. Would the integration opportunity enable entry to new market?	10		1		8.45	2	1.81
2. Would the integration opportunity facilitate or enhance regulatory compliance?	3	6	2		6.27	25	2.10
Organizational and process benefit drivers							
3. Please characterize the general extent of work process benefits likely to result from the integration opportunity:							
a. Enhanced quality	6	4	1		7.36	14	2.06
b. Enhanced reliability	2	8	1		6.27	25	1.62
c. Enhanced functionality	2	9			6.55	23	1.21
d. Enhanced productivity	8	3			8.18	4	1.40
e. Enhanced cost reduction	9	1	1		8.18	4	1.94
f. Enhanced understanding of work process state or status	1	3	7		4.36	37	2.06
g. Enhanced Predictability of work process performance	7	4			7.91	8	1.51
h. Enhanced customer focus and/or satisfaction	2	6	1	2	6.27	25	1.62
i. Enhanced security of data	1	8	2		5.73	32	1.62
4. Please characterize the general extent of benefits derived from the integration opportunity on work process outcomes:							
a. Enhanced adaptability/flexibility/robustness in responding to varying conditions	1	9	1		6.00	31	1.34
b. Enhanced access to information	6	5			7.64	9	1.57
c. Enhanced product speed-to-market	8	3			8.18	4	1.40
d. Enhanced project schedule performance	8	1			8.67	1	1.00
e. Enhanced management of human resources	3	6	2		6.27	25	2.10
f. Enhanced management of physical resources		9	2		5.45	34	1.21
5. Frequency of integration opportunity application to projects							
a. For what portion of projects is this integration opportunity applicable?	5	5	1		7.09	19	2.02
b. How often is this integration opportunity applicable on a project?	6	5			7.64	9	1.57
6. To what extent would the integration opportunity enhance strategic decision-making?	6	5			7.64	9	1.57
7. To what extent would the integration opportunity enhance tactical decision-making?	4	7			7.09	19	1.51
8. To what extent would the integration opportunity enhance *inter-company efficiency*?	4	7			7.09	19	1.51
9. To what extent would the integration opportunity enhance *intra-company efficiency*?	5	6			7.36	14	1.57
10. To what extent would the integration opportunity enhance concurrent use of data with external organizations (inter-company level)?	7	3	1		7.64	9	2.06
11. To what extent would the integration opportunity enhance concurrent use of data by internal organizational units (intra-company level)?	8	3			8.18	4	1.40
12. To what extent would the integration opportunity enable subsequent leveraging of data (e.g., for further data analysis or application in a later phase or by other parties)?	7	3	1		7.64	9	2.06
13. To what extent would the integration opportunity enhance work sharing (i.e., with high value engr. centers or among different shifts, etc.)?	5	6			7.36	14	1.57
14. To what extent would the integration opportunity enhance the quality of data for downstream users?	5	6			7.36	14	1.57
15. To what extent would the integration opportunity allow for delayed commitment or decision-making in some other task (and which is viewed as beneficial)?	1	10			6.27	25	0.90
16. To what extent would the integration opportunity help resolve data versioning problems among different users?	1	7	3		5.45	34	1.81
17. To what extent would the integration opportunity allow for consolidation or elimination of existing software applications and/or custom system-to-system interfaces?	1	10			6.27	25	0.90
18. Can the integration opportunity utilize/leverage established data standards used by the current process?	2	6	1		6.33	24	1.80
19. Can the integration opportunity utilize/leverage industry-wide data standards such as ISO 15926 and Industry Foundation Classes (IFC)?	4	3	1		7.13	18	2.23
20. Can the integration opportunity utilize existing commercially proven applications?	7	2			8.33	3	1.32
People/roles/training benefit drivers							
21. To what extent would the integration opportunity enhance ease of application (and training) in comparison to existing tools and/or methods?		9	2		5.45	34	1.21
22. To what extent would the integration opportunity enhance employee morale or the work environment?	2	6	3		5.73	32	2.10
23. To what extent would the integration opportunity enhance or encourage positive behavioral change (e.g., enhanced collaboration, adherence to corporate work processes, etc.)?	5	5	1		7.09	19	2.02

Table 2
List of hindrances and importance scores.

