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Building a Strategic Action Plan for the Ontario Construction Industry to Tackle Future Pandemics

A research project by the University of Toronto

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In collaboration with
Residential and Civil Construction Alliance of Ontario
Ontario Society of Professional Engineers
The Residential Construction Council of Ontario

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Executive summary

This report summarizes the results of a research project conducted by a team from the University of Toronto on means to help the construction industry predict, plan and manage future pandemics. The project was conducted in collaboration with the Residential and Civil Construction Alliance of Ontario (RCCAO), the Ontario Society of Professional Engineers (OSPE), and the Residential Construction Council of Ontario (RESCON). The project was funded by the Natural Science and Engineering Council of Canada (NSERC) as part of its COVID-19 research initiative.

The project scope specifically does not include health and safety issues (such as masking, hygiene, and physical distancing). These issues are well researched, documented, and are part of the legal mandates in many cases. Instead, this work is focused on the resilience of the overall industry against the challenges of future pandemics. How should we reformulate project design and construction methods to adapt to the disruptions of pandemics? How can industry organizations collaborate to tackle the pandemic collectively?

The components of the proposed action plan and key recommendations are listed below. The main recommendation is that industry associations and government agencies should enact a mechanism to implement such an action plan. Without that, it will not be possible to use it for managing future pandemics. The implementation mechanism can include establishing a committee or an industry-academia initiative to periodically monitor its application and overall pandemic preparedness.

The proposed action plan includes 79 best practices. They were developed based on literature reviews of best practices in the construction industry and other industries, reviews of relevant research work, an industry-wide survey, and interviews with industry experts. The best practices were categorized along the following dimensions

- Phase: preparedness, detection and replanning, implementation, evaluation, and recovery
- Level: enterprise, industry, community
- Domain: health and safety, construction and project management, business management, public policy, design and engineering, supply chain
- Stakeholder: government, industry entities, contractors, developers/owners, consultants, suppliers, financial/insurance institutions, media, research, and education

The research also developed an assessment of the impact and feasibility of each best practice. For that, the survey results were analyzed using two major approaches: 1) statistical analysis and 2) network analysis. The first approach looked at key statistical indicators such as frequency, average values, etc. Aware of the interlinks between the best practices, the team created a matrix of relationships/dependency between the

best practices. This enabled the creation of a network for the best practices. Network analysis measures, particularly centrality, were used to examine the role and importance of each best practice.

The shortlist of the top best practices was developed using a score based on impact, feasibility, and centrality. The top best practices are:

1. Think About Growth Strategy
2. Create Videos of Proper PPE Use
3. Hazard identification
4. Vertical Integration
5. Review Insurance Policies
6. Adopt E-Permitting
7. Revisit Resource Plans
8. Improve Adaptability
9. Collaborate with Other Provinces or Countries
10. Co-assess Preparedness Plans with Governments

The project also created an interactive web portal to help industry practitioners navigate the best practices and study their impact and feasibility. In addition, the portal allows users to contribute ideas for additional best practices. It is hoped that a team from the industry can periodically check these ideas and add them to the list accordingly.

Acknowledgment

The research team and the collaborating organizations acknowledge the funding provided by NSERC (Natural Science and Engineering Council) as part of their COVID-19 action plan.

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Introduction

The COVID-19 pandemic has had an unprecedented impact on all aspects of society. Having a complex, *ad hoc* scope of projects and an extended supply chain, the construction industry faced enormous challenges during the pandemic. The construction industry is one of the largest industries in Canada, generating approximately $142 billion to the Canadian economy annually and representing 7.2% of Canada's gross domestic product (GDP) [1]. More than 1.5 million people work in the construction industry, indicating its immense social and economic impacts on Canadian communities [2]. By March 27, 2020, all provinces and territories of Canada declared states of emergency or public health emergency due to COVID-19. In April 2020, the construction industry GDP dropped 20.9% compared to March 2020 and 20.6% compared to April 2019 [3].

On March 17, 2020, the Government of Ontario declared a state of emergency to contain the spread of COVID-19. Because of the importance of the construction industry, the Government of Ontario authorized construction to remain open; and assigned more than 150 inspectors to enforce hygiene in work sites [4]. However, later, Ontario decided to shut down all non-critical construction sites to prevent the spread of the virus. As a result, the construction industry GDP of the second quarter of 2020 in Ontario declined 12.2% compared to the first quarter of 2020 [5]. The repeated disruption that ensued throughout the open-and-close cycles over 15 months showed that the construction industry was not prepared for pandemics (indeed the whole country). The last pandemic, that is comparable to COVID-19 in severity, is the 1918 "Spanish Flu". It took place over 100 years ago. In recent years, the relatively "mild" pandemics, such as SARS and H1N1, created a false sense of competency/preparedness. Despite warnings from researchers of a pandemic threat, governments and businesses have devoted minimum resources for such an unlikely event. This has led to the vulnerability we experienced during COVID-19.

This research project aimed to build a dynamic strategic action plan for the Ontario construction industry to overcome future pandemics. The strategic action plan comprises a set of 79 best practices that are focused on industry-level collective actions rather than site-level health and safety practices. Using an interactive web portal, industry practitioners can update and revise the plan as their experience with emergency and pandemic situation advance. Appendix A lists all 79 best practices.

Methodology

This research project was a fact-finding, knowledge discovery type of work. The methodology included the following steps:

Developing an initial list of best practices: in this step, pandemic-related best practices from other industries and countries were benchmarked. Additionally, the research team synthesized best practices in the construction industry based on literature reviews and through conducting informal interviews with experts (Appendix B summarizes the main findings of the literature reviews). By the end of this step, 79 best practices were identified as elements of an action strategy by the industry.

Engaging stakeholders: stakeholders were engaged through four different channels: two surveys, formal interviews with industry experts, and an interactive website. The first survey collected the evaluation of industry practitioners regarding the proposed best practices in terms of two main metrics: their possible impact (value) and feasibility. A second, limited survey was conducted with industry experts to examine

the connections between the best practices: which best practices are related? The collected relationships formed a matrix, which was then used to establish a network of best practices. Network analysis produced a third metric for evaluating best practices: centrality. The latter refers to its role in enabling other best practices. The importance ranking of a best practice was calculated based on its individual impacts and feasibility as well as its centrality in the network.

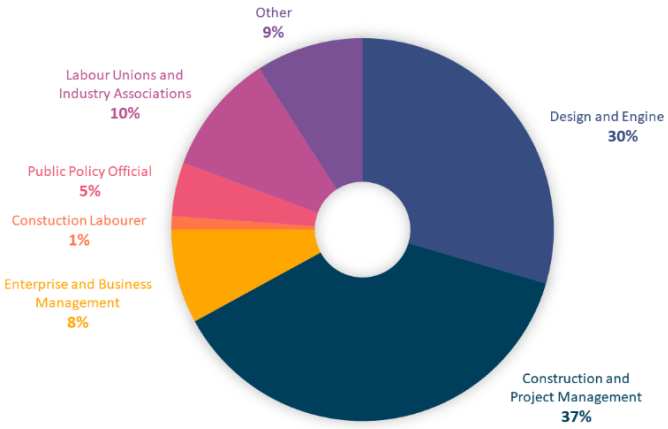
Interviews with industry experts: this formal set of interviews amid to assess the overall structure of the proposed action plan in light of the challenges they faced and potential difficulties in implementing the proposed best practices.

