4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

A FRAMEWORK FOR CONSTRUCTION STRATEGY FORMULATION

Ngoc Tran[1], Alan Russell[2], and Sheryl Staub-French[3]

[1] PhD Candidate, Department of Civil Engineering, University of British Columbia, Vancouver, British Columbia, Canada.
[2] Professor, Department of Civil Engineering, University of British Columbia, and Chair, Computer Integrated Design and Construction, Vancouver, British Columbia, Canada.
[3] Associate Professor, Department of Civil Engineering, University of British Columbia, Vancouver, British Columbia, Canada.

Abstract**:** Examined in this paper is how contractor and construction manager decision making and judgment in response to client objectives, project constraints and changing conditions during project execution can be aided by a structured framework and approach for construction strategy formulation and assessment of multiple alternatives. Construction strategy is expressed in terms of strategy modes and tactical variables and accompanying values. Complementing the framework for assessing compliance with client objectives and workability of a strategy from a contractor perspective is the use of a relatively coarse representation of a project in the form of a linear planning based process model and companion product model, a Building Information (BIM) product model, and visual representations of data derived from these two models. Use is made of an in-progress large-scale, mixed use, urban-based, high-rise construction project comprised of multiple sub-projects to illustrate how elements of the framework can be applied in practice to provide value to client and contractor alike. Follow up work to enhance usability of the framework is briefly discussed, with emphasis on mapping issues.

1 INTRODUCTION

We present a framework in aid of the desire by those participating in large complex projects, to formulate and assess alternative construction strategies with emphasis on time performance, given a fixed project design. By assessment we mean determining compliance with contractual and regulatory requirements as well as passing judgment on process workability. The value of such a framework is further enhanced when design features are also in play, providing the opportunity for a wider range of execution strategies. To date, a number of excellent tools have been developed by the academic and software communities for examining at a detailed level the performance of a strategy once it has been formulated and modeled. But when the exploration of alternative strategies and supporting tactics is required in a timely manner at the outset or during execution of a project in aid of decision making to comply with contractual requirements or particular project conditions and client or contractor objectives, current ad hoc processes are slow and costly, and hence the exploration process tends to be very limited, despite the opportunity to create substantial value. We seek to address this deficiency. Helping to motivate our interest in this topic was recent extensive involvement with a project which included rehabilitation of an existing hotel, and construction of a deep parkade structure and a 48 story commercial and residential tower. This hotel/commercial/residential project transitioned through several strategies due to initial attempts to complete it in time for a world sporting event which were derailed by difficult economic and market conditions, and challenges posed by problems encountered with offshore procurement of the enclosure system. The strategy, tactics and process modeling components of our framework proved useful in telling the story of how execution of the project evolved in the face of the conditions encountered, as well as in providing insights as to how one might proceed given current project status. More recently still, we have had the opportunity to interact with the project management team of a large, complex, mixed-use project which has provided us with additional insights on the need for and challenges involved with examining alternative strategies to satisfy both client and contractor objectives. Complementing our work has been a thorough examination of the literature by Tran *et al.* (2012) which has both reinforced the need for such a framework as well as helped to provide useful building blocks for our work. In this paper, we overview elements of our approach, and then examine in greater depth the topics of strategy and supporting tactics, and how working at a reasonably aggregated level of detail can assist in both formulating alternative strategies as well as evaluating their relative effectiveness. The topic of framework validation is not addressed herein, although it is being pursued through application to actual project scenarios as well as synthetic ones derived from past projects with which the authors have had some involvement.

The paper, which is somewhat exploratory in nature, is structured as follows. In section 2, we outline in some detail the main components of our framework, and identify several of the challenges that must be resolved in order to develop a robust and practical toolkit. Then, in section 3 we examine the topic of construction strategy and its constituents. Features of a real life mixed-used case study project are described in section 4. Application of aspects of the framework to the case study project is presented in section 5 in order to highlight the capabilities that such a framework should possess and the complexity of formulating, modeling and assessing construction strategies. We conclude in section 6 with a brief discussion of ongoing work directed at addressing ease of use of the framework with emphasis on how to accomplish flexible mappings between a BIM product model and a process system product model.

2 FRAMEWORK OVERVIEW

Depicted in Figure 1 are the primary elements of our framework. In formulating it, we seek to maximize the assistance that can be offered through computer-based modeling of the product and process dimensions of a project, and currently available data visualization capabilities. We do not seek, however, to automate either strategy formulation or strategy evaluation; our belief being that is best done by seasoned construction personnel because of their more comprehensive understanding of a project and its nuances and the capabilities and concerns of its participants. Nevertheless, some computer-based assistance could be provided for these functions. The primary elements are as follows. First is a strategy layer in which strategy is formulated at one or more levels of a project (component, system, subproject, project), and articulated both in terms of urgency level (strategy mode) as well as in terms of specific tactical variables. This layer is elaborated upon, including definitions, in section 3. The second layer relates to product and process modeling using modern BIM and planning and scheduling tools. Shown on the left hand side of Figure 1 is the BIM product model (e.g. Autodesk Revit®) plus what is labelled as Enhanced BIM for construction. The first of these relates to the finished artifact, and contains little information as to how a project is realized. As noted, however, the product model is subject to change, either through owner initiated change orders, or, because one is exploring design alternatives, not just alternative construction strategies. It is the Enhanced BIM model that needs to reflect how the project is to be realized. What is required is the two-way exchange of data between the project's BIM and process models. As discussed briefly later, it is this two-way exchange of information, predicated on a specific construction strategy that poses significant challenges. Depicted on the right hand side of Figure 1 is the process modeling of the project (planning and scheduling). Again, two process model versions are indicated. The first corresponds to state-of-the-art modeling which is reflected in a number of commercial software packages. Again, the model is subject to modification because of owner or project condition induced changes, thereby necessitating in some cases the exploration and evaluation of alternative construction strategies. In modifying the process model, data from the product model may be required, and in addition, process data may need to be provided to the Enhanced BIM model so that construction strategy can be visualized in four dimensions, either using BIM or some other software tool. Also shown on the right hand side of Figure 1 is an Enhanced process model, by which we mean a process model that contains its own product model, albeit at a different level of granularity than a BIM model and which also makes use of a time-space planning paradigm (Stradal and Cacha 1982). A process based product model provides a major component of our framework, as it greatly facilitates the interaction between a BIM product model and a process model. We seek to demonstrate that potential that such a model offers, not how best to realize it. We make use of our own implementation, but it is the concept that is relevant, not the particular details. Interestingly, one could treat the WBS modeling (Chau et. al. (2005) and Kang