Higher mean rank indicates greater mean value.	Importance score						
	Count				Mean		St. dev
Higher st.dev rank indicates smaller st.dev value.	H	M	L	D	Value	Rank	
Market/legal hindrances							
1. To what extent might security and holder-of-data requirements restrict the integration opportunity?	4	6	1		5.82	15	1.94
2. To what extent might intellectual property demands restrict the integration opportunity?	2	7	2		5.00	22	1.90
3. To what extent might the integration opportunity require modifying contractual agreements?	1	4	6		3.64	32	2.06
4. To what extent might the integration opportunity increase the possibility of misuse or mishandling of data?	5	6			6.36	9	1.57
5. To what extent does the integration opportunity challenge legal ownership of data?	2	8	1		5.27	20	1.62
6. To what extent does the integration opportunity presents GEC (Generally Embargoed Countries) or other technology export control challenges?		5	5	1	3.64	32	1.57
7. Will local customs and laws limit/restrict application of the integration opportunity?	4	3	2		5.67	16	2.50
8. Will labor agreements limit/restrict application of the integration opportunity?	3	3	3		5.00	22	2.60
Organizational and process hindrances							
9. To what extent would successful implementation of the integration opportunity require a modified internal and/or external organizational culture?	8	3			7.18	3	1.40
10. To what extent would successful implementation of the integration opportunity require modified business procedures?	2	7	2		5.00	22	1.90
11. To what extent will developing/establishing the integration opportunity be difficult because of …							
a. Uncooperative internal parties	4	7			6.09	11	1.51
b. Uncooperative external parties	5	5	1		6.09	11	2.02
c. Timing of data availability		9	2		4.45	27	1.21
d. Ill-structured data, including multiple sources and/or formats	2	7	2		5.00	22	1.90
e. Lack of upper management support	11				8.00	1	0.00
f. Limited financial support	8	2	1		6.91	4	2.02
g. Lack of related business process definition	2	8		1	5.55	18	1.21
12. To what extent will implementing/deploying the integration opportunity be difficult because of…							
a. Uncooperative internal parties	6	5			6.64	5	1.57
b. Uncooperative external parties	5	5	1		6.09	11	2.02
c. Timing of data availability		9	2		4.45	27	1.21
d. Ill-structured data, including multiple sources and/or formats	1	7	3		4.45	27	1.81
e. Lack of upper management support	10	1			7.73	2	0.90
f. Limited financial support	7	3	1		6.64	5	2.06
g. Lack of related business process definition	2	9			5.55	18	1.21
h. Geographical dispersion of users		4	7		3.09	34	1.51
13. To what extent will limited expertise hinder creation/implementation for integration opportunity?	5	3	1		6.33	10	2.18
People/roles/training hindrances							
14. To what extent are basic capabilities for implementation lacking in the proposed user community?	2	7			5.67	16	1.32
15. To what extent does the integration opportunity require							
a. Increased basic training effort in related business processes?	2	8	1		5.27	20	1.62
b. Initial training effort for the integration opportunity tool(s) itself?	3	5	3		5.00	22	2.32
16. To what extent will follow-on/second wave training on the integration opportunity be important?		9	2		4.45	27	1.21
17. To what extent will sustained support resources be required?	1	7	3		4.45	27	1.81
18. To what extent are champions difficult to identify at the user and/or manager levels?	6	5			6.64	5	1.57
19. To what extent will there be difficulty achieving clarity on ownership of the integration opportunity?	4	7			6.09	11	1.51
20. To what extent will there be difficulty in gaining the commitment of the data providers to comply with the data entry standard/procedure?	6	5			6.64	5	1.57

and 2. "D" was counted as Medium weight for scoring purposes.) As an example of scoring, question 1 had ten respondents score it with high importance and one respondent score it as low, giving a mean score of 8.45 and a standard deviation of 1.81. Table 1 also gives the rank of this question compared to the others (in this case 2 out of 37). Note that absolute ranking of questions should be interpreted cautiously as the mean scores are relatively close. For example, the highest ranked question has a mean of 8.67 and the 18th question (one-half of 37 questions) has a mean score of 7.13.

As all the questions that made the benefit driver list (Table 1) were deemed by the research team to be important enough to be included, it is not surprising that the spread of rankings is not large. However, some comments on specific questions or comparison between groups of questions are worthwhile. The largest set of questions (3–20) is categorized as organizational and process benefit drivers. Within this broad category, question three (with sub-questions 3.a–3.i) pertains to work process benefits resulting from the integration opportunity being considered. In this subset, the most important benefit driver is indicated as enhanced productivity, closely followed by enhanced cost reduction and enhanced predictability. These are not surprising results as productivity, cost, and predictability are broadly seen as important measures within the capital projects industry.

The set of benefit driver questions under the question four (4.a through 4.f) relates to the benefits derived from the integration opportunity on work process outcomes. In general, these questions scored quite high as a set, with particular importance given to project schedule performance and product speed to market as well as enhanced access to information. Subsequent questions (5 through 20) focus on more specific benefits to the organization and process. Interestingly, among these questions, question 16 (integration opportunity helps to resolve data versioning problems) scores somewhat low with three of eleven team members answering low importance and seven answering medium importance. This is somewhat in conflict with the widely acclaimed benefit that version control is an important benefit of integrated data solutions. Of course the low responses could be an indication that this is no longer a problem due to existing accomplishments with version control within their organizations. Question 20, which relates to the use of existing commercial applications, is interesting for its high mean score of 8.33 and rank of third overall. This indicates a strong preference amongst the industry team members for moving away from development within the organization to a preference for buying and implementing off-the-shelf applications.

The scoring of implementation hindrance questions followed the same general procedure as with driver questions. The only significant

difference is that the weights of high, medium and low were scored as 8, 5 and 2 with unimportant being scored as 0. The slight change in the scoring reflects the thought that the medium and high importance hindrances would be relatively farther from a 0 score than the low importance hindrances. Table 2 shows for each hindrance question the high, medium, and low counts, the mean and standard deviation, and overall rank.

As ranked by the research team, the most important hindrances relate to lack of upper management and financial support — these are of course prerequisites for any implementation. The next highest ranked hindrances concern implementation difficulties around changes to culture, identification of champions, and cooperation with internal parties during deployment. Also highly ranked was question 20 which assesses the difficulty in gaining the commitment of data providers to comply with new data entry procedures. This specific requirement has been observed by O'Brien [4] who noted the importance of those who need to seed data and those who span boundaries between a specific information system and other information systems.

The hindrance questions specifically differentiate the development of the integration opportunity from the implementation or deployment of the integration opportunity. This is seen in the sets of questions under 11 and 12 in Table 2. Within these questions, it is interesting to note that the more highly ranked hindrances include cooperation of internal and external parties, whereas difficulties with ill structured data were seen as relatively less important — perhaps because this hindrance was seen as largely a technical hurdle as opposed to a people hurdle. With respect to implementation, question 12.h on the geographical dispersion of users was ranked relatively low with a score of 3.09 and the bottom ranking of 34th overall. Whereas previously geographical dispersion may have been seen as a hindrance, it appears that the norms of working virtually with distributed teams may have reduced what has been seen previously as an important hindrance [52,53].