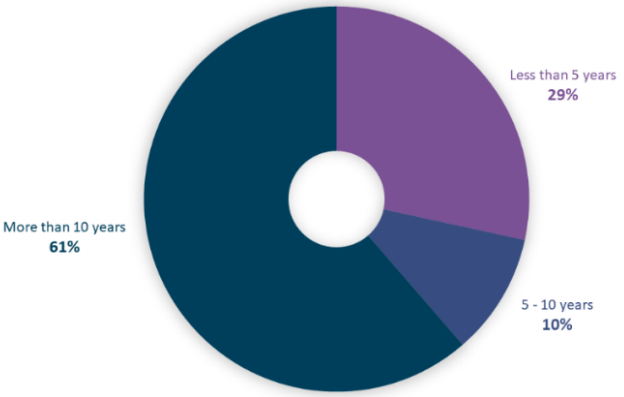
An interactive website: the site (https://constructioninpandemics.ca/) is a two-way communication channel where the best practices are shared with industry practitioners. It provides them with a continuous chance to contribute new best practices or comment on the implementation of the proposed strategy.

Results of the First Survey

The details of conducting the survey are discussed in Appendix C. Below are the main highlights.

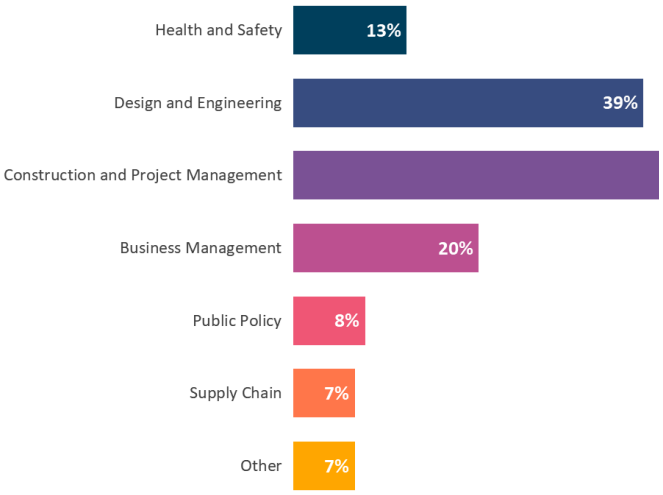
88 respondents participated in the survey, which was significant to drive conclusions. 59% of all surveys were fully completed (all questions were addressed by the participant). 37% of the respondents worked in the construction management field, while 30% of them worked in the design and engineering fields. The respondents represented a diverse set of stakeholders in the industry, including labour unions, industry associations, public policy officials, business management, and construction labourers. 9% of the respondents identified as "Other" professions, which included material suppliers, researchers, media, and lawyers.

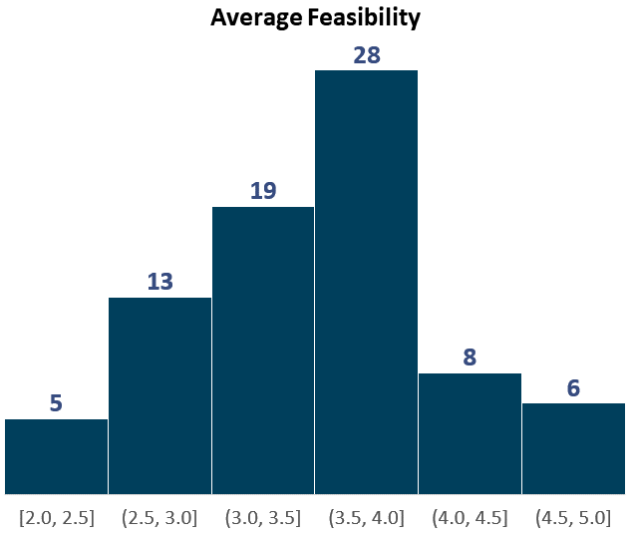




61% of the respondents have been working in the construction industry for more than 10 years, while 29% of respondents have less than 5 years of experience. The diversity of experiences offered a good balance to complement new thinking with the experience of established norms.

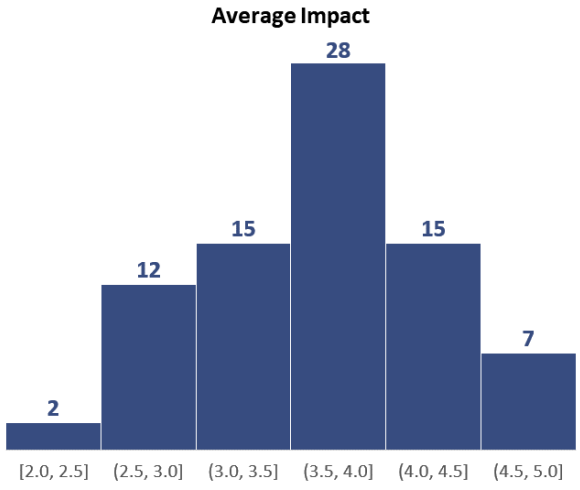
The proposed strategy categorizes the best practices along six main domains of knowledge/ expertise. The backgrounds and professional expertise of the respondents were collected to verify that the six proposed domains were well covered. The results showed that only 7% of people selected the "Other" option and most expertise fit into one of the six proposed domains.





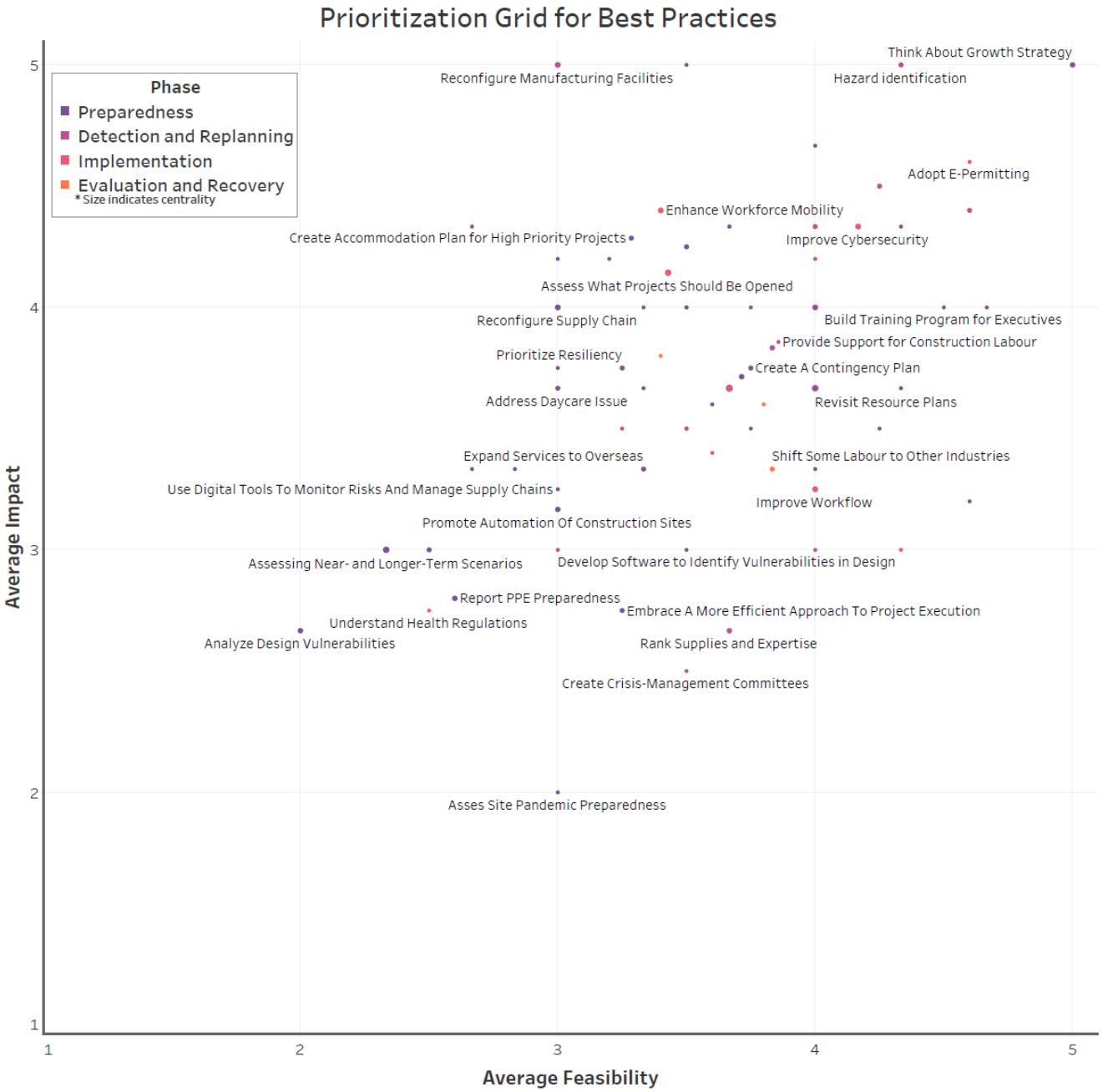
A total of 79 best practices were included as seeds for further contribution from the respondents. They were asked to score each proposed best practice on two dimensions: impact and feasibility. A scale of 1 to 5 was used. A rating of 1 means the best practice is not effective (has very low impact), or is not feasible (hard to enact/use); and a rating of 5 means the best practice is very impactful or very feasible. The average impact rating of all the best practices was 3.7, with over 80% of best practices having an impact rating above 3. The average feasibility rating of all the best practices was 3.6, with over 75% of best practices having a feasibility rating above 3.