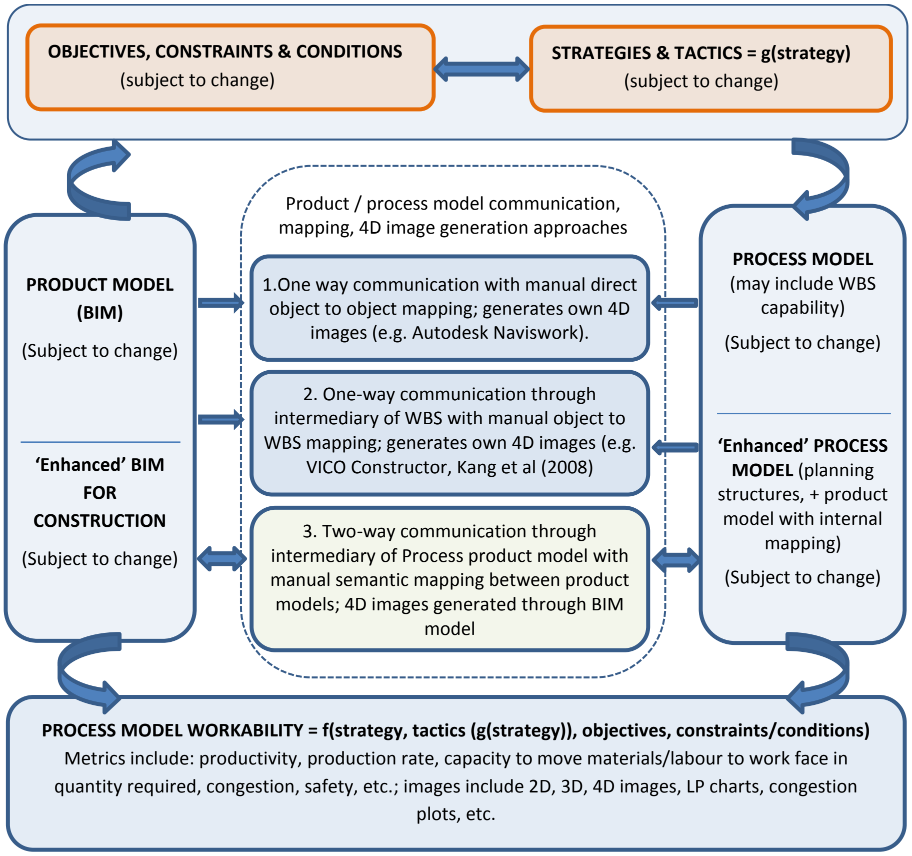


Figure 1 Overview of Framework for Construction Strategy Formulation and Assessment

et. al. (2010)) that is present in a number of commercial process model systems as a process product model (albeit a rather 'light' model). But missing from such an approach is the rich attribute set of product modeling components essential to assessing strategy workability. We use a time-space process modeling paradigm as consideration of the spatial context is central to the consideration of both construction strategy and schedule workability. Shown as part of the second layer in the middle of Figure 1 are three different communication strategies between the product (BIM) and process (planning and scheduling) representations of a project. The first of these corresponds to the current state of the art as described in (Autodesk Naviswork®). There is substantial tedium in carrying out the manual mapping of the process and product models – i.e. there is a one way exchange of information between the product and process models with the utility used to visualize project status at any point in time (see the unidirectional flow of data as per the arrows out of the process and product models). The second mechanism (e.g. VICO Constructor®) for communication shown involves working through the WBS – again, one way flows are involved, and a manual mapping between BIM and the process model is still required. The third mechanism, the one espoused by the authors involves a process-product model and involves a two way exchange of data between the BIM product and the process models. Again, manual mapping is required. However, in the case of a fixed design, the mapping between product and process models within process view is relatively stable while the mapping between the process view product model with BIM is often modified in response to project changes and the need to explore alternatives. The mapping is between classes of objects which reduces the mapping effort. The bottom layer of Figure 1 relates to the assessment of compliance with contractual and regulatory requirements plus workability of a construction strategy. We differentiate between the concepts of constructability and workability. The former relates to how readily a specific design can be constructed (Construction Industry Institute (1986)), while we define the latter to be whether or not the construction process envisaged is achievable – i.e. are production rates and the implied productivity rates achievable, can materials and labour be moved to the work face at a rate consistent with the planned production rate, is there sufficient space in which to work, etc. Interestingly, the literature has not focused extensively on how one assesses the workability of a construction strategy, given a plan and schedule, and the physical attributes of the components to be constructed. We have found data visualization to be of significant value in terms of examining schedule workability using product and process data, including its combination and transformation.

