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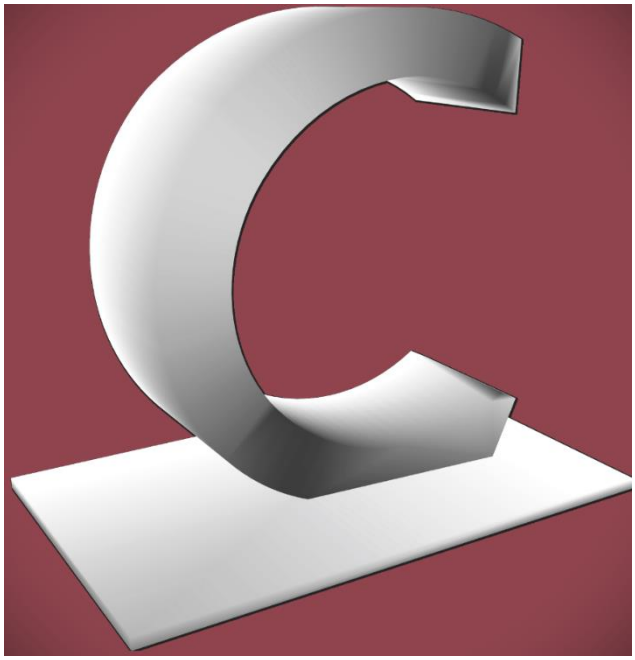
and Environmental Engineering

WHITE PAPER

CONSTRUCTION PROJECTS
AND PROCESS INTELLIGENCE



DIGITALIZATION
&
CONSTRUCTION PROCESSES MANAGEMENT

Results of a construction industry-wide investigation, through subject matter experts, on construction processes and business data requirements in Canadian construction market,

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DISCLAIMERS

The information and results presented in this document report on the interviewees' point of views on the subject and the authors' results interpretation, but in neither case do they necessarily represent the views of any of the affiliated/involved organizations. The authors declare that the information reported in this document is truthful and accurate as of its publication date without any conflict of interest.

The identity of interviewees is not disclosed to maintain their privacy.

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ETHICS APPROVAL CERTIFICATE

The experiment that forms the foundation of this report was reviewed by and received an ethics approval certificate from Concordia University under certificate number 30016847.

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EXECUTIVE SUMMARY

Despite broad experience in managing construction 'projects', when it comes to harnessing business operational data to efficiently manage and improve 'processes', the construction industry has fallen behind several other industries. Aiming to investigate this aspect in the Canadian construction market, this study provides an **industry perspective on construction process management** and its main challenges within the Architecture, Engineering, Construction, and Facility Management (AEC/FM) domain. These challenges primarily concern managing **construction operations** across project life cycle phases, from planning and tendering to execution and post-construction. The study seeks to explore and shed light on such complexities, particularly on critical **business processes and business data requirements** essential for successful project management in construction.

The main goal of this investigation is to provide a comprehensive analysis of the common trends, barriers, and insights of data-driven process management in the construction industry. The objectives include (i) capturing construction professionals' inputs to better understand the degree of involvement of various expertise in different phases of construction projects; (ii) identifying and analyzing key business processes across project phases and identifying unique challenges, and their impact on the overall project timeline; and (iii) investigating business operational data needs necessary for data-driven decision-making in construction projects.

The present study adopts a qualitative approach through **a series of 18 semi-structured interviews** completed between February and August 2023 with **subject matter experts** that enables respondents to provide detailed insights while responding to specific and structured questions. These interviews were carefully designed and structured to include both open and closed-ended questions derived from a comprehensive literature review framework and validated with industry professionals. These questions were formulated in a way to collect the construction process-related experience (i.e., tacit knowledge) from industry professionals. In total, 18 subject matter experts from North America were interviewed. Their professional background included a wide range of professional roles and experience managing construction projects. This diverse representation of interviewees enriched the study to cover key business processes across construction project life cycle phases.

The study explores the relevance of these processes documenting **process bottlenecks** and **information exchange requirements** among stakeholders reported by the interviewees and emphasizing the critical role of data in informed decision-making within the construction industry. With **32%** of respondents referring to at least one process from the pre-construction phase, this phase bears the highest degree of **process interplay** (i.e., the degree to which each process contributes to affecting other phases). This indicates that decisions or actions taken in pre-construction are highly influential on the construction activities. Notably, the "Submittal and Transmittal Approval" process in pre-construction emerged as the most impactful on project completion timelines, mainly due to its requirement for frequent stakeholder involvement and a clear line of accountability for timely reviews and decision-making, which are essential for smooth process progression.

Furthermore, the study observed (i) a marked increase in data production and collection by both private and public entities; and (ii) an increased need for defining a solid data strategy to support efficient operational decision-making. However, data integration from multiple siloed data sources poses a significant challenge, with missing data identified as the primary cause of poor data quality. The interview findings strongly support the observation that the construction industry has fallen short in adopting emerging technologies and **data-driven decision-making** approaches that consider the DIKW (Data-Information-Knowledge-Wisdom) hierarchy implementation across all projects' life cycle phases that enable **process intelligence** to support and improve construction processes and **project management**.