All the best practices' feasibility and impact ratings were also positively correlated with a correlation coefficient of 0.46. The positive correlation suggested that best practices with higher impact ratings are not necessarily more difficult to implement.



Prioritizing the Best Practices

Two approaches were used to rank the best practices. The first approach is a prioritization grid [18]. On the X-axis is "Feasibility," which refers to how feasible it is to implement a best practice. On the Y-axis is "Impact," which indicates how effective the best practice is. All the best practices were plotted onto the grid as dots located based on their impact and feasibility. The size of each dot refers to the centrality of the best practice. Bigger nodes in the top-right quadrant are the most important ones.



The second approach of prioritizing best practices was a numerical approach that utilized each best practice's feasibility, impact, and centrality. First, the feasibility, impact, and centrality ratings were normalized since they were on different scales. Second, a score for each best practice was developed by multiplying the normalized feasibility, impact and centrality ratings (see the equation below). This means that a best practice will only get a high score if it has a high feasibility rating and a high impact rating and is central. Note that centrality can range from 0 to 1. Some best practices have a centrality of 0 (they were not connected to any other best practices). Therefore, we used *1+centrality* as the third factor in the prioritization formula. In this way, the best practices with no centrality can maintain a non-zero score (preserving their impact and feasibility). At the same time, for well-connected best practices, their rank is boosted by their role in the network. The equation for this approach is shown below (See Appendix D for more details):

$$Prioritization\ Score = Feasibility \times Impact \times (1 + Centrality)$$

The top 10 best practices ranked by the prioritization score are shown below.

Best Practice	Prioritization Score
Think About Growth Strategy	1.08
Create Videos of Proper PPE Use	1.00
Hazard identification	0.90
Vertical Integration	0.87
Review Insurance Policies	0.87
Adopt E-Permitting	0.85
Revisit Resource Plans	0.84
Improve Adaptability	0.81
Collaborate with Other Provinces or Countries	0.79
Co-assess Preparedness Plans with Governments	0.75

The best practice "Improve Adaptability" joined this list mainly because it has the highest centrality. This showcases the importance of the network view of the best practices. Best practices with high centrality might not necessarily have high feasibility and impact ratings. However, they are important because they influence/enable other best practices.

Framing the Best Practices

To provide depth to the scope of the best practices, each was categorized along four dimensions: Phases of action, Levels of action, Domains of action, and key Stakeholders. This is meant to help transfer the best practices into a strategy that can include a timeline; establish a hierarchy that defines the scope of action at different levels of the industry structure; identify expertise needed; set a role for each stakeholder.

Phases of Action

The first dimension, "Phase of action," defines at which stage a best practice is to be implemented. The proposed four phases were meant to represent the whole life cycle of a pandemic response plan. Therefore,

by categorizing best practices along this dimension, a timeline could be established for the process of pandemic management. The four phases are as follows (See Appendix E for more details):

- Preparedness: This phase includes assessing the level of industry preparedness and developing plans, benchmarks, measures for what the industry needs to do. This should be repeated frequently.
- Detection and replanning: Each pandemic will be different; no plans will be able to meet the challenges of a new pandemic. Therefore, suggested best practices should be adjusted to fit the specific challenges of a new pandemic.
- Implementation: This phase primarily includes best practices that relate to actions on the ground regarding issues such as workforce management, project organization and plans, contractual changes, supply chain disruptions, and business management issues.
- Evaluation and recovery: This phase aims to assess the performance of the industry in handling a pandemic to improve the preparedness for the next one, and to support the transition to a suitable "new normal". The recovery path (and best practices/action needed) for the industry might be different in future pandemics. However, the general strategies should be very similar.

Levels of Action

The second dimension of the framework is the "Levels of action." Based on the WHO (World Health Organization) guidance, it is necessary to classify all the best practices into different business levels. Project-level practices are not included in the framework since the scope of this study goes beyond site health and safety practices. The proposed levels in the framework emphasize business management, collective actions and policy and communication issues. They include the following three levels:

- Enterprise level: Mostly addresses the operation and management of construction-related activities during a pandemic. It is mostly oriented towards contractors and consultants to help them cope with/survive the pandemic.
- Industry level: These are best practices that require the collaboration of stakeholders within the construction industry that will improve the overall resilience of the industry. Different stakeholders often have different priorities, and conflicts of interest are common. Therefore, best practices at the "Industry" level were designed to enable different stakeholders to work towards a common goal to stabilize the market and to protect the whole industry.
- Community level: A "Community" level was added for two reasons. We need to consider the life of construction labour outside the site. What can be done to protect them and to safeguard against them spreading the disease? On the other hand, the construction industry represents a significant portion of our daily lives. The industry has a crucial role/responsibility in executing any national plan and in helping communities cope with the pandemic.

Domains of Action

By classifying best practices into different knowledge/experience domains, we can identify the expertise that are needed to develop and manage the strategy. We can also identify the stakeholders within and without the construction industry who should be involved in the action strategy. A total of six domains were proposed in the framework, which are:

- Health and safety: management and business aspects of effectively implementing health and safety regulations (such as PPE and physical distancing) under the stressful circumstances of a pandemic. How to coordinate with local health and safety administrations?
- Construction and project management: Best practices that could assist the reconfiguration of projects to adapt to pandemic limitations. At the project level, actions can include changes to contracts, schedules, construction methods, and technologies, etc. At the industry level, this includes best practices that can alleviate workforce issues such as labour shortage, or supply chain disruptions.
- Business management: Best practices that help firms in the construction industry survive the impacts of the pandemic (including finance and operation challenges). Pandemics cause a lot of uncertainties about current and future projects, which will require expertise in change management and business resiliency and agility practices.
- Public policy: Potential public policies that could help the construction industry during a pandemic. Some of the potential policies include economic support and stimulus plans from the governments. The industry should be proactive and suggest public policies (changes) that are most needed and most beneficial to the survival of the construction industry during a pandemic.
- Design and engineering: Changing our practice in project design and planning to directly incorporate the impacts of pandemics is not feasible and may not be an effective approach. Rather, the industry, especially contractors and consultants, should establish guidelines and promote a mentality to consider and assess the overall resiliency of designs and work plans. How to improve the design of facilities and their work plans so that they can be more adaptive to severe conditions (that can range from climate issues, to trade conflicts, to pandemics)?
- Supply chain: Construction requires a lot of materials from Canada and other parts of the world. The disruptions in the supply chain during COVID-19 have led to serious material supply issues for the construction industry. What best practices can be used to stabilize and sustain reliable supply chains? How much local production should be targeted? How to incorporate suppliers' resiliency in the overall pandemic management strategies?