To date, we have expended considerable effort on formalizing the concept of construction strategy in operational terms in order to assist personnel to think about strategy and supporting tactical variables in a creative or generative manner. This is elaborated upon in the next section and then applied in sections 4 and 5. Currently we are focused on efficient communication between BIM and process models as a function of strategy (e.g. definition of space – e.g. zoning) and grouping of components of like kinds (e.g. rectangular columns vs. round columns, etc.). The search is for a way of mapping that reduces the manual burden on the user and which avoids the need to redefine mappings from scratch every time a major change is made either in construction strategy or in the BIM product model. Findings from this aspect of the work will be presented elsewhere.

3 OPERATIONALIZING THE CONCEPT OF CONSTRUCTION STRATEGY

Strategy in the context of a capital project, whether it be a private or public sector initiated one, has several dimensions, which include financing strategy, marketing strategy, project procurement strategy (e.g. design-bid-build, CM@Risk) construction strategy, etc. (Artto, et al. (2008)). These strategies are not independent of one another, with construction strategy, our particular focus, being shaped in part by higher level strategies.

The topic of construction strategy is an important one for several reasons. From a client perspective, in setting contractual milestone dates which may be driven by market conditions, user requirements or rate of return requirements, it is important to determine a priori that the desired dates are achievable. This in contrast to assuming that the construction community has a magic wand to make the prescribed dates come true, whether or not they are realistic. The ‘magic wand’ phenomenon exists, unfortunately, both in the private and public sectors, especially for those not engaged on an ongoing basis with capital projects. An important decision by a contractor is whether or not to bid a project, given tight timelines. Thus, the ability to determine early on how such timelines may be complied with while gaining a competitive advantage is very important, especially if one can add value by determining how such timelines can be bettered with certainty. Lastly, once a project is underway, given the inevitable changes in conditions that can occur, several or many of which may be beyond the control of the contractor, the question becomes, how best to respond. The last two scenarios speak to the need to be able to formulate and evaluate in a timely and cost effective manner alternative strategies.

Our formal definitions of strategy, strategy mode, tactical variables and workability are summarized as follows. A strategy for constructing a spatial/system element of a project consists of an approach comprised of a strategy mode and the means for achieving it in the form of specific tactical variables and accompanying values, selected in response to client or contractor objectives and project constraints and conditions, as of a specific point in time. Construction strategy at the overall project level consists of the set of strategy modes and supporting tactical variables and values for all spatial/system elements that define a project as of a specific point in time.

Depicted in Figure 2 is a visual representation of our concept of strategy, in the context of the hotel/commercial/residential project described previously. The spatial component treats the 4 main subprojects of this project. The time axis depicts the points in time when strategy mode changed for one or more spatial components. ΔT corresponds to the time required to identify the most appropriate change in strategy, given a change in project conditions. The vertical axis corresponds to possible strategy modes, with modes being identified in shortened form for readability. For example, modes M_1 to M_3 correspond to modes selected at project initiation, and relate to normal duration, phased duration, and accelerated duration. The remaining modes correspond to choices that apply during project execution, including normal duration (M_4), owner directed acceleration (M_6) or cash flow conserving (M_9), modes experienced on the actual project illustrated.

A comprehensive but incomplete list of tactical variables at three project levels is shown in Figure 3. The decision criteria and constraints indicated in parts 1 and 2 of Figure 3 (also see layer 1 in Figure 1) guide the selection of the most appropriate tactical variables and corresponding values to use at the spatial component/system level (item 4), at the interfacing amongst spatial components (item 5), and in terms of shared facilities at the overall project level (item 3). The development of a computer aid to suggest helpful mappings between strategy mode and tactical variable choices will be explored as part of our future work on strategy. As discussed later in section 5, work space zoning, work sequencing, site access (which was complicated by the presence of a number of constraints) and sub-project linkages were important tactical variables when formulating overall project strategy.

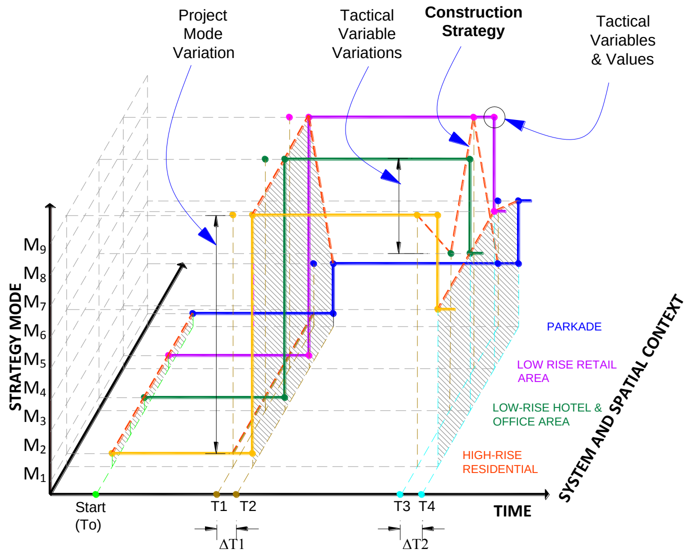


Figure 2 Strategy modes vs. temporal and spatial dimensions of a project

Assessment of a strategy deals with determining its feasibility and workability, and identifying opportunities for improvement via strategy mode or tactical variable/value changes. Feasibility addresses compliance with constraints – contractual and regulatory requirements, site access conditions, etc. As observed previously, workability seeks answers to questions such as: *Can labour and material resources be delivered to the work face at the rate required? Are spans of management control compatible with the distribution and pace of work? Will one or more work spaces be overly congested?, etc*.