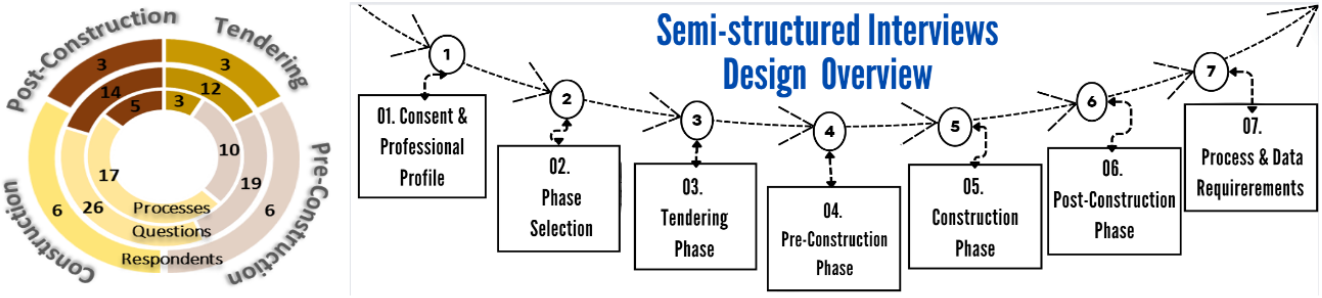
1. INTRODUCTION

Despite current digital transformation attempts, the productivity in the construction industry has remained stagnant with only 1% growth over the past two decades compared to the 3.6% productivity growth of the manufacturing industry during the same period, according to McKinsey & Company (2017). One of the main causes of this problem is that most efforts are put into managing 'projects' and less into managing 'processes. In other words, **construction processes are frequently overlooked** across the project life cycle lacking visibility and understanding of real **process performance**. If these processes are not properly managed, this can lead to work disruptions, **productivity loss**, time and cost overruns, and even project failure. In this regard, construction projects are **process-heavy** encompassing a diverse range of processes across various phases, involving multiple parties and actors, which can significantly impact the overall project performance. Cross-phase analysis is crucial for seamless project progression and success. Processes within phases contain valuable interconnected business operations and information exchange that is crucial for unlocking the project's success. Therefore, in pursuit of effective cross-phase management, two critical aspects must be given due attention. The first is process performance monitoring awareness, which involves a comprehensive understanding of how processes are performing against project objectives or Key Performance Indicators (KPIs). The second is data-informed decision-making, which empowers project stakeholders to make informed choices based on fact-based insights. While the construction industry has made strides in leveraging digital technologies like **Business Process Management (BPM)** and Building Information Modeling (BIM) to enhance project life cycle management, there remains a noticeable gap when coming to the integration management of business processes across all project phases. To tackle this gap, semi-structured interviews with subject matter experts were conducted to enrich and extend the comprehensive theoretical research performed on the topic with practical insights.

In this document, the most relevant findings of these interviews are reported, and a **data-driven decision-making approach** is introduced for enabling project and **process intelligence**, aiming to enhance construction performance. It turns out that: (i) processes under the preconstruction phase are notably influencing and being influenced by processes from other phases; (ii) the project's completion timeline is significantly affected by those processes in various phases that necessitate frequent and immediate revisions or actions to maintain smooth project progress. For instance, the submittal and transmittal approval process that requires frequent stakeholder actions (i.e., day-to-day) to ensure all technical documents are reviewed and approved in a timely manner; and (iii) while data has experienced substantial growth in the last three years and has been utilized in operational decision-making, the quality of the collected data has been subpar, leading to challenges for stakeholders in its effective use. Participants report spending a **significant amount of time** (i.e., more than 15 hours each week) in **data wrangling** that frequently ends up being wasted due to poor data quality or lack of data integration. Thus, the **key barriers to adopting a data-driven approach**, as identified by interview respondents are as follows: (i) unstructured data; (ii) diverse challenges in making data usable; (iii) limited or non-existent corporate data strategy to build **organizational memory** that strengthens business competitiveness; (iv) absence of real-time or semi-real-time automated data transfer, data integration, and data insights; (v) lack automated methods for process modeling and near real-time performance monitoring; and (vi)lack performance benchmarks on the required time to collect, analyze, and communicate data according to the type of processes being assessed in different projects. In addition to these findings, the following sections provide a more detailed analysis of the semi-structured interviews' results.

2. THE INTERVIEW

Interviews with subject matter experts provide a practical industry-oriented perspective on project and **process management in the AEC/FM domain**. Semi-structured interviews facilitate capturing tacit knowledge from the respondents by allowing them to answer both open-ended questions to more freely explain their viewpoint on certain topics and closed-ended questions to assist formal knowledge aggregation in a more structured format. The interviews comprised three major sections and seven main components, as shown in Fig. 1.



Section ID	Component ID	Content Focus On	Question(s) No.	Questions Focus On	Sample Interview Questions			Insights Reference
I	1	Consent & Professional Profile	1-11	Roles & Experience Involvement at Project Level Involvement at Company Level	**Q4.** What best describes your professional role? **Q6.** How many years of experience do you have in the construction industry?	**Q7.** What type of construction projects do you typically work on? **Q8.** What is the average base contract value of the construction projects you work on?	**Q10.** Approximately how many projects does your company complete per year?	Fig. 2 Fig. 3 Fig. 4
	2	Phase Selection	12-15	Construction Project Phases	**Q12.** Our research has identified four major phases in a construction project which are: Tendering; Pre-construction; Construction; Post-construction. In your opinion, do these four phases represent adequately the lifecycle of a construction project? **Q15.** On which of these phases do you want to give more insights about?			Fig. 5
II	3	Tendering Phase	15-27	3 key identified processes	**Q16.** How would you rate the level of importance of the processes listed below with respect to your role? **Q24.** Which processes have the greatest impact on the project's completion timeline and requisites?	**Q21.** List up to 3 observed process bottlenecks or glitches? **Q26.** If applicable, what are the typical synonyms of each process?	**Q25.**What other phase(s) of the project would be highly affected by these processes? **Q27.** Which actors do you believe are associated with each process and what information is communicated between you and other actors?	Fig. 5 Fig. 6 Table 1
	4	Pre-Construction Phase	28-46	10 key identified processes				
	5	Construction Phase	47-72	17 key identified processes				
	6	Post-Construction Phase	73-86	3 key identified processes				
III	7	Business Processes & Data Requirements	87-105	Industry needs and requirements on business process and data management	**Q87.** Has the volume of your project data increased over the last three years?	**Q90.** What percentage of your project data is available and suitable for decision-making? **Q99.** What are some challenges with using your data?	**Q102.** How much of your data is bad or unusable (ie:poor quality, inaccurate, untimely, incomplete or missing)? **Q103.** Why is the data poor quality?	Fig. 7 Fig. 8 Fig. 9

Fig. 1. Design Overview of Semi-Structured Interviews

The first section comprised questions focused on the **respondents' professional background** as well as on the selection of a construction project phase in which they have had a higher involvement and experience. The second section was fully process-oriented including specific questions related to **key business processes** across project phases. Finally, the third section investigated **business operational data needs** and requirements to support data-informed decision-making in construction projects. To limit the interviews' duration to about one hour, while every participant received 15 questions in section 1; the total number of questions in each interview

depended on the phase and business processes relevant to the respondent. As a result, the longest interview included 55 questions (out of about 105 questions in the pool). Interviewees were directed to respond to questions according to their main area of expertise. The existing literature and initial data collected from industry experts suggested that most construction projects follow a life cycle of four main phases after the feasibility of a project is approved, **i.e., *pre-construction* (*design included*), *tendering, construction,* and *post-construction***. The interview was designed to cover the main work processes involved in these phases, and the participants were selected to support the knowledge requirements related to those processes. Normally, the tendering and post-construction phases are less process-heavy than pre-construction and construction. A balanced number of industry experts were interviewed proportional to the number of identified standard processes under each stage.

PROFESIONALS' BACKGROUND

In total, 18 subject matter experts, located and practicing in North America, were interviewed. Fig. 2 shows the years of interviewees' **work experience, grouped by roles**. It is worth noting that several of these experts have held more than one role throughout their professional careers. It is worth noting that some of the interviewees have had multiple roles throughout their professional careers. In those cases, each participant can have more than one role. Besides, these roles were sub-grouped by the construction project phase selected by respondents as the one they are most familiar with.