Stakeholders

By assigning relevant stakeholders to best practices, each stakeholder will know exactly which best practices apply to them and require their actions. A total of nine stakeholder groups were proposed, which are listed below:

- Government (including MOL, WSIB, regional and provincial health agencies)
- Industry entities (labour unions, industry associations, and professional associations)
- Contractors
- Developers/Owners
- Consultants
- Suppliers
- Financial/Insurance Institutions
- Media
- Research and education

Comments from the Survey

Input from experts who participated in the two surveys was tracked to harness their insights. 28% of the surveyed best practices received at least one comment. Most of the comments included suggestions for improving the best practices and potential difficulties in implementation. Some of the examples are listed below:

For the best practice "Improve Adaptability," one of the comments suggested that it should be a guiding principle that is specifically encouraged as a standard practice rather than specific to a pandemic. For the best practice "Provide Support for Construction Labour," it was suggested that key statistics about the impacts on construction labour should be tracked and used to pursue government support. One of the comments suggested that the tracked statistics should align with the strategic objectives that are critical to the government (e.g., Health & Safety, Prosperity).

Few comments pointed to issues that could be relevant to the scope and implementation of some of the best practices. For example, one of the respondents expressed concerns about the best practices that suggested to "Embrace A More Efficient Approach to Project Execution," which suggested using flexible project delivery systems and methods to address pandemic challenges, got a key comment: "The major problem during the current pandemic was the lack of public employees working and processing permits." To address that, "Adoption of E-permitting" and overall advancement in BIM are needed.

Some respondents also expressed concerns about implementing some of the best practices. One respondent noted that there could be financial difficulties in the best practice "Maintain a Stable Workforce." Best practices such as "Enhance Workforce Mobility," "Acceleration Toward Sustainability," and "Analyze Design Vulnerabilities" also got similar comments about potential financial difficulties. All best practices require some financial resources to implement to an extent—pandemics cost money. Therefore, studies on how to implement these best practices without incurring too many financial burdens should be conducted. Another theme observed regarding implantation issues is that most of the best practices require the collaboration of the whole industry or even collaboration with other industries. This is one of the biggest challenges in implementing a pandemic action strategy. Who can orchestrate the planning and execution of the strategy? Industry associations are potentially most suitable for leading the implementation of these best practices. Governments should also support the implementation by making appropriate and actionable policies.

Interview Highlights

A total of 4 interviews were conducted with industry experts. The aim was to get experts in the domain to look at the totality of best practices, evaluate the overall context of the COVID-19 experience, and discuss the comments received in the survey. When the participants were asked about what kind of challenges they faced since the beginning of the pandemic, most of the responses centered around the uncertainties in their operations. Their recommendations for addressing such uncertainties were to focus on having an open mind, communicating, and sharing information often. The experts noted that while there are usually tensions between parties, these actually lessened during the pandemic—there was a general understanding in the industry that everyone was facing these challenges together. "Can we do this in a more organized manner in the next pandemic?" is the big question.

In terms of major changes to the industry, one participant noted that the industry was realizing the value of having formalized work processes through the entire lifecycle of a project. Formalized process structures, in contrast to *ad hoc* ones, enable parties to understand who is doing what, which data is needed, what decisions need to be made, etc. It is a first step to the much-needed process automation in the industry. It is clear that virtual work and online systems were essential to business survival in the pandemic. In the construction industry, BIM (Building Information Modeling) is seen as the natural start/base for establishing process structures and promoting more automation in data generation and processing. Equally important to technology, is the flexibility of the project delivery system. One participant said that they had not observed any contract changes due to the pandemic, while another participant said that they have seen new clauses being added and prices being inflated. One participant noted that integrated project delivery (IPD) was now better perceived by the industry since it can offer much more agility and lower risks compared to the traditional design-bid-build system.

Agility in work planning was crucial in the pandemic. There were also reports of labour shortages. One participant also suggested that labour productivity was down by 10-20 due to the extra health and safety precautions, but they have not experienced significant delays due to the loss of productivity. However, there were some delays due to supply issues. Products coming from outside of Canada faced significant delays. This emphasizes the importance of having more locally produced material. The pandemic also highlighted another advantage of modular/prefabricated construction since it requires fewer people on site.

Who should oversee the implementation of the proposed strategy? The participants were also asked about their opinions on developing a common pandemic preparedness plan. Similar to the survey results, while most participants believe that it is a good idea to have such a plan for the industry, they were not optimistic about the feasibility of its adoption and execution by the industry. They, however, provided potential pragmatic options. One participant suggested that, at minimum, a working group could be set up as a forum to discuss and assess potential responses. Alternatively, an industry-academia project can be set up to periodically collect best practices and score industry preparedness levels. While the government is not expected to lead the strategy implementation, it can play a significant role by embedding some of its elements in its policy making.

Conclusions

Obviously, and much like the whole country, the construction industry was caught off-guard when COVID-19 hit. At the same time, the industry learned valuable lessons in dealing with the pandemic. This research project developed a framework and an interactive website to help the construction industry collect best practices and build a strategy to better prepare for and manage the next pandemic. The top best practices to help the construction industry tackle the next pandemic are:

1. Think About Growth Strategy
2. Create Videos of Proper PPE Use
3. Hazard identification
4. Vertical Integration
5. Review Insurance Policies
6. Adopt E-Permitting

7. Revisit Resource Plans
8. Improve Adaptability
9. Collaborate with Other Provinces or Countries
10. Co-assess Preparedness Plans with Governments

The way we think, the very role of executives and project managers, and the drivers of their work must evolve to make the above best practices a reality. Five key themes should now be embedded/emphasized in our management practices/decision making:

1. Prepare for the future
2. Collaborate with others
3. Adapt to challenges
4. Manage current operations [effectively]
5. Protect employees.

Recommendations and Next Steps

The Achilles heel of this roadmap is the implementation mechanism. Who should oversee the execution of these best practices? A government body may not be the best option. Instead, an industry task force or a committee may be more feasible. Another possibility is to develop an industry-academia initiative, where students are hired biannually to update the best practices.

However, the most impactful action that can be implemented over the next few years is to develop a set of simulation models to help analyze key issues that can take place in the next pandemic. For example, material prices have soared during COVID-19. In the case of lumber, that was mainly due to the shutting down of mills. In the case of many other materials/supplies, it was because of the interruption of the supply chains. A simulation model that can model/analyze the supply chain and the impacts of interruptions can be very handy in studying future pandemics.

Having these simulations handy can serve two purposes. First, for companies and organizations that want to implement elements of preparedness, they can use (and amend) these models to study scenarios for the future. Second, the models can streamline and formalize some of the analysis that should be conducted when the next pandemic hit. The rapid and unpredictable nature of pandemic spread did not allow policy makers to generate and carefully study options for action. If we develop these simulations, fewer improvisions could be needed. For example, models can simulate the economic impacts of shutting down the construction industry in the next pandemic. In Ontario, there was confusion about opening or shutting down the industry, and about what is and is not essential construction. Being labour-intensive and having a multiplier factor on employment and economic growth, we need to be able to study the impacts of different options for the shutdown of construction projects and their impacts on people and the economy. In the same vein, a simulation model for where to invest post-pandemic can be very helpful in expediting the recovery. Typically, governments invest in the industry to stimulate the economy. Can we be ready to advise the government about how and where stimulus funds should go to gain higher impacts?

Similarly, developing and sharing optional revisions of typical contract clauses can help create a healthy framework for collaborative management of future pandemics. Also, suggesting updates to supplier and insurance agreements could be very helpful.

Finally, there should be a consorted effort to advance abilities in construction automation. On the hardware side, we need to study the feasibility of robotics and pre-manufacturing in the industry. Where, when, and in what way should we invest and change our practices to adopt deeper levels of site automation? Automated sites and pre-manufacturing can shift labour to work in a more protected, factory-like environment and significantly reduce interruptions. More importantly, and on the software side, BIM is one of the most effective means to help the industry quickly and collaboratively study the impacts of pandemics and in re-configuring project-level plans. Unfortunately, Ontario is lagging behind other jurisdictions in the USA (and, in a more significant way, Europe and East Asia). This has to change for the sake of industry efficiency and resilience.