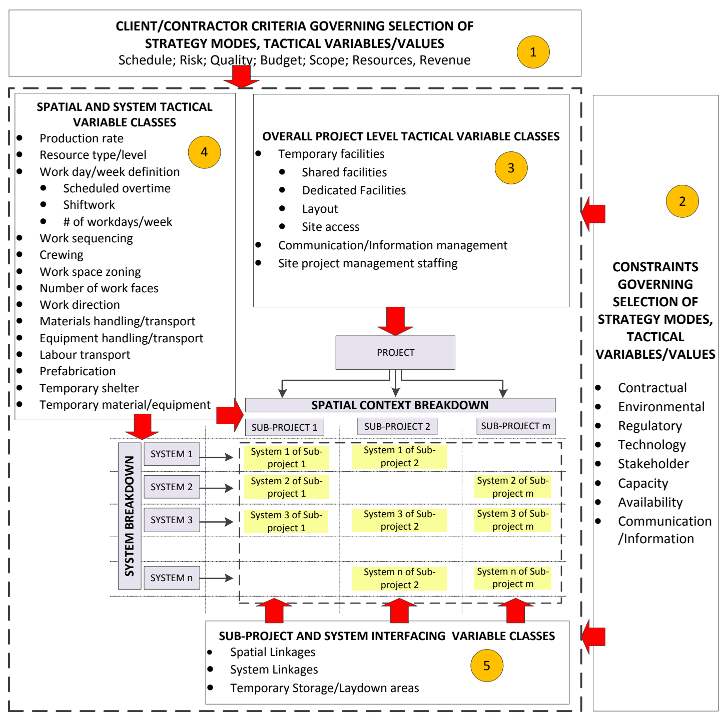


Figure 3. Objectives, constraints and tactical variables associated with strategy formulation and assessment

Benefits claimed for the strategy framework and partially validated to date include: (a) it provides a structured vocabulary for communicating about strategy at the project level; (b) it makes transparent the modes at the subproject / systems level that can be pursued and the tactical variables that can be employed to achieve these modes; (c) it makes clear the context in which one is working, both at the start of the project and during its execution in terms of objectives driving the project, participant decision criteria, and constraints that shape choice of strategy mode and related tactical variables; (d) it allows one to see the 'big' picture of a project and how the major components interact with one another; (e) it assists in providing insights on the workability of the decisions / choices made; and (f) it helps to suggest ideas for improving project performance and adding value.

4 CASE STUDY FEATURES

Our case study project, currently in progress, is a large scale mixed used one comprised of a 5 level parkade, a podium that houses retail/commercial areas including a theatre, a 19 story office building and two residential towers of 25 and 34 stories, respectively, that connect with one another through a shared building area (i.e. a project comprised of 5 sizeable subprojects). Project delivery is by way of CM@Risk. A BIM massing model for the project is shown in Figure 4. It provides product information helpful in assessing the efficacy of the overall project strategy, despite its simplified form. A site plan showing placement of the various buildings on the substructure is presented in Figure 5. To help the reader grasp project scale, a panorama of the site as of very late 2012 is presented in Figure 6. All structures shown in Figure 4 are concrete except for structure C which is steel-framed. The area of the site is slightly more than 125,700 ft^2. The site slopes downward from North to South. Street level access to the podium level is achieved on the Northwest corner of the site, just east of the two residential towers. This is important because the city will not allow any of the traffic lanes adjacent to all 4 sides of the side to be used for storage or extended material off-loading. Thus completion of the podium level as soon as possible in the Zone A area shown on Figure 5 is desired. The duration of the base schedule is 41 months, with project start being approximately 3 months later than originally anticipated. It is desired to shorten project duration to 38 months for reasons described later. The CM@Risk firm has developed an extensive schedule containing more than 15,000 activities and is making use of BIM to help validate the schedule. A linear planning (LP) representation of an aggregated model of the plan and schedule derived from the detailed schedule is presented in Figure 7. It provides substantial insight into the base schedule strategy and how it might be modified, insights not easily gleaned from the bar chart schedule used by the CM. Noteworthy is a zoning of the site into West and East, with work moving from West to East.

The project goal is to have all major components of the project completed at the same time, with completion being governed by the duration of the tallest residential tower. The base schedule appears to have considerable ‘room to maneuver’, but this is necessitated by the significant complexity of the project. There is a delicate balance that the CM has to maintain in terms of managing client expectations (i.e. achieving performance promised) and keeping for itself flexibility in terms of its overall approach in order to meet client expectations, even if it appears that one or more of these performance expectations could be bettered.

5 STRATEGY TO MAKE UP TIME

As seen from Figure 7, the delayed start by 3 months of the project means that it will not be completed until December 2015. From the perspective of all users of the facility, this is unsatisfactory, especially for the retail merchants who will miss the lucrative Christmas season. The question becomes – how best to recover the time lost, and possibly more? The specific strategy explored below is that of the authors, and is used for illustrative purposes only. However, it does allow us to address a number of the issues and strategy framework features set out in sections 2 and 3. One option for making up time lost would be to achieve better balance in the production rates amongst activities in the major superstructure components. This can be observed from an examination of the upper part of Figure 7. However, it is best to leave such a strategy in reserve in case there is a need later in project execution to accelerate, either because of other delays or because of the desire to complete earlier in order to enhance marketing efforts. Also, failure to explore ways to shorten project duration through a more refined approach to substructure work including excavation and shoring (component A in Figure 4) before this phase is completed would be an opportunity lost. It is clear from Figure 7 that if the foregoing front-end work could be sped up, then all superstructure components would be completed earlier. Effectively, a ‘rigid body’ shift would be affected, while leaving the interfacing between components intact. Thus maximum leverage would be achieved.