Fig. 2. Respondents' years of experience by professional role and project phase

COMPANIES' & PROJECTS' SIZE

At an aggregated level, reviewing the **main project types** the respondents have been involved in, against their **average project base contract values** (PBCV), Fig. 3 shows that most project contract values are over $1 million CAD involving different project types. For infrastructure projects including wastewater treatment plants, the

average base contract has been over $1 billion CAD. Besides, some of the companies where the respondents come from, manage between 100 and 1,000 projects under construction per year with contract values over $100 million CAD as shown in Fig. 4. From this figure, it can be also noticed that one out of the three respondents under the tendering phase indicated that the company manage between 10 to 25 projects with average PBCV ranging from $1M to $5M CAD. As per projects under pre-construction, five out of six participants who accepted to respond to this question, specified that their companies manage between 1 and 10 projects with PBCV ranging from $5M to 1B CAD. Finally, two out of three participants accepted to respond to this question under the post-construction phase, and one of them indicated that the company manages between 10 to 25 projects whose PVCV are between $1M to $5M.

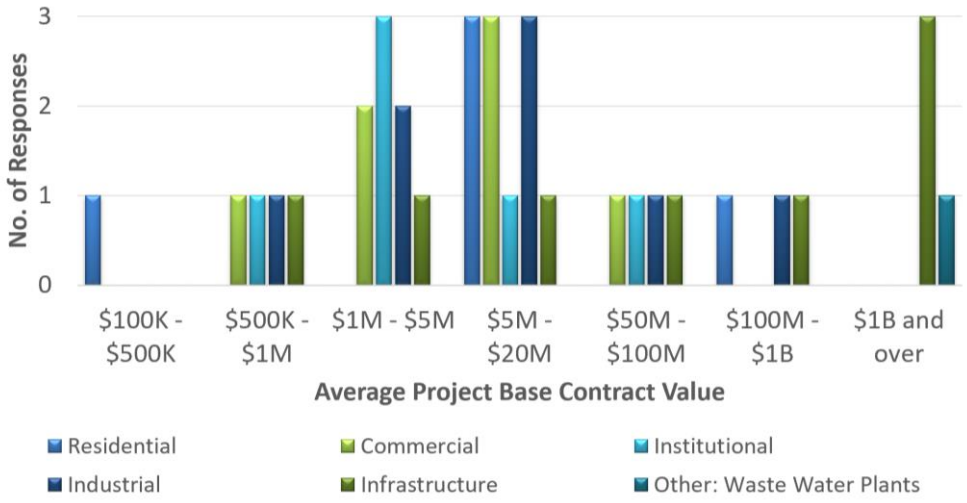


Fig. 3. Project types (response counts) vs. Average project base contract values

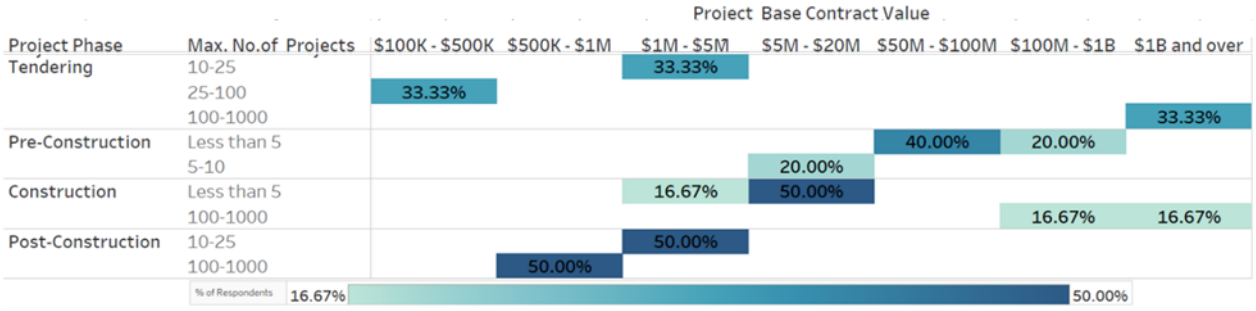


Fig. 4. Respondents' support (%) by project contract value, project phase and no. of managed projects per year

3. CROSS-PHASE PROCESS MANAGEMENT

A comprehensive list of **business processes** across each phase of a construction project's life cycle is shown in Fig. 5. These processes were identified based on an exhaustive analysis of the literature, validated by industry experts. The interviewees were tasked with indicating the **process interplay**, i.e. the degree to which each process contributes to affecting other phases. This diagram was derived from analyzing the interviewees` responses to questions such as those described in Fig. 1. The three main parts of the diagram show the distribution of processes across different project phases, the number of responses supporting the importance of each process, and the percentage of cross-phase interplay. The connections demonstrate the flow and influence of each process from one project phase to another, indicating which phases are most affected by these processes and to what extent. The cross-phase analysis presented in Fig. 5 reveals that with **32%** of all identified processes, the pre-construction phase bears the highest number of process interplay indicating that decisions or actions taken in pre-construction are highly influential on the later construction activities.