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Appendix A: The Best Practices

1. Record Keeping: Develop internal protocols aimed at accurate and contemporaneous documentation of the impact of the pandemic on your business for further analysis and possible claims.
2. Leverage Available Logistics Capacity: Estimate available logistic capacity. Pre-book freight capacity. Collaborate with all parties to jointly leverage freight capacity.
3. Rebalance Supply Chains Toward Resilience: Build inventory, secure critical materials and long-lead items, and identify alternative suppliers.
4. Increase Digitization: Use 4D and 5D simulations to replan projects and reoptimize schedules, use online channels for monitoring their employees' well-being through apps, ordering construction materials, managing scarce resources more accurately, and maintaining cash flow.
5. Augmented Consolidation: Companies can look to consolidate to establish economies of scale and to support investment in IT, talent, R&D, and technology.
6. Vertical Integration: Companies can look to vertically integrate to increase efficiency and increase resilience.
7. Acceleration Toward Sustainability: Governments can stimulate the economy by encouraging measures to meet carbon reduction targets, with a combination of policy changes and direct public investments.
8. Create Standby Arrangements: Create standby arrangements designed to take the worst-case scenario (contract terminations) out of the equation and enable a framework for a speedy recovery.
9. Shift Some Financial Risks To Owners And Lenders: Owners and lenders can extend time or help contractors stay afloat and be ready for project restart.
10. Use Digital Tools To Monitor Risks And Manage Supply Chains: Improve end-to-end transparency by connecting the entire value chain with a seamless flow create a comprehensive view of the supply chain through detailed sub-tier mapping.
11. Preserve Supplier Network: Accelerate payments or guarantee bank loans to give key vendors a lifeline if possible.
12. Review Insurance Policies: Understand whether the impacts of the pandemic on your capital project and construction programs are covered. Record events and impacts as specifically as possible to help support claims.

13. Review Contracts: Understand force majeure clauses and whether pandemics are defined as force majeure events. Assess whether the current conditions meet those definitions. Understand contract terms around delays, time extensions, unforeseen conditions, excusable conditions, and liquidated damages, including the notification requirements in each case.
14. Refresh Risk Analysis: Consider different scenarios for how your projects may play out across planning, design, and management. Include market factors such as disruptions to the supply chain; potential insolvency and bankruptcy of suppliers, vendors, subcontractors, and contractors; and delays in obtaining permits. Assess the costs and benefits of project shutdowns versus slowdowns. Prioritize responses and mitigation activities based on the probability and impact of risks manifesting themselves. Revisit risk registers regularly and consider potential risks and mitigation steps broadly.
15. Revisit Resource Plans: Identify current key resources as well as those required for the duration of the project—through planning, design, and management. Understand resourcing trends on a real-time basis to be able to forecast changes to productivity compared to the plan.
16. Perform Schedule Assessment and Time-Impact Analysis: Perform a scheduled assessment or time-impact analysis, including examining the status of material procurement on your projects, to identify latent delays in the schedule. Determine causation and attribute delay as appropriate.
17. Real-Time Scheduling: Using real-time data enable schedulers to make better-informed decisions around scheduling labour and materials for each project.
18. Promote Automation of Construction Sites: Improve productivity for highly repetitive tasks using advanced automation and robotics technologies while creating a safer work environment. For example, drones could be used for performing inspections and surveying.
19. Revisit Societal Risk Compact: Companies, regulators, policymakers, insurers and investors should all play a part in a more proactive approach to managing catastrophic risk. Insurers, reinsurers, risk advisers and asset managers need to create new mechanisms for affordable risk sharing and transfer, partner with governments to improve loss remediation and public assistance schemes and help corporate and institutional clients do a better job of ex-ante risk avoidance and mitigation.
20. Prioritize Resiliency: Help to standardize public disclosures about risk exposure and investments in resiliency. Encourage and inform the development of reinforcing policy and regulatory frameworks. Exert clout as large corporate investors, ensure resiliency is appropriately prioritized in strategic decision-making, capital allocation and investor conversations.

21. Improve Adaptability: Improve the ability to adapt as the scenarios and probabilities change, improve agility and speed by learning what worked and didn't work.
22. Preserve Cash and Maintain Liquidity: Develop a single view of your liquidity position and outlook. Launch decisive actions to preserve cash. Implement immediate mandates to reduce spending. Control all cash outflows. Prepare enterprise models based on different macro scenarios.
23. Keep Communication Lines Open: Communicate regularly with customers to reaffirm continued service. Inform suppliers of real-time changes and stay in touch with vendors to avoid disruptions. Update lenders on cash-preservation actions and discuss concessions you may need in the future. Connect with other key stakeholders supporting the business through this exceptional period.
24. Assessing Near- and Longer-Term Scenarios: Assessing potential developments and trends at the industry and company levels by looking across possible outcomes to understand what actions to take in any scenario. Then define the triggers that narrow the range of possible outcomes and link incremental actions to those triggers, creating a relevant and adaptable plan.
25. Enhance Workforce Mobility: Implement engineered seat isolation systems, vehicle-capacity restrictions, daily sanitation, and staggered workforce transport times.
26. Create Crisis-Management Committees: Create crisis-management committees composed of different stakeholder groups to monitor progress, make decisions, and ensure productivity in their return to work.
27. Monitor Health and Safety: Use pre-screening, self-reporting, social distancing, mental health well-being, and contact-tracing technologies onsite.
28. Promote Prefabricated Modular Construction: Build an incentive program to accelerate the adoption of prefabricated modular construction to increase construction/cost efficiency.
29. Identify Critical Suppliers: Focus on the most critical materials, equipment, products and tier 1 suppliers should help prioritize and expose key vulnerabilities. Once those susceptible factors are identified, determine how reliant they are on the regions affected.
30. Create A Contingency Plan: Review project controls, risk management and governance processes to make sure they are robust enough to provide early warnings of any cost, time or contractual issues arising from the possible scenarios.
31. Think About Growth Strategy: Plan growth strategy after stabilizing the current situation. Systematically review the experiments that Covid-19 provoked, and the lessons learned from them. Structurally analyze where the industry is likely to be in two, five and ten years.

32. Embrace A More Efficient Approach to Project Execution: Start construction until a far greater percentage of engineering and procurement deliverables are available. Steepen the construction S-curve so construction starts later but still completes at the same time. By having more work fronts available when construction commences, the commodity curves can ramp up and reach peak productivity much quicker, potentially saving months in the construction duration.
33. Track and Monitor Workforce: Track where employees have worked and report to public health units if there is a risk of exposure.
34. Adopt E-Permitting: Allow designers, permit applicants and plans examiners to be connected through an electronic platform when applying for permits to increase efficiency.
35. Improve Cybersecurity: Improve cybersecurity as sensitive information is being transmitted through the internet as working from home is widely adopted.
36. Improve Workflow: Sequence trades and reducing overlaps, reducing the number of workers assigned to a particular task or area.
37. Improve Health and Safety Awareness: Emphasize to workers the impact of accident or ill-health on their families, and/or the financial impacts. Provide constant reminders, encouragement, and reinvigoration of safety and health messaging.
38. Manage Anxiety: Let your employees know that you are looking ahead, that your organization is staying well-informed and that you can answer their questions. Communicate and share openly. Show that you understand that it is stressful. Reassure—as best you can, while still acknowledging the difficulty of the situation. Understand and provide support when stress has become unmanageable for individual employees.
39. Hazard identification: Understand the potential hazards that can be caused by the pandemic, identify the threats and determine the level of protection needed.
40. Address Future Pandemics in Contracts: Four different approaches could be taken with different risk allocations: 1. The contractor assumes all schedule and price risks arising from existing or future pandemic circumstances. 2. Contractor assumes no risk of delay or increased costs arising from unanticipated circumstances relating to pandemics. 3. Contractor assumes cost but no schedule risk arising from unanticipated pandemic circumstances. 4. Contractor and owner agree on a contingency for cost and time impacts which may be applied when the contractor incurs cost or experiences delay arising from unanticipated pandemic circumstances.
41. Track Preparedness Plan: Build a mechanism to track the efficiency and the quality of government preparedness plans to assess if they are ready for the next pandemic.