In the base plan and schedule, the contractor has chosen to pursue a conservative substructure strategy which has parkade excavation and substructure finished before starting superstructure construction of the spatial components on top. The contractor’s strategy places a higher priority on horizontal spatial and

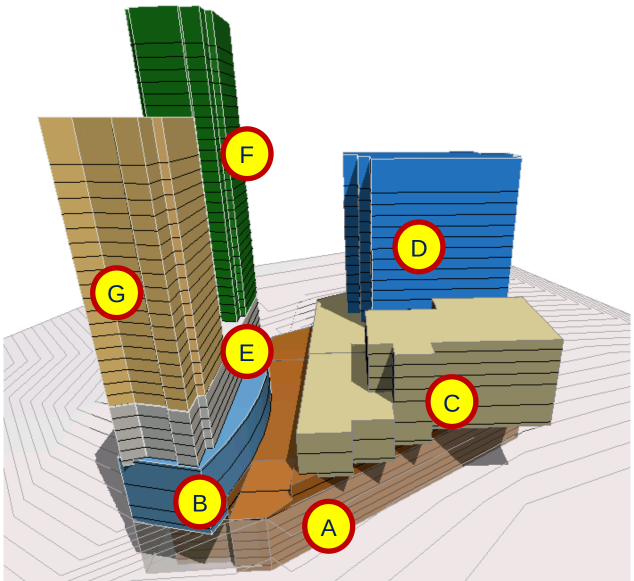


Figure 4 Massing of project components

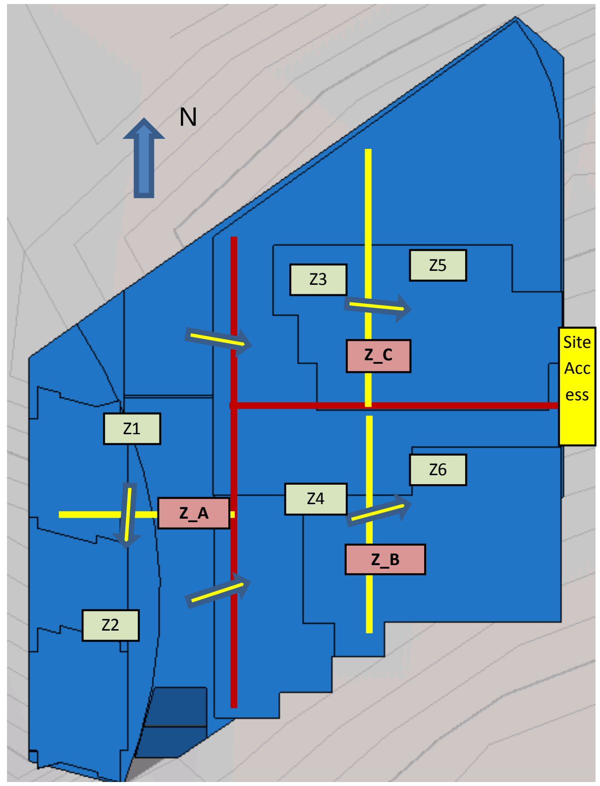


Figure 5 Site plan with zoning for substructure and placement of towers on top

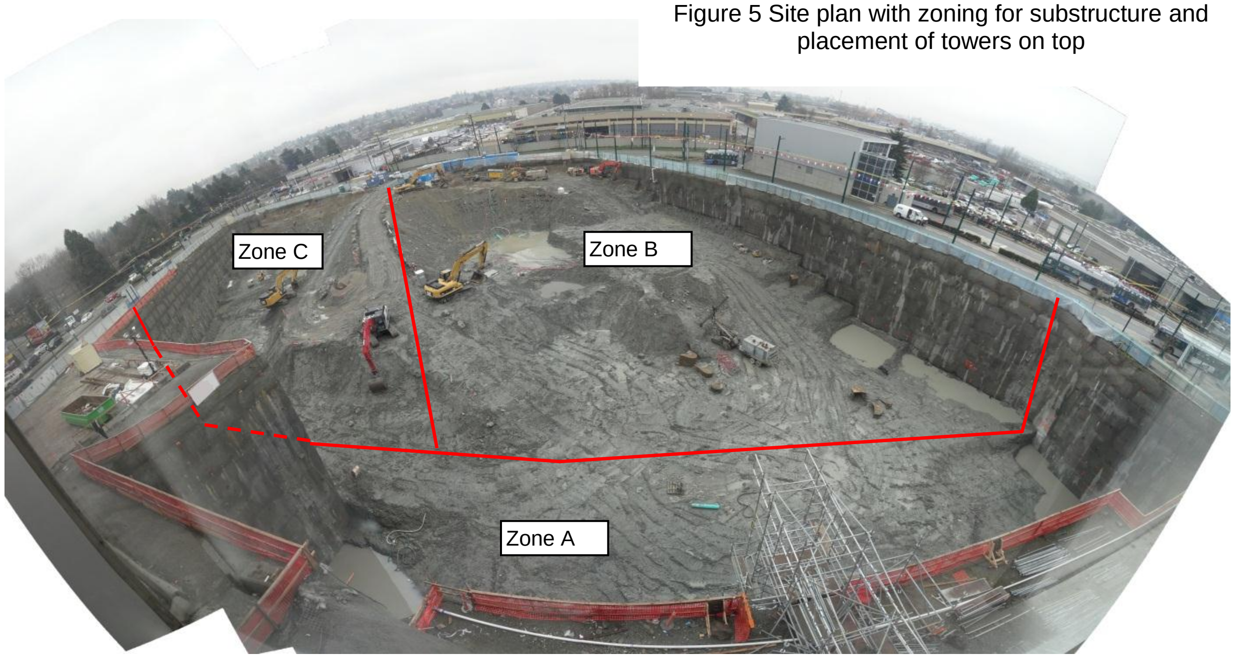


Figure 6 Panorama photo of the excavation