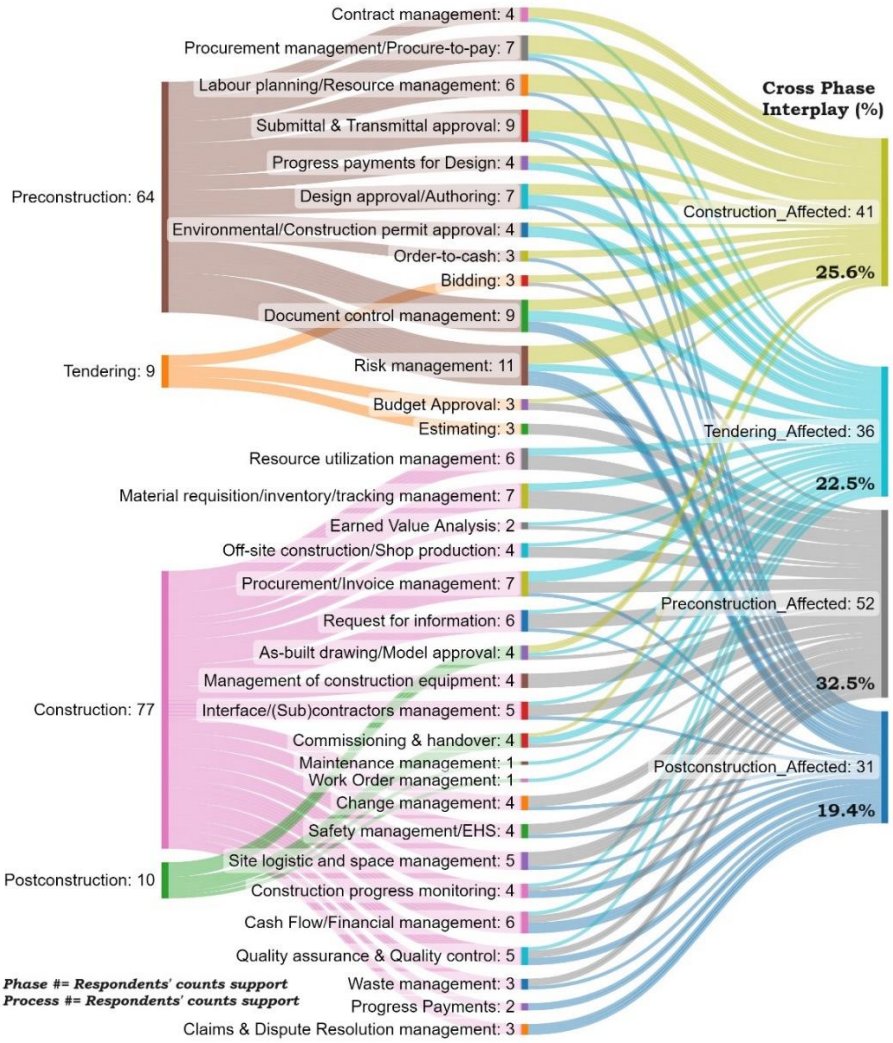


Fig. 5. Cross-phase process impact and interplay according to respondents

Risk management, **document control management, and submittal and transmittal approval** (all belong to pre-construction phase) are highlighted with a higher count (11 and 9, respectively), underlining their significance in the project management process.

In terms of strategically enhancing decision-making, the diagram can be also interpreted as a map of information flow, **process improvement**, and resource allocation prioritization. For instance, "**Labour planning/Resource management**" requires significant information exchange between the pre-construction and construction phases, which suggests the need for robust communication procedures. Moreover, the flow patterns can highlight areas for process improvement through overlapping processes analysis. For example, **"Request For Information" and "Procurement management/Procure-to-pay**", critical processes that are highly influenced by the pre-construction phase with high count of responses (6 and 7, respectively) which can cause work disruptions due to approval and response delays affecting multiple phases and the overall project timeline. If, for instance, the procurement process is inefficient or has many issues, it could delay the start of the construction phase, since materials and services may not be procured on time. Thus, it also highlights the necessity of automating the Procure-to-Pay process in construction. The processes' counts can also assist project managers to prioritize resources. In fact, processes with higher counts may warrant more attention and resources, considering their perceived importance by the respondents which are mainly project managers.

TENDERING

As seen in Fig. 5, tendering processes contributed about 5.6% of overall cross-phase influences. Among these processes, **"bidding" and "budget approval"** showed higher interplay with construction and pre-construction phases. "bidding" process affect the project's cash flow during the construction phase, where the effects of contingencies on final price should be considered to secure the contract by offering a compelling bid while ensuring that they can manage the project profitability. The "budget approval" effect highlights the dynamic nature of budget management underscoring the need for continuous financial oversight in project, where changes are common and have significant cost. Besides, the interviewees stressed that the "cost estimation" process has a direct influence on the pre-construction phase and subsequent phases, as inaccuracies can lead to significant cost overruns. The key challenge is maintaining precision, particularly with contingencies. Refining and updating estimates in the pre-construction phase are essential. With historical data and analytics, it is recommended to enhance the accuracy of cost estimations in the tendering phase. It is also worth noting that reported bottlenecks such as **contractors' overpricing**, and incomplete design can highly influence subsequent project phases in terms of time and cost impacts.

PRE-CONSTRUCTION

Noticeably, a majority of business processes under the pre-construction phase can significantly impact the construction phase. "**Risk Management**" stands out as the leading factor, garnering 7% of the total respondents' attention. This process leads to higher interactions with tendering (18%), construction (45%), and post-construction (37%) phases. More specifically, respondents emphasized the impact of the "Submittal & Transmittal Approval" and "**Document control management**" processes on the construction phase. The importance of "Risk management" underscores the identifying and mitigating risks early in the project lifecycle.

“Document control management” and “**Submittal & Transmittal approval**” also indicate the critical nature of managing documentation and approvals in maintaining project integrity and communication. Upon checking other processes such as “**Design approval/Authoring**”, it is pivotal in preconstruction, establishing project scope to meet client needs, and maintaining budgetary goals. Delays in this phase can ripple into tendering, construction, and even post-construction, causing broader schedule setbacks. Therefore, respondents suggested increasing collaboration by considering more **collaborative delivery methods** such as Integrated Project Delivery (IPD) or Progressive Design Build (PDB) to (i) streamline approval protocols; (ii) reduce back-and-forth communication, and (iii) foster collaboration with early contractor involvement to ensure the design's constructability.

CONSTRUCTION

As noted in Fig. 5, the construction phase is referred by respondents to hold the 2nd highest cross-phase process interplay with **25.6 %.** the “Procurement management” process (during the construction phase) has interrelations with the tendering phase (43%), pre-construction phase (43%), and post-construction phase (14%). Also, the "Material Management" process plays a significant role in the project`s success. Late material deliveries or untimely requisitions can directly impact the project timeline. Therefore, effective material management during construction also results from careful financial and resource planning during pre-construction. Besides, the **"Material Management", "Procurement", and "Request for Information (RFI)"** processes are interrelated not only with one another but also, they can be influenced by other processes such as "Design Approval/Authoring", and "Submittal/Transmittal Approvals". For instance, an approval delay of a material-related submittal can affect both the response time of an RFI and the procurement of that material.

POST-CONSTRUCTION

The cross-phase process interplay for the post-construction phase was supported by 6% of respondents with the **“As-Built drawing/model approval” and “commissioning & handover”** processes holding the main interplay with the tendering and construction phases, meaning that these two processes have a cumulative nature in a way that to test and deliver the built facility, it is necessary to have properly managed and collected all material and equipment as well as the technical and design documentation of what was included in the bid (tendering phase), what was procured (in both pre-construction and construction phases), and what was built (construction phase). For example, improper tagging or identification of electrical and mechanical equipment as well as of MEP systems and poor management of submittals and technical sheets will impact the project close-out. These two interrelated processes are critical for construction **project close-out** and include the owner’s **standard operating procedures** and required information exchange such as **operation and maintenance manuals** for the handover to facility managers.