Some hindrances reflect experience limitations in the industry. Question 13, which addresses to what extent limited expertise will hinder creation/implementation of the integration opportunity, is ranked fairly high with a mean score of 6.33 or 10th overall. This reflects an acknowledgment that broad skills in developing and deploying applications such as those that are IFC or ISO 15926 compliant are relatively rare at the moment. Question 14 asks to what extent are basic capabilities for implementation lacking in the proposed user community, which also receives a fairly high-ranking of 16 and a mean score of 5.67. This acknowledges that technical skills amongst personnel within the firms are highly variable and that the assumption that all users have basic computer skills may be incorrect. This is in line with question 18, difficulty to identify champions at the user and/or manager levels, which is ranked fifth with a mean of 6.64.

The hindrance questions acknowledge several market/legal hindrances. While these scores tend to be in the middle or bottom half of the raw scores (the exception being question four, increasing the possibility of misuse of data) they deserve some discussion as they represent specific hindrances that are not always well recognized in the literature. Question 2 acknowledges that intellectual property demands may restrict the integration opportunity — an example would be sharing the specifics of factory layout with outside companies. Questions 1 and 6 concern data security as well as generally embargoed countries (GEC) and technology export control restrictions. Global firms are likely to encounter such issues on a relatively frequent basis. One research team member responded with an “it depends” answer to the GEC question noting that context around the integration opportunity would determine his answer. Question 3 concerns the extent to which the integration opportunity might require modification of contractual agreements. While seen by the team as a relatively low hindrance in terms of implementation success with a mean of 3.64, it was broadly noted that incorporating contractual language for data handover and data format requirements is a recommended practice that more firms should consider when contracting. Questions 7 and 8 concern local customs, laws, and labor agreements which would restrict implementation. An example would be labor agreements regarding who must enter data. The set of market/legal hindrance questions represents specific hindrances that companies observe. While not seen as important as some other hindrances, as a set these questions have a somewhat higher standard deviation than the other hindrance questions representing disagreement among the team members about their relative importance. It is likely that the business line of the firm has some influence on the respondents. For example, firms in the high-technology sector may have greater concerns about intellectual property than firms in other sectors.

6. Results from 16 information integration test cases

The previous section presents RT258's assessment of the general importance of questions. This section discusses the results from analysis of specific applications. As part of the validation of the IOP Tool, the research team applied it to sixteen cases from the team member companies. The test cases are listed in Table 3. All cases were submitted by the CII member companies which are large firms mainly operating in the industrial construction sector. As shown in the table, there is a wide range of information technologies involved in the integration cases. Eleven of the sixteen test cases are from contractors, four from owners, and one from a supplier. The cases do not represent a random sample as they were nominated by the companies. However, the test cases represent a wide range of information integration implementations both in scope and scale and may be considered a reasonable sample of the type of efforts undertaken within the capital projects industry. Research team members generated one or more sample cases from recent implementations in their company; the team members conducted the evaluation with input from others in their company with specific knowledge of the implementation. As the team members were involved in the generation of drivers and hindrances, interpretation of the questions was not a concern. As such, potential for misinterpreting the questions was removed from the evaluation and hence the results are interpreted to be well considered responses to the questions.

Table 4 details responses from the 16 sample cases for benefit drivers. The IOP Tool offers users a slightly broader range of answers

Table 3
Description of test cases.

Respondent type	Description
Contractor	Vendor data integration with engineering/construction/client applications Vendor 3D model integration
Contractor	Estimating integration with 3D models, material quantities, and takeoff
Owner	Integration using 3D model with spool drawings and Bills of Material (BOM)
Owner	Time and attendance gate log system integrated with billing system
Contractor	Progress measurement system integration information about work scope, work package Construction schedule information integration (limited success)
Contractor	Document management system integration Schedule information integration P&ID integration
Owner	Project execution management system phase I Project execution management system phase II
Contractor	Integration between material management system and enterprise resource planning (ERP) Data sheet and drawing representation interchange
Contractor	3D smart model
Vendor	Data sheet and drawing representation interchange

Table 4
Responses from the 16 test cases for benefit drivers.