42. Co-assess Preparedness Plans with Governments: Establish frequent communication with governments to co-assess vulnerabilities and improve preparedness plans.
43. Understand Health Regulations: Establish a clear map for all stakeholders to understand the legal and administrative responsibilities required and mandated by health agencies at all levels.
44. Work with Health Agencies: Conduct frequent workshops with health agencies to discuss and follow up with compliance and levels of preparedness within and outside the industry.
45. Independent Preparedness Assessment: Establish an independent data collection and preparedness assessment program to evaluate the preparedness of the industry (for example, a bi-annual research project to collect data and develop a score for preparedness).
46. Reconfigure Supply Chain: Rethink the supply chain. Develop a plan on how much local production capacity should be maintained for what products and expertise.
47. Negotiate Trade Agreements: Participate in trade agreement discussions and policy making to make sure there will be a reliable flow of products and materials.
48. Reconfigure Manufacturing Facilities: Work with key manufacturing companies (for example, car manufacturers) to study how to reconfigure some of their unused facilities to produce urgently needed products in the construction industry.
49. Build Business Cases for Rapid Investments: Build business cases for rapid investments in reconfiguring elements of the industry to cope with pandemics. For example, estimate the ROI for government programs that can be enacted to support the industry during the pandemics—if the government invests in securing and safeguarding construction practices, what are the economic and health returns.
50. Model Possible Scenarios: Build large-scale simulation models to study possible business and project management scenarios under pandemics.
51. Build Training Program for Executives: Build a training program for executives regarding management practices during pandemics and make it available online.
52. Assess Site Pandemic Preparedness: Ministry of Labour, Training and Skills Development should include an annual assessment of pandemic preparedness in their site inspections.
53. Showcase Preparedness Plans: Establish a program for companies to volunteer to showcase and examine their preparedness plans. For example, this program can include an annual hackathon/competition to challenge a company with a hypothetical scenario of a pandemic.
54. Rank Supplies and Expertise: Establish a ranking system for supplies and expertise that should be given priority in a pandemic.

55. Rank Project Priority: Establish a ranking system for projects that should be kept running under any circumstances.
56. Create Videos of Proper PPE Use: Create videos for the proper use of PPE onsite and best practices of managing pandemics in the context of the construction industry.
57. Analyze Design Vulnerabilities: Consulting engineers can add a special analysis to their designs that includes assessing the vulnerabilities and a list of actions that could be taken in the case of a pandemic.
58. Develop Software to Identify Vulnerabilities in Design: Develop a BIM-based software system that can help consulting engineers and general contractors pinpoint key points and issues that relate to a pandemic in their site (For example, you can upload your BIM file to the system, and it will return it to you with red-marked pandemic-related issues and best practices).
59. Ensure Price Stability: Provide incentives, or build a relationship, or develop an agreement, or form a strategic alliance with suppliers to ensure price stability during pandemics.
60. Maintain Insurance Premium Levels: Provide incentives, or build a relationship, or develop an agreement, or form a strategic alliance with insurance companies to maintain current premium levels during pandemics.
61. Build a reliable action plan for the government: Prepare what-if scenarios for possible pandemics implications and discuss this with the government to make sure they are ready and aware of the needs of the industry and avoid having them iterate or try different ideas back and forth. Build a reliable action plan for the government.
62. Meet with Health Agencies: Instead of just complying with health agency regulations, set frequent meetings with them to help direct their resources and policy making to address the needs of the industry.
63. Report PPE Preparedness: Mandate the suppliers of PPE to publish an annual report about their preparedness and storage capacity.
64. Connect Owners with Contractors: Build a platform for large developers/owners to inform them about the risks and their role in supporting the contractors during a pandemic.
65. Work with Canada Infrastructure Bank: Negotiate with the Canada Infrastructure Bank to pursue them stepping in with guarantees for contractors during this period.
66. Address Daycare Issue: Governments and companies can work together to address daycare issues, especially for women working in the construction and engineering industry.

67. Maintain A Stable Workforce: Build models and policies to advise companies about the importance of keeping your workforce. Maintaining a stable workforce will be beneficial in the long term.
68. Transfer the Pandemic into Opportunity: Prepare ready business plans to configure or start small companies that can directly help manage pandemic-related issues. For example, be ready to get labour on temporary leaves of absence new jobs that help overcome the problem that got them to be unemployed. Transfer the pandemic into opportunity.
69. Create an Accommodation Plan for Infected Employees: Companies should prepare an accommodation plan for any employees who get infected so they can receive proper treatment if necessary and be ready to get back to work as soon as possible.
70. Create Accommodation Plan for High Priority Projects: Companies should create an accommodation plan to isolate workers such as they are in a clean bubble" for highly important projects. This way they will not be infected and will not infect others and they can continue to be working on their sites.
71. Assess What Projects Should Be Opened: Moving to a new house is a major issue for buyers, and it pushed the government to open smaller projects early. Study this. Find a way to assess which projects should be opened, when, and under which conditions. The government should also have plans to alleviate the problems of the home buyers to reduce their pressure on the industry.
72. Provide Support for Construction Labour: Track and communicate statistics about the impacts of leave of absence, rent and other issues on construction labour to the government. Use these statistics to pursue the government to provide support for them.
73. Boost Labour Morale: Develop videos about how construction labour is also “essential labour” and are also “front-line labour”. They do an equally important job to health care staff—without them, the infrastructure will stop.
74. Shift Some Labour to Other Industries: Reach out to other industries to see if construction labour on leave of absence can be re-hired to help them (For example, the trucking industry or the manufacturing industry).
75. Accelerate Approval Process: Accelerate the approval process of large projects in rural and northern areas as the health and safety risks in these areas are relatively low and can provide ways to keep labour working.
76. Expand Services to Overseas: Build an incentive program and platform for Canadian consulting agencies to reach out and offer their services to developing countries.

77. Set up Early Warning System: Create a system to gather pandemic-related information around the world in order to start preparing for a possible pandemic as soon as possible.
78. Collaborate with Other Industries: Work with other industries to develop the preparedness plan so that experiences from other industries can also help strengthen the plan.
79. Collaborate with Other Provinces or Countries: Work with other provinces or countries and share experiences with each other.

Appendix B: Literature Review

There is limited research work concerning pandemics (and emergency management in general) in the construction management domain. Also, the majority of existing research work focused on managing public health issues during a pandemic. One of the key guides in the domain is the World Health Organization (WHO) Pandemic Influenza Risk Management Guidance [8]. It employed a risk-based approach that characterizes pandemics as a continuum of four phases. Risks in each phase are to be assessed and managed. The four phases are the interpandemic phase, alert phase, the pandemic phase, and the transition phase. The WHO guidance also listed six essential categories of risks. Industries that are directly and heavily impacted by a pandemic, such as the aviation, tourism, and hotel industry, have shown interest in developing pandemic preparedness plans in the past. However, most of these plans employed a reactive approach that focused on response rather than preparedness.

Pandemic preparedness plans for the construction industry started to emerge after the outbreak of the COVID-19. Canadian Construction Association (CCA) published the "COVID-19-Standardized Protocols for All Canadian Construction Sites", which contains mostly site-level health and safety practices [9]. CCA also published "Post-COVID-19 contingency planning for the Canadian construction industry", which summarized some actions and considerations for contractors to ensure the continuity of the industry [10]. In another example, Regina Construction Association (RCA) also published a similar document to ensure business continuity during an influenza pandemic [11]. This document adopted the four pandemic phases concept from the WHO guidance and recommended a few actions in each phase. All the actions from the two documents addressed only risks to and actions by contractors.