4. PROCESS RELEVANCE & BOTTLENECKS

The processes deemed most critical, based on respondents' feedback, are highlighted per level of importance in Fig. 6 and Appendix IA. As observed in the figure, there are important relations and variations between the significance of these processes and their potential impact on a **construction project's completion timeline**. In the case of tendering, the interviewees unanimously emphasized the **"Bidding" process** is the most preeminent business operation with **66%** of the respondents stating that it can have an important effect on the project's completion timeline. Given that the foundations of project planning are laid during the bid preparation, the synergy is not surprising. Under the **pre-construction phase**, four out of ten identified processes stood out in terms of significance, i.e., "Contract Management", "Design Authoring/Design Approval", "Procurement Management", and "Submittal & Transmittal Approval". Several factors may contribute to this, yet a salient evaluation from a time approval perspective suggests that the Submittal and Transmittal approvals often necessitate frequent **stakeholder involvement** and decision-making to facilitate the seamless process progression (83%). This is closely followed by the importance of design approvals and procurement management, while issues related to contract management may have critical implications on the project completion timeline.

Under the construction phase, the three most important business operations according to respondents (out of a total of 17 processes) include **"Progress Monitoring"**, **"Material Management"**, and **"Change Management"**, which can also have a high impact on the overall timeline of construction projects as they primarily deal with 'day-to-day' or 'week-to-week' actions and approvals aimed at controlling project progress and ensuring adherence to the schedule. At a lower level of respondents' support, "space-time planning" of construction operations is recognized as another critical process during the construction phase. Last but not least, at the end of the construction phase and during the post-construction phase, the **"Commissioning & Handover" process** holds a significant mid-level position in both regards. equally rated at **67%.** It shows that stakeholders may perceive a balanced risk for this process, which can be more manageable.

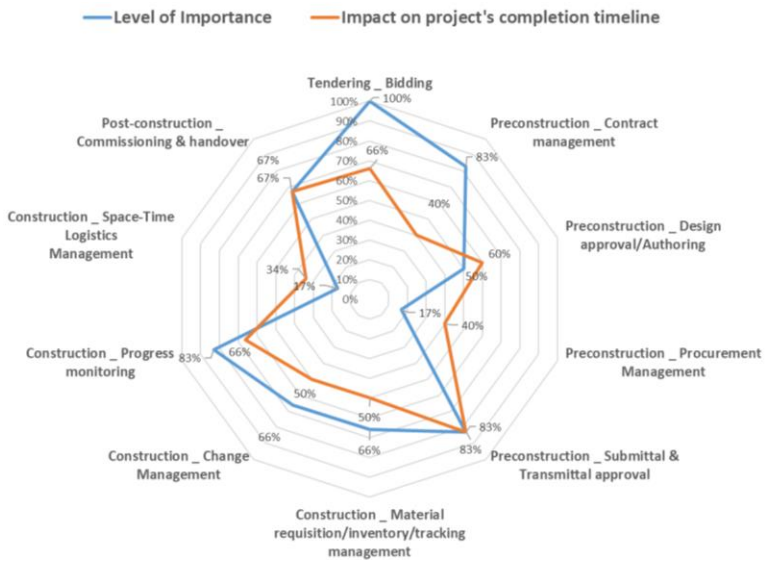


Fig. 6. Priority processes and their effects on project's completion timelines

To better understand the challenges hindering these processes, the main **process bottlenecks** perceived by the interviewed industry experts for high-impact processes of each phase are presented in Table 1. These bottlenecks can have a **direct impact on project timelines** that result in cost overruns. For instance, inaccurate estimations, overpricing, and inadequate material tracking during the 'Bidding' and 'Material Management' business operations diminish process efficiency, increase costs, and potentially lead to significant project delays.

Table 1. Identified process bottlenecks by respondents per project phase

Phase	Process	Identified Bottlenecks?
Tendering	Bidding	Missing or Incomplete Drawings; Contractors' Overpricing; Unreliable and inaccurate Estimations
Pre-Construction	Contract Management	Legal department revision; information management; BIM not specified in the contract; Inexperienced Project Manager
	Design Approval	Poor communication; lack visibility on approvers; delays in revision times; delays in approval times
	Submittal/ Transmittal Approval	Poor track of logs; manual workflows; revision delays
	Procurement Management	Lack of monitoring of vendors' prices; poor visibility on vendor agreements; foremen not ordering from partner vendors
Construction	Material Management	Unplanned daily orders by supervisors; poor inventory management; ordering much more than needed; poor material tracking
	Construction Progress Monitoring	Reporting more progress than the real one; poor visibility on remaining work and time to complete it; Overlapping activities too much
	Site-Space Logistics Management	At peak time conflicting cranes/machines
	Change Management	Getting all answers at the right time from different parties involved; poor coordination; contract clauses not specific enough; scope and exemptions not detailed enough; getting clients' approvals; change revisions; delays in estimating and submitting change
Post-Construction	Commissioning & Handover	Lack of process visibility; Non-standard punch list process; Inexperienced Owners

Concerning the key processes outlined in Fig. 6 and Appendix IA, the interviewees were also tasked with identifying the **actors linked to each process** and delineating the nature of **information exchanged** during the execution of these processes as well as the main **process stakeholders**, as detailed in Appendix IB.

5. DATA-DRIVEN DECISION MAKING

To ascertain business data requirements, a crucial initial step involves outlining business goals, comprehending **core processes**, monitoring main **business KPIs**, and identifying **information needs**. As respondents grapple with effectively collecting and utilizing data, it becomes imperative to establish a **data strategy** capable of providing **visibility over business operations**. As part of this, for example, a Data Insight Generator (DIG) [3] can be implemented and supported by advanced digital technologies/platforms. This procedure should encompass the determination of the data needed to be collected and their data types, automated data acquisition, data quality enhancement, structuring data, the implementation of information systems to facilitate data integration [4] and data analytics to subsequently extract **valuable insights for decision makers** and stakeholders.

BUSINESS DATA NEEDS

From the interviewees' responses, it can be noted that they predominantly oversee financial and production data, encompassing cost, budget, profitability, and productivity. This shows an inclination toward increasing revenue or cost control for both private and public entities. From the initial perspective, the survey respondents emphasized the **significant growth in the amount of data** captured and formalized (in the form of structured or unstructured databases) in the last three years for private, public, and other entities, mainly during the construction and preconstruction phases (as shown in Fig. 7). Conversely, the tendering and post-construction phases have witnessed neutral growth primarily within the public sector.