– "N/A" is marked for standard deviation if the question has yes/no type answer.	Respondents' answers								
	Count						Mean		St. dev
– Higher mean rank indicates greater mean value.	H	MH	ML	L	N	N/A	Value	Rank	
Market/legal benefit drivers									
1. Would the integration opportunity enable entry to new market?					14	2	0.00	37	N/A
2. Would the integration opportunity facilitate or enhance regulatory compliance?	4				8	4	1.33	36	N/A
Organizational and process benefit drivers									
3. Please characterize the general extent of work process benefits likely to result from the integration opportunity:									
a. Enhanced quality	7	6	1	1	1		3.06	10	1.18
b. Enhanced reliability	4	9	2	1			3.00	11	0.82
c. Enhanced functionality	8	5	1	2			3.19	6	1.05
d. Enhanced productivity	10	3	3				3.44	1	0.81
e. Enhanced cost reduction	3	6	5	2			2.63	22	0.96
f. Enhanced understanding of work process state or status	3	9	3			1	3.00	11	0.65
g. Enhanced predictability of work process performance	6	5	2	3			2.88	15	1.15
h. Enhanced customer focus and/or Satisfaction	5	6	3	2			2.88	15	1.02
i. Enhanced security of data	2	5	2	2	3	2	2.07	31	1.44
4. Please characterize the general extent of benefits derived from the integration opportunity on work process outcomes:									
a. Enhanced adaptability/flexibility/robustness in responding to varying conditions	5	5	3	3			2.75	21	1.13
b. Enhanced access to information	7	6	1	2			3.13	9	1.02
c. Enhanced product speed-to-market	1	3	1	3	3	5	1.64	34	1.43
d. Enhanced project schedule performance	4	8	2	2			2.88	15	0.96
e. Enhanced management of human resources	3	4	4	4	1		2.25	28	1.24
f. Enhanced management of physical resources	1	3	5	2	1	4	2.08	30	1.08
5. Frequency of integration opportunity application to projects									
a. For what portion of projects is this integration opportunity applicable?	10	2	3	1			3.31	3	1.01
b. How often is this integration opportunity applicable on a project?	9	4	3				3.38	2	0.81
6. To what extent would the integration opportunity enhance strategic decision-making?	1	3	2	5	3	2	1.57	35	1.28
7. To what extent would the integration opportunity enhance tactical decision-making?	5	1	5	3	1	1	2.40	25	1.35
8. To what extent would the integration opportunity enhance *inter-company efficiency*?	5	4	5		1	1	2.80	20	1.15
9. To what extent would the integration opportunity enhance *intra-company efficiency*?	7	5	3			1	3.27	4	0.80
10. To what extent would the integration opportunity enhance concurrent use of data with external organizations (inter-company level)?	3	4	5	2	2		2.25	28	1.29
11. To what extent would the integration opportunity enhance concurrent use of data by internal organizational units (intra-company level)?	5	6	4		1		2.88	15	1.09
12. To what extent would the integration opportunity enable subsequent leveraging of data (e.g., for further data analysis or application in a later phase or by other parties)?	9	3	2	2			3.19	6	1.11
13. To what extent would the integration opportunity enhance work sharing (i.e., with high value engr. centers or among different shifts, etc.)?	4	6	1	2	3		2.38	26	1.50
14. To what extent would the integration opportunity enhance the quality of data for downstream users?	6	5	4	1			3.00	11	0.97
15. To what extent would the integration opportunity allow for delayed commitment or decision-making in some other task (and which is viewed as beneficial)?	2	3	5	2	2	2	2.07	31	1.27
16. To what extent would the integration opportunity help resolve data versioning problems among different users?	8	2	2	2	1	1	2.93	14	1.39
17. To what extent would the integration opportunity allow for consolidation or elimination of existing software applications and/or custom system-to-system interfaces?	2	7	2		5		2.06	33	1.53
18. Can the integration opportunity utilize/leverage established data standards used by the current process?	13				3		3.25	5	N/A
19. Can the integration opportunity utilize/leverage industry-wide data standards such as ISO 15926 and Industry Foundation Classes (IFC)?	8				5	3	2.46	24	N/A
20. Can the integration opportunity utilize existing commercially proven applications?	11				3	2	3.14	8	N/A
People/roles/training benefit drivers									
21. To what extent would the integration opportunity enhance ease of application (and training) in comparison to existing tools and/or methods?	2	8	2	2	1	1	2.53	23	1.13
22. To what extent would the integration opportunity enhance employee morale or the work environment?	3	4	3	3	1	2	2.36	27	1.28
23. To what extent would the integration opportunity enhance or encourage positive behavioral change (e.g., enhanced collaboration, adherence to corporate work processes, etc.)?	5	6	3	1	1		2.81	19	1.17

to each question than the importance scores as ranked by the CII research team. For each question, respondents could answer high, medium high, medium low, low, none, and not applicable. (A few questions have just a yes/no/not applicable rating.) Compared to the importance rankings conducted by team members, respondents were given a more precise scale with regard to medium–high and medium–low to encourage more thoughtful answers than just medium. None as a response for specific question is meant to indicate that there is no benefit to the particular driver, whereas not applicable is meant to indicate that the question is completely irrelevant to the integration opportunity being evaluated. This differentiation is made clear in the instructions to the IOP Tool. Table 4 shows both the count for each response as well as the mean and standard deviation of the responses. The mean is calculated on a weighted scale where high counts as four, medium–high as three, medium low as two, low as one, and none as zero. A "not applicable" response is not weighted. Question rank based on the mean is also provided in the table. Note that the few questions with yes/no responses have a mean score but not a standard deviation.

As can be seen from Table 4, the range of answers for each benefit driver question is fairly high. Only question one – entry to new markets – has as a response none or not applicable for all respondents. From this score we do not conclude that the question is unimportant (it was ranked second in the importance scores — Table 1); rather the

Table 5
Responses from the 16 test cases for hindrances.