The limited number of published works in construction emergency management is focused on theory formulation. Most were also focused on project-level analysis, in contrast to the industry-wide level. Loosemore devised a grounded theory of construction crisis management [13]. He concluded that construction crisis management is about handling a disruption of multiple interdependent activities carried out by different organizations with different interests, which were often conflicting. As such, the core issues in a construction crisis were social adjustments, behavioural instability, information management, and conflict management. Loosemore and Hughes also stressed the importance of flexibility in a construction crisis [14]. Zhong and Pheng emphasized the importance of effective communication management during crises based on complexity theory, which Loosemore also stressed in his grounded theory [15]. Öcal et al. also investigated the extent of crisis management in the Turkish construction industry and found that systematic crisis management was only adopted by a small number of large construction companies [16]. Together these studies suggested that flexibility, effective communication, mutual sensitivity between project members, and collective responsibility, and teamwork were essential in crisis management in the construction industry.

In summary, while pandemic preparedness plans exist for some industries, including the construction industry, most of these plans were *ad hoc* and lacking details. These plans also mainly focused on the project-level practices with limited attention on organizational and industry-level practices.

Appendix C: Conducting the Surveys

The first survey aimed to collect structured feedback on the proposed best practices from construction industry professionals. The survey started with three questions to collect basic information about the respondents, including profession, areas of expertise, and years of experience. The six areas of expertise correspond to the six domains of action in the best practices framework.

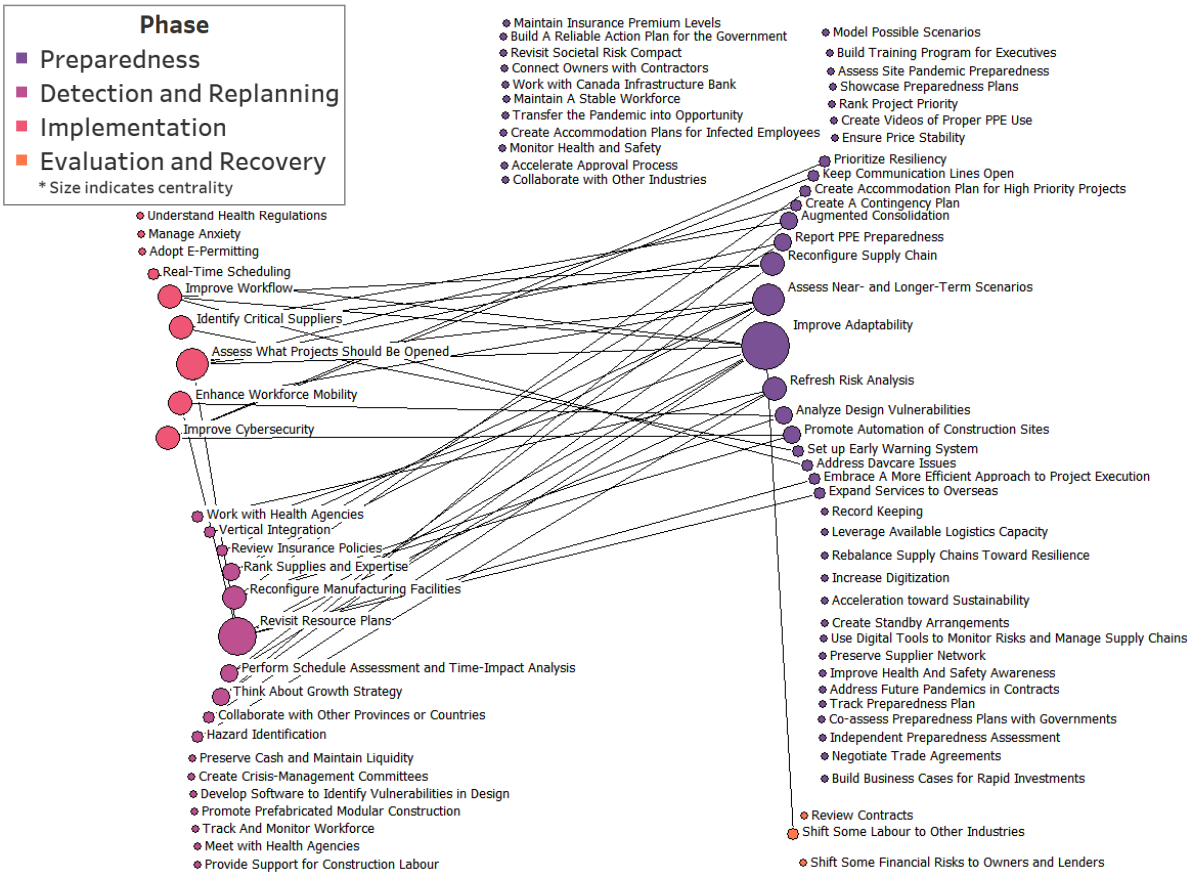
To make sure the survey does not consume a long time from participants, each participant was given questions about only eight randomly selected best practices, each with a set of questions that contains four categorization questions, two rating questions, and an optional commenting question. With sets of eight questions, participants can comfortably finish all of them in 15 minutes, which is the ideal length for online surveys [19], [20].

The four categorization questions required the participants to classify best practices along the four dimensions of the framework. Participants were allowed to choose multiple subcategories in each dimension since some best practices could belong to multiple subcategories. For the participants to understand the proposed best practice framework and answer the four categorization questions, a brief explanation of the framework and the definitions of all the subcategories were provided at the beginning of the survey. The two rating questions required the participants to rate the feasibility and impact of best practices on a scale of 1 to 5. A rating of 1 means the best practice is not feasible or not effective, and a rating of 5 means the best practice is very feasible or very effective. Finally, the optional commenting question allowed the participants to add comments regarding best practices. At the end of the survey, the participants were guided to the interactive website and encouraged to provide more input.

The second survey aimed to establish the relationships between best practices to build a network. By building a network and performing network analysis, another metric, centrality, was used to evaluate the importance of best practices (along with impact and feasibility). Centrality recognizes the importance of the connectedness of best practices. A best practice with higher centrality means that it is more connected to other best practices. If a best practice has a high centrality, it is logical to prioritize implementing that best practice to support the implementation of connected best practices. Since the initial set of best practices had 79 best practices, the theoretical total number of possible connections is 79 x 79, or 6,241. Since the relations between best practices do not have directions and self-relations are not possible, the number of possible relations is actually 3,081. As the proposed best practices framework used a categorization approach, it was unnecessary to investigate best practices that share the same subcategories since they are already connected. This reduced the number of possible connections to 109. The remaining 109 connections were manually examined to rule out illogical relations. The final number of connections that required investigation was 54. During the survey, each participant was given 18 possible relations to assess (to comfortably finish the survey within 10-20 minutes). For each relationship, the participants were asked to rate the existence of a relationship between two best practices on a scale of 0-5. A rating of 0 means the two best practices are not related at all, and a rating of 5 means the two best practices are closely related.