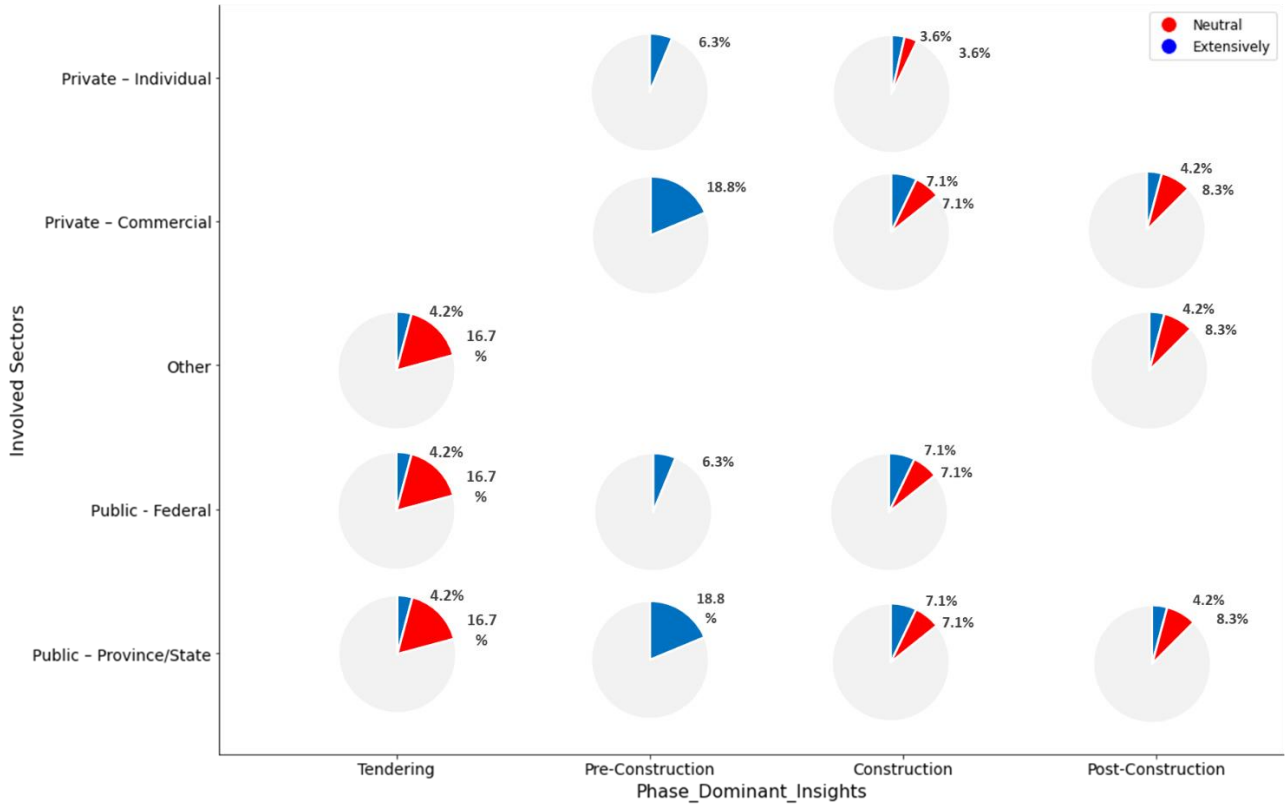


Fig. 7. Data growth over the last three years

Moreover, core processes during the construction phase center around **progress monitoring**, **change management**, and **resource allocation**. Thus, gathering execution data related to those processes and identifying main chokepoints can help extract valuable insights. Take, for example, the collection of data concerning 'change order revisions', a bottleneck in the change order management process. The insight for this bottleneck is to have continuous visibility on the revision of changes and the status of these revisions concerning their review and approval. This endeavor undoubtedly presents the opportunity to establish connections with financial aspects and conduct analytical assessments for mitigating risks derived from those changes while enhancing business operations and enabling process transparency. Therefore, gathering high-quality data related to these processes along with financial data can provide more opportunities to extract valuable fact-based insights.

In recognition of the transformative potential of data-informed decision-making in enhancing **process efficiency** and facilitating **cross-phase management**, 14 data-related inquiries were posed to industry experts. Some examples of these questions can be found in Fig. 1. In this regard, they are depicted in Fig. 8 underscoring a pressing concern within the construction industry, highlighting the critical need for **enhancing data quality** and improving **data usability** for enabling data-driven decision-making processes across various project stages. It is notorious that the readily available noisy data is being used for decision-making, which not only results in process inefficiencies but also can eventually lead to project failure. Therefore, considering these aspects can help construction organizations to better establish an effective **data management strategy** to increase their corporate memory. It should be noted that, to ensure clear understanding, the terminology used in the questions was clarified for the interviewees at the start of each interview section. For example, distinctions were made between ‘bad data’ (data with inconsistent values) and ‘wrong data’ (consistent values, but inaccurate).

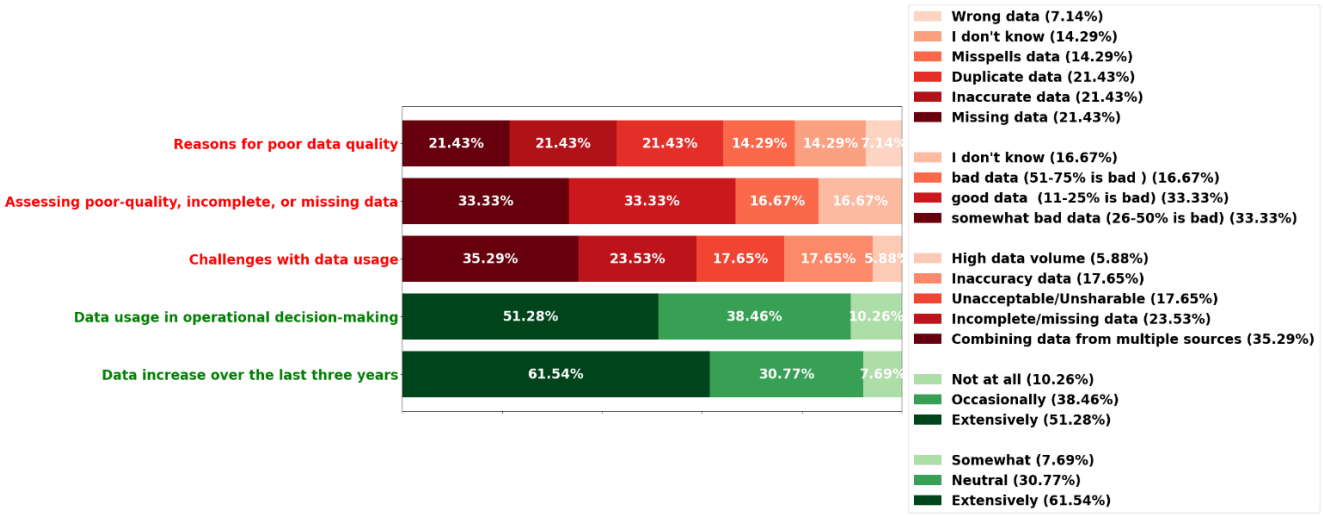


Fig. 8. Data quality challenges for data-informed decision making.