– "N/A" is marked for standard deviation if the question has yes/no type answer.	Respondents' answers								
	Count						Mean		St. dev
– Higher mean rank indicates greater mean value.	H	MH	ML	L	N	N/A	Value	Rank	
Market/legal hindrances									
1. To what extent might security and holder-of-data requirements restrict the integration opportunity?	2	3	2	4	5		1.56	16	1.46
2. To what extent might intellectual property demands restrict the integration opportunity?		1	1	6	8		0.69	31	0.87
3. To what extent might the integration opportunity require modifying contractual agreements?	1	4	1	3	7		1.31	23	1.45
4. To what extent might the integration opportunity increase the possibility of misuse or mishandling of data?	1	2	1	7	5		1.19	27	1.22
5. To what extent does the integration opportunity challenge legal ownership of data?	1	2	1	3	9		0.94	29	1.34
6. To what extent does the integration opportunity presents GEC (Generally Embargoed Countries) or other technology export control challenges?			3	2	9	2	0.57	32	0.85
7. Will local customs and laws limit/restrict application of the integration opportunity?					16		0.00	33	N/A
8. Will labor agreements limit/restrict application of the integration opportunity?					16		0.00	33	N/A
Organizational and process hindrances									
9. To what extent would successful implementation of the integration opportunity require a modified internal and/or external organizational culture?	4	3	3	2	4		2.06	4	1.57
10. To what extent would successful implementation of the integration opportunity require modified business procedures?	2	5	6	2	1		2.31	2	1.08
11. To what extent will developing/establishing the integration opportunity be difficult because of …									
a. Uncooperative internal parties		6	4	6			2.00	6	0.89
b. Uncooperative external parties		3	1	6	4	2	1.21	26	1.12
c. Timing of data availability		3	4	7	2		1.50	19	0.97
d. Ill-structured data, including multiple sources and/or formats	1	5	2	6	2		1.81	10	1.22
e. Lack of upper management support	1	2	2	7	4		1.31	23	1.20
f. Limited financial support	2		5	9			1.69	13	1.01
g. Lack of related business process definition	1	3	3	7	1	1	1.73	12	1.10
12. To what extent will implementing/deploying the integration opportunity be difficult because of…									
a. Uncooperative internal parties	1	4	2	7	2		1.69	13	1.20
b. Uncooperative external parties	1	2	4	5	3	1	1.53	18	1.19
c. Timing of data availability		3	7	4	2		1.69	13	0.95
d. Ill-structured data, including multiple sources and/or formats	2	3	5	4	2		1.94	9	1.24
e. Lack of upper management support	1		6	4	5		1.25	25	1.13
f. Limited financial support		1	2	8	5		0.94	29	0.85
g. Lack of related business process definition	1		4	10		1	1.47	20	0.83
h. Geographical dispersion of users	2	1	3	6	4		1.44	21	1.31
13. To what extent will limited expertise hinder creation/implementation for integration opportunity?	3	1	1	4	6	1	1.40	22	1.59
People/roles/training hindrances									
14. To what extent are basic capabilities for implementation lacking in the proposed user community?	1	3	3	6	3		1.56	16	1.21
15. To what extent does the integration opportunity require									
a. Increased basic training effort in related business processes?	1	6	6	3			2.31	2	0.87
b. Initial training effort for the integration opportunity tool(s) itself?		8	5	1	1	1	2.33	1	0.90
16. To what extent will follow-on/second wave training on the integration opportunity be important?	2	1	8	5			2.00	6	0.97
17. To what extent will sustained support resources be required?	3	3	3	6	1		2.06	4	1.29
18. To what extent are champions difficult to identify at the user and/or manager levels?	2	1	6	5	2		1.75	11	1.18
19. To what extent will there be difficulty achieving clarity on ownership of the integration opportunity?		1	3	7	5		1.00	28	0.89
20. To what extent will there be difficulty in gaining the commitment of the data providers to comply with the data entry standard/procedure?	3	2	6	2	3		2.00	6	1.37

16 test cases did not address this particular benefit. Question 1 is the only question amongst the benefit drivers to have such a strong skew to none or not applicable.

Questions 3.a through 3.i, which address benefits to the work process derived from the integration opportunity, generally have a higher mean score than questions 4.a through 4.f, which address benefits to work process outcomes. This is an interesting observation as the general importance scores assigned by the research team show the opposite result (Table 1). For these 16 cases it would appear that their justification was based more on their ability to benefit work processes than to benefit project outcomes.

Questions 5.a and 5.b relate to the frequency with which the particular integration opportunity is applicable to projects. Both questions had a very high score of 3.31 and 3.38 ranking them as third and second overall (only question 3.d – enhanced work process productivity – scored higher). This indicates that firms may give priority to investing in integration opportunities that can be repeated. This finding is also supported by questions 8 and 9 which identify benefit drivers for inter- and intra-company efficiency. Intra-company efficiency was ranked fourth with a mean score of 3.27 whereas inter-company had a lower score of 2.8 and ranked 20. This further suggests a focus on benefits that can be internally realized. Similarly, questions 10 and 11 relate to concurrent use of data by external and internal organizational units. There is a higher focus on concurrent use of data by internal units than by external units.

Questions 12, 13, and 14 relate to data sharing and leveraging of data by downstream users. These have a fairly high-ranking which may indicate a trend among firms to recognize the value and benefits of electronic project information. This is seen in several of the following questions which relate specifically to adoption of data standards and common software platforms. For example, question 16 shows fully half of the applications being considered see a strong benefit to resolve data versioning problems, although there is a long tail and are some low and none responses. This finding is consistent with other literature but is somewhat in conflict with the general importance scores by the research team (Table 1, above) where versioning was seen as mid to low importance. There is also a strong push towards the use of established internal data standards and at least

some recognition of the use of industry data standards such as ISO 15926 and IFC. Questions 17 and 20 also show a fairly frequent desire to use common and, in particular, commercial applications.

Finally with respect to benefit drivers, questions 21, 22 and 23, which relate to people and training benefits, show a fairly wide range of responses although there is a trend to score them high to medium–high. This suggests that benefits to the organization including ease of training, morale enhancement and positive behavioral change are seen as benefits when integration opportunities are being considered for implementation. For example, for one test case a significant organizational problem was poor adherence to corporate workflow standards and adoption of the integration opportunity was seen as a way to enforce consistency in corporate processes across the distributed organization.