subproject linkages over vertical ones. The question becomes, is there a strategy that allows one to pursue both horizontal and vertical directions of work simultaneously, with appropriate lags between work at different vertical locations? In seeking an answer to this question, tactical variables of interest drawn from tactical variable categories 3, 4 and 5 in Figure 3 are work space zoning, work sequencing, number of work faces, site access and sub-project linkages. In particular, one seeks to capitalize on project scale by using a more fine-grained zoning than the simple West/East zoning reflected in Figure 5. Specifically, if

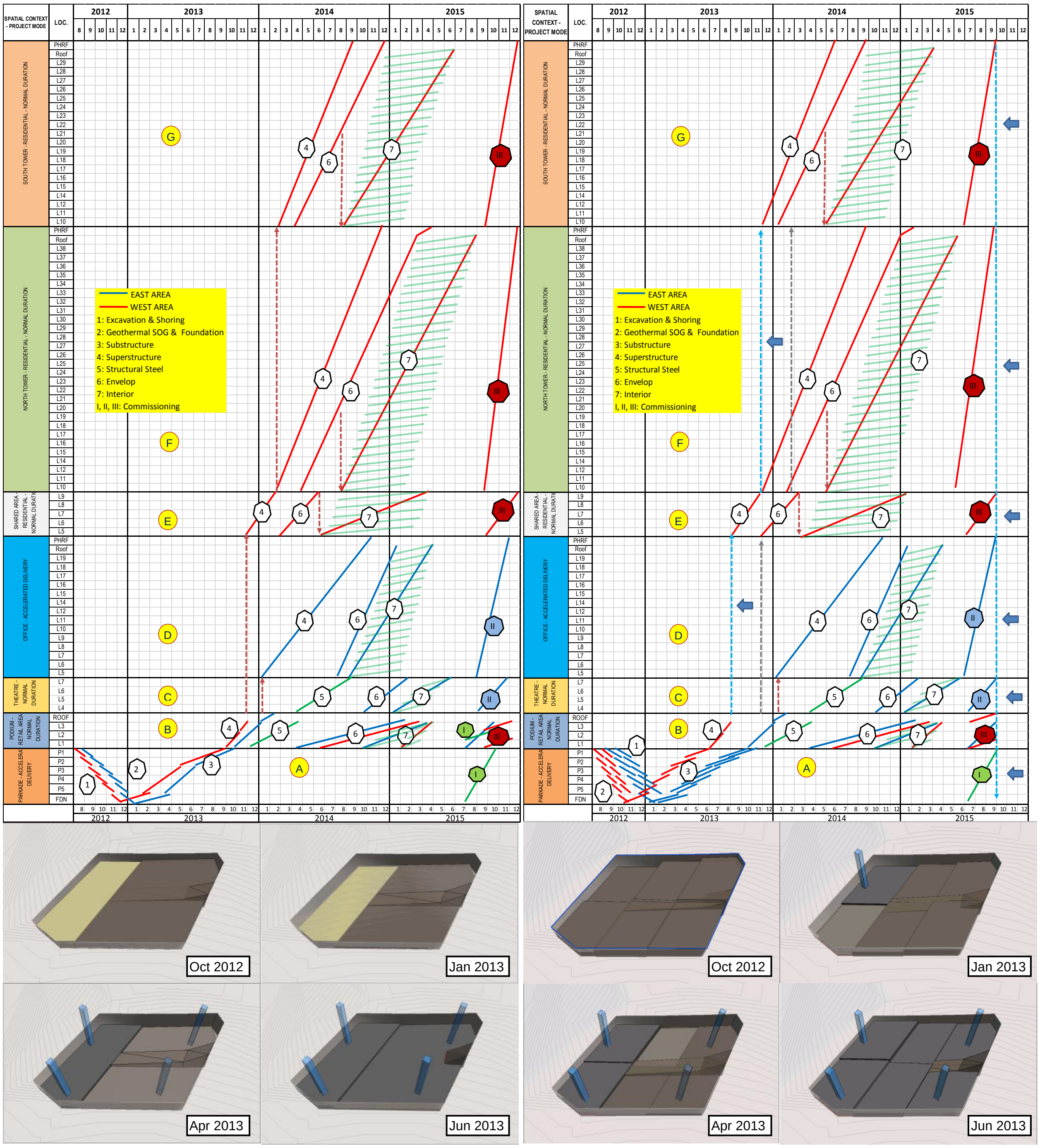
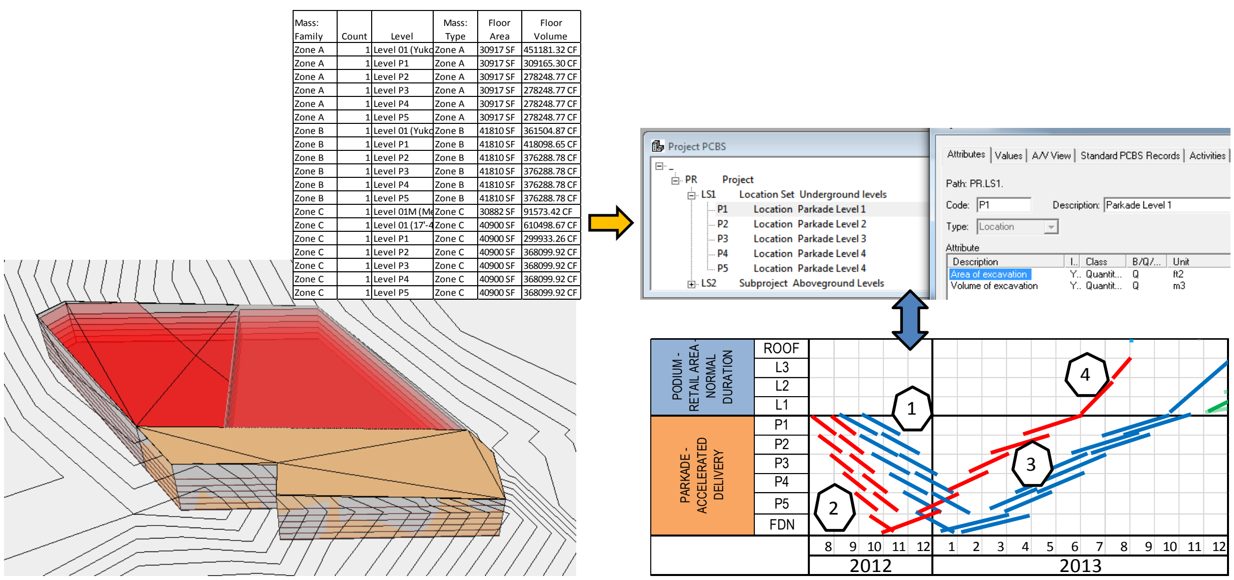