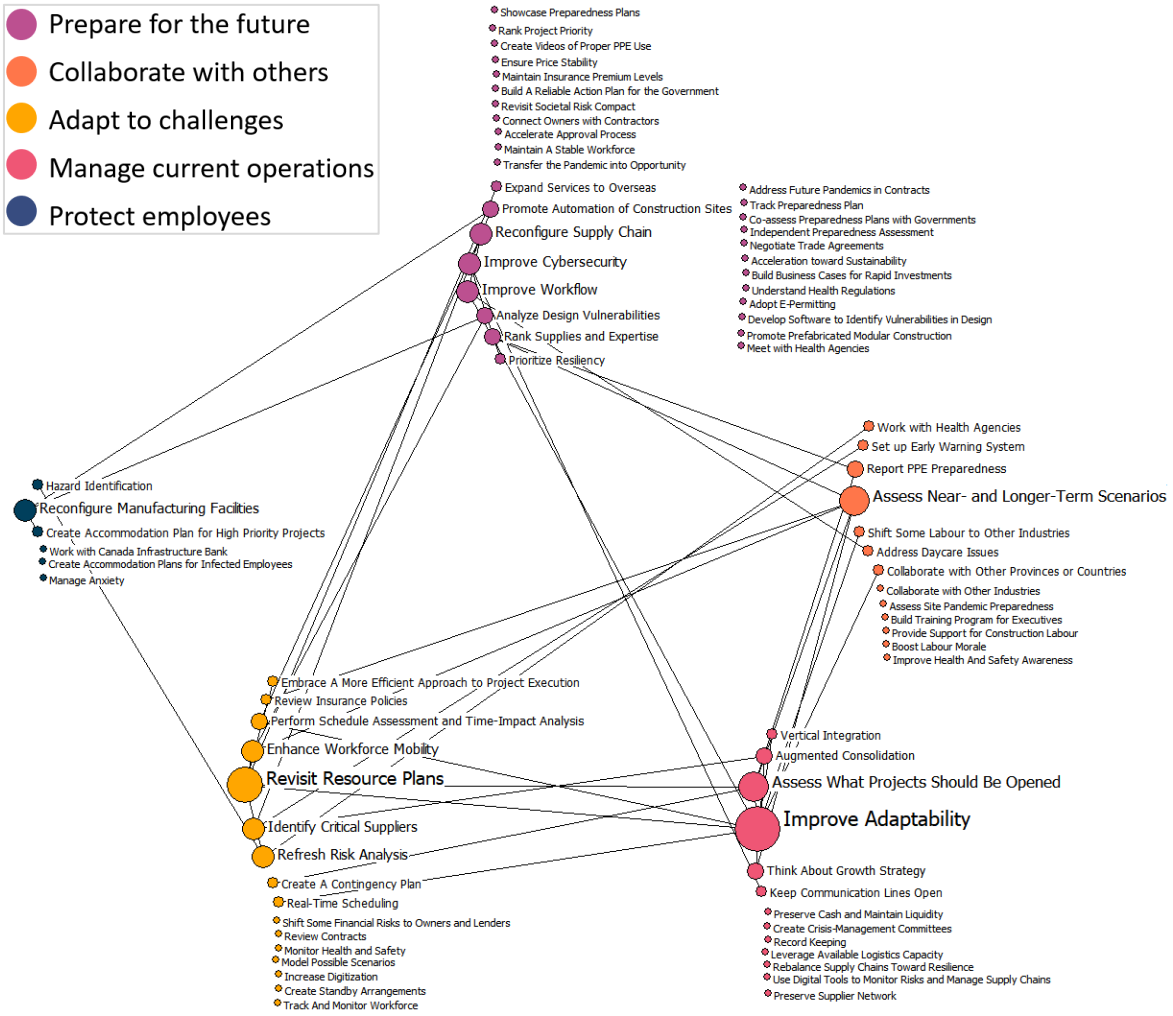
Appendix D: Network Analysis

The second survey received a total of 12 responses with a 100% completion rate. All best practices were arranged in a matrix. Every cell is a potential relationship between two best practices. The ratings received for each connection were averaged. If the average of the ratings in a cell is above 2.5, then a connection is assumed. Based on this threshold, a total of 37 connections were established. The matrix for all the best practices and their connections were imported into the UCINET software for network analysis. The most fundamental network analysis measure is the calculation of the centrality, which can be used to find the most influential node in the network. There are multiple ways for defining centrality. Degree centrality is the simplest. It counts the number of connections each node has [17]. It is reasonable to assume that a node with many connections might have more influence in the network. Eigenvector centrality is a natural extension of the degree centrality as it accounts for the importance of the connected nodes [17]. Degree centrality awards each node the same value for each connection, irrespective of its own importance. Eigenvector centrality is a weighted number that considers the importance of the connected nodes. This means that a node that connects to fewer nodes with high importance will likely have a higher eigenvector centrality than a node that connects to more nodes with low importance. Eigenvector centrality was used for analyzing the centrality of the best practices network. As shown below, most of the connections were between the preparedness phase and the detection and replanning phase and between the preparedness phase and the implementation phase. This indicates that preparedness is the most important dimension in the best practices' framework.



Clustering of Best Practices

Centrality is a node-oriented measure. Clustering considers the density of the links in a network to detect groups of very well-connected nodes such that they represent a legitimate sub-network of their own. The Hierarchical Clustering function in the UCINET was used to detect node clusters. Five clusters were identified. They were centered around the following concepts: Prepare for the future, Collaborate with others, Adapt to challenges, Manage current operations, and Protect employees. The five clusters represented a set of overarching principles that should guide our thinking in the future.



The top 10 best practices ranked by eigenvector centrality are shown below.

Best Practice	Eigenvector Centrality
Improve Adaptability	0.503
Revisit Resource Plans	0.428
Assessing Near- and Longer-Term Scenarios	0.410
Asses Site Pandemic Preparedness	0.251
Enhance Workforce Mobility	0.211
Improve Workflow	0.191
Perform Schedule Assessment and Time-Impact Analysis	0.176
Report PPE Preparedness	0.148
Refresh Risk Analysis	0.145
Vertical Integration	0.142

Appendix E: Details on the Phases of Action

The first phase, "Preparedness," is the most important phase in our strategic action plan. The term "preparedness" refers to the ability of organizations or individuals to anticipate and respond effectively to the impact of probable, imminent, or present hazards. In the context of this research project, the best practices in the "Preparedness" phase should enhance the ability of the construction industry to anticipate and respond effectively to the impact of a future pandemic. These best practices do not have to be pandemic-specific, but they will place the construction industry in a better position when the next pandemic hits. For example, digitization was proven to be key in the tackling COVID-19 pandemic. However, digitization is designed and adopted by an organization to, mainly, improve efficiency. Yet, it has a significant role in surviving a pandemic. Therefore, some best practices in this phase might not seem to be related to pandemic preparedness at first glance, but they will, indirectly, enhance the pandemic preparedness of the construction industry. The best practices in this phase are also expected to be constantly updated based on new research and development in the construction industry.

The second phase, "Detection and replanning," includes best practices that aid the process of adjusting the preparedness plan based on the specific characteristics of future pandemics. Since the characteristics of future pandemics are unpredictable, the preparedness plan created based on the experiences of COVID-19 will not be fully applicable to the next pandemic. Therefore, the construction industry needs to have the ability to detect potential pandemics first. After detecting a potential pandemic, actions need to be taken to study the characteristics of the pandemic quickly and how it may impact the construction industry.

The third phase, "Implementation," primarily includes best practices that address workforce, supply chain, and business and management challenges that arise in a pandemic. While the most apparent best practices for the "Implementation" phase are site health and safety practices, they are not within the scope of this research project. There are also plenty of resources/guidelines from governments and industry associations about site health and safety practices. Thus, they are not be included in our set of best practices. Through literature review and expert interviews, workforce, supply chain, and management are identified as the three major challenges the construction industry faced during the COVID-19 pandemic. The best practices in this phase are expected to be different for each pandemic to adapt to the specific challenges posed by future pandemics. In addition, as the construction industry evolves, some of the best practices in this phase might become obsolete, which will require updates.

The fourth and last phase is "Evaluation and recovery," which includes best practices that are designed to assess the performance of the construction in handling the current pandemic and how to improve the preparedness plan while transitioning to the new normal. Knowledge on pandemic preparedness can keep accumulating if efforts are dedicated to reviewing the lessons learned from previous pandemics. The recovery path for the construction industry might be different for future pandemics; however, the general strategies should be very similar.