Table 5 shows the responses to hindrance questions for the 16 test cases. As with benefit drivers, the table shows the questions, the respondent count (high, medium–high, medium–low, low, none and not applicable), the mean and standard deviation and the rank based on the mean. Overall, the range of scores as expressed both in the lower means and higher standard deviations indicate that the implementation hindrances are more variable than the drivers. With the exceptions of questions 7 and 8, which address local customs and labor agreements that limit application of the integration opportunity, all the questions have a fairly wide variance in their answers. Questions 7 and 8 have a no response by all respondents, which the authors interpret as factors that did not apply to the sample rather than a statement of their general importance or lack thereof.

Most of the implementation hindrance questions have a fairly widespread response from high to none; relatively few have a not applicable rating. This suggests that the set of hindrances identified are broadly applicable to projects within the capital projects industry. A few hindrances have a somewhat bimodal distribution of either high or low/none. Question 3 which pertains to modifying contractual agreements has four medium–high responses and seven none responses, which suggests that the hindrance should not be overlooked and when applicable is likely important. Similarly, question 9 which addresses organizational culture modifications has four responses marked high and four marked none with a fairly even distribution in between. Cultural considerations – perhaps reflected through required adherence to new workflows – are likely to be an important consideration. This is also reflected in question 10 that addresses requirements for modified business procedures; this question has a rank of 2 showing it affects most of the 16 test cases.

Questions 11.a through 11.g address difficulties in developing or establishing the integration opportunity. Questions 11.e and 11.f address lack of upper management and financial support were rated highly on the team importance scores (Table 2) but score much lower on the test cases. This is perhaps because these implementations would not have been considered without financial support or management support (although as Table 5 shows it was a high hindrance for at least some of the test cases). Some of the highest rankings among these questions are 11.a – uncooperative internal parties and 11.d – ill-structured data. These findings are echoed in the responses to questions 12.a through 12.h which pertain to implementing or deploying the integration opportunity (as opposed to development). For these questions, uncooperative internal parties and ill structured data were ranked the highest. Further high-ranking was given to timing of data availability.

The sub-questions under 12 echo those of 11, however 12.h adds geographical dispersion of users. While this was seen as a high to medium–high difficulty in three of the 16 cases, the remainder marked this response as low. This is an interesting finding as *a priori* one might suspect geographical dispersion would be a significant problem. However, the relatively low ranking may indicate that the increased use of work sharing tools and virtual working may be reducing this problem. This is also found in the importance scores (Table 2).

Questions 14 through 20 relate to people/role/training hindrances. As above, answers here show a wide range of responses. Question 15 asks to what extent does the integration opportunity require increased basic training effort in related business processes (15.a) and to what extent does the integration opportunity require initial training effort for the resulting tools (15.b). These are the two highest ranked questions by mean. It is not surprising that question 15.b is the highest ranked question as training effort typically is an implementation challenge [3,11]. It is more surprising that 15.a is so highly ranked as this indicates a lack of corporate training in accepted business processes. The research team did have several discussions suggesting that information integration efforts do expose inconsistencies in adherence to corporate work processes. A supposition worth further testing is that companies are selecting integration opportunities for exploration/implementation when there is a belief that corporate work processes are not being adhered to and hence there is a desire to create tools to enforce standardization.

Beyond questions 15.a and 15.b, the remaining questions 14–20 are generally ranked highly, with questions 16, 17 and 20 in the top ten and question 18 ranked as eleven. Questions 16 and 17 suggest the importance of considering follow-on training and sustained support resources to assure successful implementation. Question 18 suggests the potential challenges of identifying champions, although the variance in this question is fairly high. Question 20 which remarks on the importance of gaining the commitment of data providers to comply with the data procedures is ranked number six by these test cases and was ranked as number five in the importance scores (Table 2). These results indicate the general importance of considering human factors when implementing integration tools.

7. Discussion

The sections above present the specific factors identified by the research team as well as both the research teams' ranking of questions as well as application to 16 test cases that represent a cross section of information integration implementations in the capital projects industry. Comparison is made between the two independent assessments with some discussion of particular questions in the context of the existing literature. This section builds from the results above to draw three specific contributions in response to the two research questions outlined above. First, the benefit drivers and hindrances are seen to generalize, refine, and expand the literature, particularly with respect to the industrial construction sector. Second, analysis of benefit drivers is shown have consistent high applicability of factors that relate to benefits to work processes. Third, analysis of hindrances does not show any consistent pattern across cases. These contributions are discussed in turn.

The first contribution follows from the research question “To what extent can we generalize (and enlarge) the existing literature with respect to benefit drivers and hindrances affecting implementation?” While extensive, the construction literature on implementation has focused primarily on drawing observations around specific technologies; it is also centered in the AEC or commercial sectors. The work of the research team to identify factors together with their application to 16 test cases helps to generalize factors found in the literature to the industrial sector. That the 16 test cases vary greatly across technologies and scope of implementation provides further evidence that the specific wording of the questions is general in nature. Further review of the 16 cases by the academic team with the subjects did not identify any missing factors or obvious areas overlooked by application of the IOP tool, suggesting that the factors identified provides a reasonably comprehensive review of drivers and hindrances. Thus we are able to conclude that the identified drivers and hindrances are generalizable in terms of their applicability to the industrial sector and as such would be a good start for further studies.

Table 6
Links between the IOP Tool questions and literature.