Figure 7. Strategy, Base vs alternative

Zone A (West) shown in Figure 5 is partitioned into two zones (Z1 and Z2) then excavation and shoring work can start in zone 1, with zone 2 relatively close behind. Given the nature of excavation, work on the East side of the site will start soon after, but lag behind. Then, as soon as parkade level 5 is reached in zone 1 and the first crane is erected, structural work can commence. Two advantages accrue from this strategy. First, the podium can reach street level on the North side quickly, allowing access for deliveries to the site – i.e. the space between components C and E in Figure 4 can be used as a lay down area – an important consideration as site access on the East side of the site becomes much more restricted once substructure work is completed, and work progresses on structures C and D. Second, work can be initiated on the tallest tower, starting with the North part of structure E, thereby shifting the start times of the two residential towers, with no change to production rates of tower activities. The strategy mode still corresponds to a normal duration mode (i.e. M1 as per Figure 2), but with a greater density of work because of improved use of project scale. The change in strategy is reflected on the right hand side of Figure 7. Note the four downward saw-tooth LP activities (LP activity structures), with each activity representing both excavation and shoring. The first two activities reflect work in zones 1 and 2 in Zone A (West) while the other two reflect excavation and shoring work in Zones B and C (the four subzones, Z3 – Z6) apply to structural work). In building the substructure on both the West and East sides, the North side progresses ahead of the South side, as shown by the overlapping between levels in Figure 7, further contributing to an earlier project completion of the project.

In addition to the insights offered through the schedule representation in the upper half of Figure 7, assessment of strategy workability can be aided using 4D BIM based on the simple massing model, and a resource loaded aggregated linear planning model. Shown in the lower part of Figure 7 is a 4D representation of schedule progress for the month ends of October, January, April and June for the base construction strategy as well as for the revised strategy. Visual comparison shows that slab work on the West side of the site is near street level on the North side faster for the alternative strategy, a plus for open air access and material handling. In terms of the interchange of product and process model data and assessing strategy workability, it is important to test the reasonableness of the production rates for excavation and shotcrete shoring. Only the former is considered in Figure 8 which consists of a massing model of the excavation with zones and levels shown. Zoning information is communicated from the process model to the BIM model, enabling the computation of volume information. This information in turn is communicated back to the product model embedded in the process model. Basic checks (not shown here) can then be made on production rates in terms of volume of material produced per unit of time as well as equipment productivity, assuming the schedule has been resource loaded with the excavation equipment complement. In terms of the potential benefits claimed in section 3 for our approach, our example demonstrates in part benefits(c) through (f). The visual representation of the project schedule in the form of a highly aggregated planning model combined with a relatively simple BIM project component massing model can assist in identifying how time performance can be improved.