PROJECT AND PROCESS INTELLIGENCE

Based on the aggregated information from completed interviews, a conceptual model is proposed to provide a connected high-level view of construction projects supported by data and digitalization technologies including Business Process Management (BPM) and Building Information Modeling (BIM). The proposed model adopts the **DIKW (Data-Information-Knowledge-Wisdom) hierarchy** [7] implementation across all projects' life cycle phases to enable **process intelligence** formation as depicted in Fig. 9. It highlights **(i)** the importance of acquiring, collecting and contextualizing business data for **capturing process knowledge**; **(ii) monitoring the performance** of construction operations; and **(iii)** building business **knowledge assets** to enable data-informed decision making that enhances process efficiency across the project life cycle, to lead to project success.

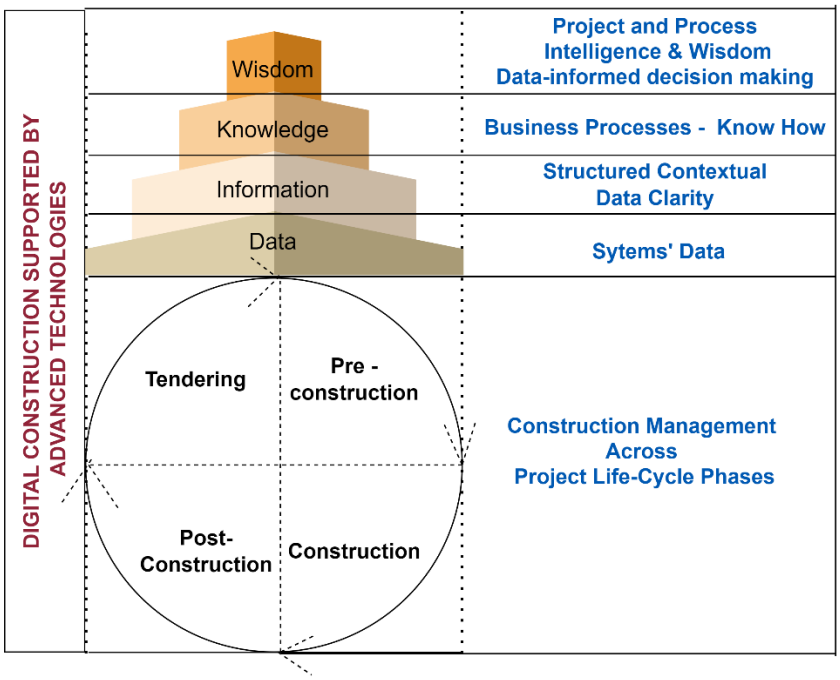


Fig. 9. DIKW hierarchy conceptual model across a construction project's life cycle

Another important aspect to facilitate project and process intelligence is **knowledge-based process modeling** [8], including the contextual process information with formal syntax and machine-readable format, to study the performance behavior of actual process executions that lead to process optimization and success. For this, building a taxonomy and a well-bounded knowledge ontology for key processes is of paramount importance. In this vein, participants were asked to provide any known terms that usually refer to the same process as listed in Appendix IC.

6. CONCLUDING REMARKS

Although stakeholders in the construction industry have broad experience in managing projects, processes within those projects tend to be overlooked. Thus, through a comprehensive analysis of interviews, this study pinpointed the potential for developing a **process-oriented data strategy** aimed to enhance process management within and, more importantly, across various phases of the project lifecycle. It also underscores the growing importance of data-driven decision-making in this domain. The interviewees, drawn from diverse backgrounds in public and private construction sectors, have been normally distributed across different project phases. The study has successfully elucidated the intricate relationships between data enrichment and process, shedding light on the prospects and limitations of harnessing data for process improvement and cross-phase analysis. These insights are gleaned from respondents' feedback, particularly focusing on the recent trends in data growth, usability, suitability, and more. Additionally, this research has crafted a conceptual model based on the DIKW hierarchy that aims to support the digital transformation journey of construction organizations to transform raw data into information and knowledge assets that enable process intelligence to monitor and enhance business processes across the life cycle of construction projects. A summary of key takeaways and findings is shown in Fig. 10.

Data Strategy

Enrich your corportate memory by: transforming raw data into "Data as an Asset"

Build your process-oriented data model

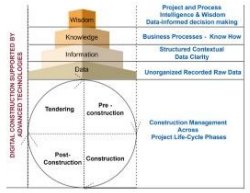
Consider process intertwinement

Enable: Process Intelligence

Identify key business processes

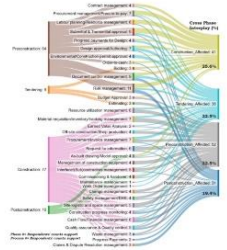
Set and monitor your Key Process Performance Indicators

Build an Intellieng Architechture for modeling, monitoring, managing and improving construction processes



Cross-phase process interplay

Monitor and quantify the comulative impact of process interplay across the life cycle phases of a construction project through automated means and advanced technologies



Tendering Phase

Constantly monitor the performance of your bidding and budget approval processes.

Identify bottlenecks such as insuficient design and contractors' overpricing

Pre-Construction Phase

Highest degree of process interplay (32%)

Special attention on the process interplay impacts of the following processes:

Risk Management
Document Control
Submittal Approvals
Design Approvals/Authoring

Construction Phase

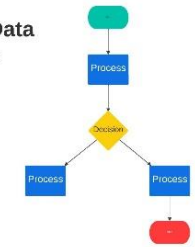
The 2nd highest cross-phase process interplay

Special attention on the process interplay impacts of the following processes:

Material Management
Procurement; RFIs
Financial- related (i.e., Cash Flow Management)

Key finding s on Business Data Challenges & Requirements

- Signigicant amount of time ends up being wasted on data integration and data wrangling attempts due to poor quality data.
- Ensure the integrity of your data
- Identify key business processes process bottlenecks



Post Construction Phase

Special attention on the process interplay impacts of the following processes:

As--Built Approvals
Commissioning & Handover
Project Close Out (incl. O&M Manuals and technical sheets)

Conclusion

Consider AI-empowered automated methods for modeling, auditing, managing and improving construction processes (i.e., process mining)

Consider adopting more Collaborative Project Delivery Methods

Do not overlook your business processes!