	Source of literature		
	Construction Industry		General business reference
	Reference	Ind. type	
Market/legal benefit drivers			
1. Would the integration opportunity enable entry to new market?			[55]
2. Would the integration opportunity facilitate or enhance regulatory compliance?	[56]	AEC	
Organizational and process benefit drivers			
3. Please characterize the general extent of work process benefits likely to result from the integration opportunity:			
a. Enhanced quality	[5,56–60]	Both	
b. Enhanced reliability			
c. Enhanced functionality	[40]	AEC	
d. Enhanced productivity	[5,11,57–59]	AEC	[16,61]
e. Enhanced cost reduction	[58,59]	AEC	[16]
f. Enhanced understanding of work process state or status	[5,62]	AEC	
g. Enhanced predictability of work process performance			
h. Enhanced customer focus and/or satisfaction	[5,10,63]	Both	
i. Enhanced security of data	[3,12]	Both	
4. Please characterize the general extent of benefits derived from the integration opportunity on work process outcomes:			
a. Enhanced adaptability/flexibility/robustness in responding to varying conditions			
b. Enhanced access to information	[5,15]	AEC	
c. Enhanced product speed-to-market			[55,64]
d. Enhanced project schedule performance	[36,38,39]	Industrial	
e. Enhanced management of human resources			
f. Enhanced management of physical resources			
5. Frequency of integration opportunity application to projects			
a. For what portion of projects is this integration opportunity applicable?			
b. How often is this integration opportunity applicable on a project?			
6. To what extent would the integration opportunity enhance strategic decision-making?	[26]	AEC	
7. To what extent would the integration opportunity enhance tactical decision-making?			
8. To what extent would the integration opportunity enhance *inter-company efficiency*?	[65]	AEC	
9. To what extent would the integration opportunity enhance *intra-company efficiency*?			
10. To what extent would the integration opportunity enhance concurrent use of data with external organizations (inter-company level)?	[40,58,59]	AEC	
11. To what extent would the integration opportunity enhance concurrent use of data by internal organizational units (intra-company level)?			
12. To what extent would the integration opportunity enable subsequent leveraging of data (e.g., for further data analysis or application in a later phase or by other parties)?			
13. To what extent would the integration opportunity enhance work sharing (i.e., with high value engr. centers or among different shifts, etc.)?	[66]	Industrial	
14. To what extent would the integration opportunity enhance the quality of data for downstream users?	[67]		
15. To what extent would the integration opportunity allow for delayed commitment or decision-making in some other task (and which is viewed as beneficial)?			
16. To what extent would the integration opportunity help resolve data versioning problems among different users?	[40–42,68]	AEC	
17. To what extent would the integration opportunity allow for consolidation or elimination of existing software applications and/or custom system-to-system interfaces?			
18. Can the integration opportunity utilize/leverage established data standards used by the current process?			
19. Can the integration opportunity utilize/leverage industry-wide data standards such as ISO 15926 and Industry Foundation Classes (IFC)?	[5,12,69]	AEC	
20. Can the integration opportunity utilize existing commercially proven applications?			
People/roles/training benefit drivers			
21. To what extent would the integration opportunity enhance ease of application (and training) in comparison to existing tools and/or methods?			
22. To what extent would the integration opportunity enhance employee morale or the work environment?			
23. To what extent would the integration opportunity enhance or encourage positive behavioral change (e.g., enhanced collaboration, adherence to corporate work processes, etc.)?			
Market/legal hindrances			
1. To what extent might security and holder-of-data requirements restrict the integration opportunity?	[12,13]	AEC	
2. To what extent might intellectual property demands restrict the integration opportunity?	[13]	AEC	
3. To what extent might the integration opportunity require modifying contractual agreements?	[3,6,11]	AEC	
4. To what extent might the integration opportunity increase the possibility of misuse or mishandling of data?			
5. To what extent does the integration opportunity challenge legal ownership of data?	[14,15]	AEC	
6. To what extent does the integration opportunity presents GEC (Generally Embargoed Countries) or other technology export control challenges?			
7. Will local customs and laws limit/restrict application of the integration opportunity?	[4]	AEC	
8. Will labor agreements limit/restrict application of the integration opportunity?			[16]
Organizational and process hindrances			
9. To what extent would successful implementation of the integration opportunity require a modified internal and/or external organizational culture?	[3]	AEC	[20–23]
10. To what extent would successful implementation of the integration opportunity require modified business procedures?			[22,33,35,50,70]

Table 6 (*continued*)

	Source of literature		
	Construction Industry		General business reference
	Reference	Ind. type	
Organizational and process hindrances			
11 and 12. To what extent will developing/establishing and implementing/deploying the integration opportunity be difficult because of …			
a. Uncooperative internal parties	[3]	AEC	
b. Uncooperative external parties			[16,25]
c. Timing of data availability			
d. Ill-structured data, including multiple sources and/or formats			
e. Lack of upper management support	[3]	AEC	[18,30–34]
f. Limited financial support			
g. Lack of related business process definition			
h. Geographical dispersion of users	[52]	AEC	[53]
13. To what extent will limited expertise hinder creation/implementation for integration opportunity?			
People/roles/training hindrances			
14. To what extent are basic capabilities for implementation lacking in the proposed user community?			
15. To what extent does the integration opportunity require			
a. Increased basic training effort in related business processes?	[3]	AEC	[29]
b. Initial training effort for the integration opportunity tool(s) itself?	[3,11]	AEC	
16. To what extent will follow-on/second wave training on the integration opportunity be important?	[3]	AEC	
17. To what extent will sustained support resources be required?			
18. To what extent are champions difficult to identify at the user and/or manager levels?			[71]
19. To what extent will there be difficulty achieving clarity on ownership of the integration opportunity?			
20. To what extent will there be difficulty in gaining the commitment of the data providers to comply with the data entry standard/procedure?	[4]	AEC	