Mass: Family	Count	Level	Mass: Type	Floor Area	Floor Volume
Zone A	1	Level 01 (Yuko	Zone A	30917 SF	451181.32 CF
Zone A	1	Level P1	Zone A	30917 SF	309165.30 CF
Zone A	1	Level P2	Zone A	30917 SF	278248.77 CF
Zone A	1	Level P3	Zone A	30917 SF	278248.77 CF
Zone A	1	Level P4	Zone A	30917 SF	278248.77 CF
Zone A	1	Level P5	Zone A	30917 SF	278248.77 CF
Zone B	1	Level 01 (Yuko	Zone B	41810 SF	361504.87 CF
Zone B	1	Level P1	Zone B	41810 SF	418098.65 CF
Zone B	1	Level P2	Zone B	41810 SF	376288.78 CF
Zone B	1	Level P3	Zone B	41810 SF	376288.78 CF
Zone B	1	Level P4	Zone B	41810 SF	376288.78 CF
Zone B	1	Level P5	Zone B	41810 SF	376288.78 CF
Zone C	1	Level 01M (Me	Zone C	30882 SF	91573.42 CF
Zone C	1	Level 01 (17'-4	Zone C	40900 SF	610498.67 CF
Zone C	1	Level P1	Zone C	40900 SF	299933.26 CF
Zone C	1	Level P2	Zone C	40900 SF	368099.92 CF
Zone C	1	Level P3	Zone C	40900 SF	368099.92 CF
Zone C	1	Level P4	Zone C	40900 SF	368099.92 CF
Zone C	1	Level P5	Zone C	40900 SF	368099.92 CF

Figure 8 BIM and Process models with exchange of quantity information

6 DISCUSSION

Motivation for our work on construction strategy is derived in part from our experience in interacting with construction personnel on how they conceive of construction strategy, select tactics to achieve it, and assess strategy effectiveness. We observe that: (i) construction personnel do not have a consistent vocabulary with which to discuss strategy nor do they have a structured approach to its consideration – at best, ad hoc approaches are used; (ii) CM personnel have a rather narrow view of strategy, and tend to think bottom-up more than top-down; (iii) aggregated representations of product and process models can provide valuable insights; (iv) use is being made of BIM in practice to assess how a project will be constructed, but the use of fine-grained product and process models and the time required for their formulation precludes the exploration of multiple strategy alternatives. The question becomes: How to operationalize a formal framework for formulating and assessing construction strategies, especially one that facilitates a speedy examination of multiple strategies, thereby providing contractors that use it with a competitive advantage and clients with enhanced value? Our ongoing work is directed at answering this question. Shown in Figure 9 is a simplified representation of a strategy formulation and assessment cycle. Challenges being addressed in ongoing work relate to items 3, 4, 6 and 7. We pose them here in the form of four questions because of space constraints: (i) What form should a computer aid take to assist construction personnel to select appropriate strategy modes and compatible tactical variables to achieve current project performance objectives?: (ii) Is it possible to make mappings that suggest preferred tactical variables as a function of choice of strategy mode?; (iii) A particularly challenging topic is how to affect a flexible mapping between process-product model and BIM product model in order to define reasonable parameter values for the process model and to aid the assessment of schedule workability?; and, (iv) what are the checks that should be executed to determine process workability and what suite of product, process, and product + process visual images can assist with these checks?

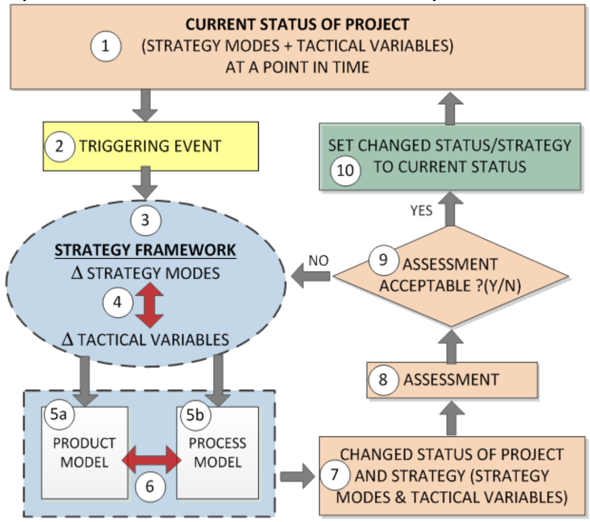


Figure 9 Cycle of strategy exploration

7 REFERENCES

Artto, K., Kujala, J., Dietrich, P., & Martinsuo, M., 2008. What is project strategy? *International Journal of Project Management*, 26(1), 4–12.Construction industry institute (CII). 1986. Constructability: A Primer. Austin Texas, University of Texas.

Chau, K. W., Anson, M., & Zhang, J. P. 2005. 4D dynamic construction management and visualization software : 1 . Development, *Automation in Construction* 14(4), 512–524.

Hartmann, T., & Fischer, M. 2007. Supporting the constructability review with 3D/4D models. *Building Research & Information*, 35(1), 70–80.

Hijazi, W., Alkass, S., & Zayed, T. 2009. Constructability Assessment Using BIM/4D CAD Simulation Model. *AACE International Transactions*, AACE, 1–15.

Jung, Y., & Joo, M. 2011. Building information modelling (BIM) framework for practical implementation. Automation in Construction, 20(2), 126–133. doi:10.1016/j.autcon.2010.09.010

Kang, L.-S., Moon, H.-S., Park, S.-Y., Kim, C.-H., & Lee, T. S. 2010. Improved link system between schedule data and 3D object in 4D CAD system by using WBS code. *KSCE Journal of Civil Engineering*, 14(6), 803–814.

Staub-French, S., & Khanzode, A. 2007. 3D and 4D modeling for design and construction coordination: issues and lessons learned. *ITcon*, 12(September 2006), 381–407.

Stradal, O. and Cacha, J. 1982. Time Space Scheduling Method, *ASCE Journal of Construction Engineering and Management*, 108(3), 445-457.

Tran, N., Russell, A., & Staub-French, S. 2012. A framework for construction strategy formulation and visualization. *Construction Research Congress 2012*: Construction Challenges in a Flat World, 189–198.