Fig. 10 Summary of key findings/takeaways of the study

It is worth noting that while this study offers valuable contributions to both research and practical applications, it does come with the following limitations. (i) the empirical data collection was centered around the Canadian construction industry; (ii) The reported outcomes of this investigation do not aim to provide any prescriptive results, but to collect the process-related experience of subject matter experts; (iii) some of the interviewed respondents admitted to not having enough experience in financial-related processes; and (iv) the research predominantly relied on qualitative interviews to explore the power of data-informed decision making on process improvement in smoothing cross-phase management. Future efforts should consider (i) to add other perspectives by involving interviewees such as experts with experience in financial-related processes; (ii) study process interconnection across the life cycle phases of construction projects to quantify the cumulative impact on construction projects' completion timelines and its potential cost overruns; and (iii) adopt the introduced conceptual DIKW conceptual model to build a robust data strategy to enable process intelligence. This strategy should include the generation of a well-founded process-oriented data model based on advanced technologies and methodologies to automatically monitor actual process performance that helps improve key business operations of construction organizations by producing knowledge assets that enrich the corporate memory of these organizations.

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APPENDICES

APPENDIX I

IA. Most relevant processes according to subject matter experts

Phase	Process	Process Importance				Impact on project's completion timeline		
		L (%)	M (%)	H (%)	N/E (%)	L (%)	M (%)	H (%)
Tendering	Bidding			**(100%)**		(34%)		**(66%)**
Pre-Construction	Contract Management			**(83%)**	(17%)	(20%)	(40%)	**(40%)**
	Design Approval		(33%)	**(50%)**	(17%)	(20%)	(20%)	**(60%)**
	Submittal/ Transmittal Approval		(17%)	**(83%)**			(17%)	**(83%)**
	Procurement Management	(17%)	**(50%)**	(17%)	(17%)	(20%)	(40%)	**(40%)**
Construction	Material Management		(34%)	**(66%)**		(17%)	(33%)	**(50%)**
	Construction Progress Monitoring		(17%)	**(83%)**			(34%)	**(66%)**
	Space-Time Logistics Management	(17%)	**(66%)**	(17%)			**(66%)**	(34%)
	Change Management		(34%)	**(66%)**			**(50%)**	**(50%)**
Post-Construction	Commissioning & Handover		(33%)	**(67%)**		(33%)		**(67%)**

IB. Non-exhaustive list of process stakeholders and information exchange

Phase	Most important process	Process Stakeholders	Information exchange/ communicated
Tendering	Bidding	bidders, professionals	posting of tender, bids
		contractors and subcontractors	consultant report, plans, tender documents, specifications, quotes, schedules, shop drawings
		legal department, risk managers	insurance, liabilities
	Contract management	Project manager, Business unit leader, client	deviations from standards or initial tendering language, uncommon languages or payment terms
		owner, designer	contract, scope of work
		PM	BIM annexure

Preconstruction		developer team	scope of project
		PM, Finance	base contract value, value of changes
	Submittal & Transmittal approval	designer, contractor	construction docs
		PM, PD, BIM lead	BIM in compliance to client standards
		PM, design team, leaders (directors)	documents that need to be submitted, packages, documents
Construction	Construction progress monitoring	site team, owners (client)	updated schedules, delays, advances, hurdles etc.
		surveillant	progress data
		foreman	forecasting details, FTC or FAC or %
Post-construction	Commissioning & handover	Landlord/owner, GC, facility managers	deficiencies list, premises' review, lease amendments
		service provider (commissioning agent), Business product manufacturers (BPM),owner	requirement checklist, as-built drawings, reports for major systems,
		PM, project coordinator, suppliers, subcontractors, engineers, shop manager	deadline, eng. schedules SB/SC, maintenance doc, warranty doc

IC. Non-exhaustive list of processes' synonyms/terms

Phase	Process	Synonyms
Preconstruction	Contract management	Contracting, contract values
	Procurement management / Procure-to-pay	Materials procurement, equipment procurement
	Order-to-cash	Subcontract, AR (Accounts receivable)
	Design approval/Authoring	CAD (Computer Aided Design) or VDC (Virtual Design & Construction)
	Document control management	SharePoint, Procore (technology to support process)
	Submittal & Transmittal approval	Technical submissions
	Progress payments for design	Invoicing, payment terms
Construction	Resource utilization management	Resource management, Labour management, (Labor, material, equipment and schedule)
	Material requisition/inventory/tracking management	Material purchase orders
	Change Management	It can involve change events, change orders, prime contract change orders, Site Instructions (SI), contemplated change notices (CCN), change requests (CR)
	Construction progress monitoring	Work in Progress (WIP); Progress Tracking
	Site logistic and space management	Staging area, laydown areas
	Quality assurance & Quality control	Deficiencies Assessment & Compliance Assurance

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DIGITALIZATION

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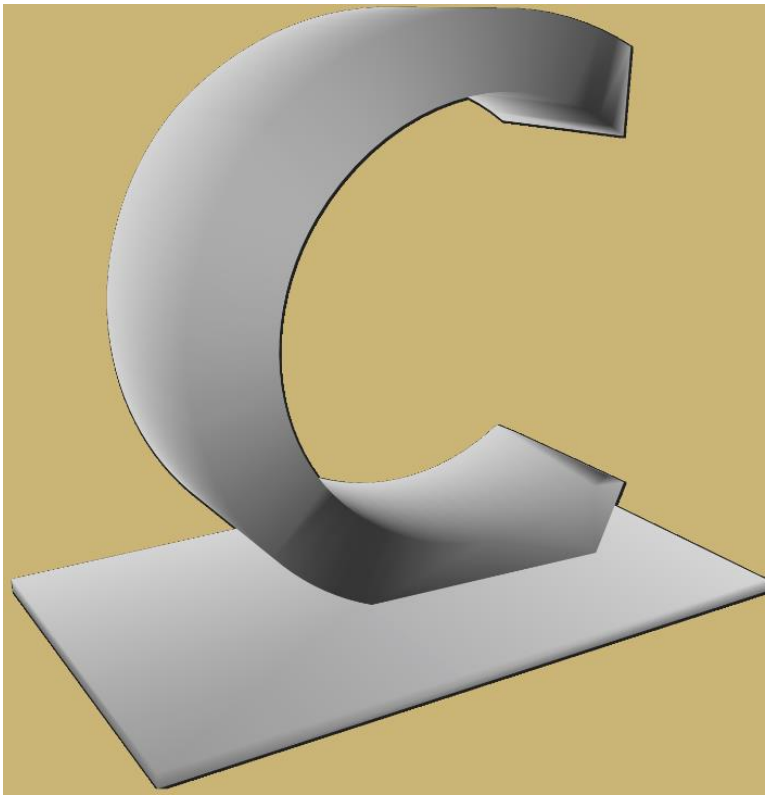
CONSTRUCTION PROCESSES MANAGEMENT



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