The work of the research team to detail specific benefit drivers and hindrances also expands and refines the existing literature. Some discussion around specific questions is provided in the analysis of the results presented in the previous sections, however Table 6 shows in detail the questions and corresponding links to both the construction and general business literature. The table also indicates whether the construction literature is based in the commercial (AEC) or industrial sectors. As can be seen from Table 6, there are several factors that no corresponding literature in either construction or the general business literature, although many of these are very specific such as hindrance question 6 that refers to generally embargoed countries. Several specific drivers are also added to both the construction and business literature with respect to organizational and work processes. Interestingly, the authors find no specific literature linking literature on information system adoption and positive people/roles/training drivers (questions 21–23); such considerations are generally made in the context of hindrances and the questions suggest the value of future research on the benefits of information systems on organization culture. A review of the hindrances references in Table 6 shows the construction literature is replete with references to market and legal adoption but has less to say about organizational hindrances as well as those related to people/roles/training. This is not to say that the construction literature does not remark on the importance of training or of organizational considerations, but rather that many of the comments are made at a higher level that do not correspond directly to the questions. In this way the factors in this paper add specificity to the existing literature.

Research question two – "Within the factors identified, are there consistent factors which are more important or more prevalent during implementation?" – seeks to extend the work above with respect to the evidence from the 16 test cases. Here there are two separate observations with respect to drivers and hindrances. First, the consistently strongest drivers across the cases are benefits to work processes, not project outcomes. This is consistent with the survey of Nitithamyong and Skibniewski [5] insofar as most of their identified performance measures relate to work processes. This focus on work process benefits is an interesting finding given the ongoing goal of measuring project outcome data for investments in information technologies (for example, the stream of research relating project performance to IT use [37,38,54]). That the strongest drivers as assessed by the 16 cases are primarily from benefits to work processes suggests that implementations stem as much from documented difficulties with existing processes as they do from outcome benefits. This may be due to the difficulty of estimating outcomes, although the authors view it as confirming evidence of the pathways found in the business literature. Current literature suggests that benefits from investment in information technologies are found through benefits to work processes; in turn, improvements in work processes are what drive superior performance [22,33]. Further examination of this proposition is worth further study in construction; Taylor's research on alignment of organizations and systems [6] and Kang's empirical evaluation [51] are starting points here.

The findings with respect to hindrances contrast sharply with those from drivers in that the results of the 16 test cases for the drivers show a wide range for each measure. This suggests that outside of a few precepts such as support of upper management, implementation challenges affect specific information integration opportunities in unique ways. Each implementation should be evaluated separately with respect to an assessment of potential hindrances as well as generation of specific mitigation plans to aid deployment. That all 16 test cases indicated at least some importance for all the hindrance questions (with the exception of two hindrances of limited scope) suggests that hindrance mitigation plans may best be developed by teams. It is unlikely that an individual will have the requisite organizational, legal, and market knowledge as well as understanding of users and support resources to create an effective deployment plan.

These findings for implementation hindrances are broadly consistent with the literature. For example, Erdogan et al. [3] and Taylor [6] both state that a holistic or systems perspective is needed for implementations to be successful. Similarly, O'Brien [4] lists a set of common implementation challenges. However, all this work seeks generality of factors that affect implementation and strives toward common recommendations. By adding more specificity to the hindrances, the research in this paper stresses the individual circumstances of any information system implementation. We conclude that the set of hindrances potentially affecting implementation is common, but the prescription for overcoming them cannot be generalized. Nor can we say that there are hindrances that are consistently more important or more commonly experiences than others, at least within the industrial sector. This has strong recommendations for practice as outlined above; for research this suggests future work that focuses less on commonality of specific hindrances but rather broader descriptions of organizational context

that may help identify sets of hindrances that work in conjunction with each other. The authors speculate this may be related to the maturity of the organization with respect to implementing technologies.

8. Conclusions

This paper makes three contributions to literature: First, the paper enhances our understanding of the range of benefit drivers and implementation hindrances with respect to information integration tools, in particular with respect to the industrial construction sector. Second, the paper makes specific assessments of relative importance of drivers. From implementations, consistent highly ranked drivers are benefits to work processes rather than project outcomes. This is a somewhat surprising finding given general importance scores that place project outcomes above improvements to work processes but is consistent with contemporary general business literature about the pathways through which investments in information technologies achieve benefits. The third contribution is the lack of evidence of consistently important implementation hindrances. It appears that every implementation has idiosyncratic conditions that require specific plans for mitigation to aid deployment. This finding is broadly consistent with the literature that argues for a systems focus on implementation, but that literature tends to argue for a common approach to listing and resolving hindrances. The detailed questions of the IOP Tool allow for a fine grained look at hindrances; no common sets of features are found suggesting even more nuanced approaches to implementation are needed than those recommended in the literature.

This research is centered in the industrial sector and, the authors' believe, strongly generalizes and expands a range of literature with respect to this sector. The findings also provide a solid foundation for future research. An immediate next step for research is to explore applications of the IOP Tool in other sectors; this would serve as a basis to test both the generality of identified drivers and hindrances and also allow comparison between the sectors. Of particular interest is to test the tool within the AEC or commercial sector as it is the predominant sector researched in this area. As such, applications of the IOP Tool and its factors could potentially generalize a range of literature tied to specific technologies. Beyond application of the IOP Tool, the 37 benefit drivers and 34 implementation hindrances provides a list of factors that could be explored in part. Researchers may wish to explore implications of specific questions; the findings detailed above in Sections 5 and 6 provide both detailed factors and quantitative results from which to explore hypotheses. More broadly, the findings about consistently important benefit drivers and the lack of consistency in hindrances across implementations argues for renewed research about the relationship between investments in information technologies, process and outcome benefits, and organizational context.

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