USING VIRTUAL PROTOTYPING TECHNIQUES FOR IMPLEMENTATION OF A VIRTUAL CONSTRUCTION ENVIRONMENT (VCE)

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ABSTRACT

The current-state-of-the-art of Virtual Prototyping (VP) for communicating project data and information is currently limited to the development of interference checking and schedule simulation (4D) tools that rely heavily on BIM models with monolithic CAD objects. While helpful, these interference checking and *macro* schedule simulation tools only scratch the surface and do not approach the possibilities of generating much needed estimates and schedules expressed in the currency of the individual work tasks that contractors and subcontractors use to bid, construct, measure and track.
Virtual Prototyping technologies provide features and capabilities that can be utilized to develop richer and more sophisticated tools to assist project participants to think, plan and conceive construction strategies at the *micro* level. At the same time, monolithic CAD objects from BIM models, produced during design phase, must be somehow transformed into a more granular and robust form amendable to representing the individual work tasks that comprise estimates and detailed schedules.
This paper discusses ongoing research work at Virginia Tech for the development of a 2nd generation Virtual Construction Environment (VCE) framework for micro project planning. The paper addresses the issue of transforming monolithic CAD objects into more granular form to correspond with work tasks. The proposed VCE framework is comprised of graphical and analytical functions for visualizing and manipulating graphical and non-graphical project information necessary to perform different work execution planning scenarios. A prototype implementation is presented to demonstrate concepts proposed.

KEYWORDS

virtual prototyping, macro and micro planning, BIM, CAD, 4D schedule simulation

1. INTRODUCTION

Technology and state-of-the-art programs are constantly evolving and making the design and planning processes easier across industries. However, the state-of-the-art for construction planning still heavily relies upon traditional methods for project planning and very little to digitally rehearse assemblies and sequences through virtual prototyping (Huang et.al, 2007). Several factors affect the lack of change within the construction industry when it comes to planning and virtual prototyping (Sarshar et.al, 2004). Until programs easily deal with common problems of interoperability and data transfer presented to project planners (Gudgel, 2007; Fox and Hietanen, 2007), virtual prototyping in construction planning will not be utilized as state-of-the-art.

Currently, Virtual Prototyping (VP) applications for construction planning focus mainly on simulation applications to communicate construction project information (time, cost, etc.), and on interference checking. While very beneficial, these processes barely scratch the surface of what VP applications can potentially handle. Virtual Prototyping applications have been investigated for planning construction sequences and resources (Waly and Thabet, 2002; Huang, et.al, 2007), but barriers still exist to take full advantage of A/E developed CAD models. One barrier is the use of monolithic CAD objects representing larger construction assemblies that do not offer the granularity needed for accurately representing construction processes. In order to be granular enough to represent work tasks the models need modification or development from scratch by the construction planner, a task not easily completed without experienced personnel, adding cost and use of resources to a project (Gugel, et.al, 2007). Only when an application allows for easily manipulation of an A/E model to accurately represent construction activities will the use of VP develop beyond common practice of schedule representation and interference checking.

The recent introduction of BIM concepts provides new opportunities to develop richer and more sophisticated VP applications. BIM allows for digitally modeling the facility so that "the model and its properties and attributes are the information of record for the project" (ENR, 2008). The Contractor's Guide to BIM (Ernstrom et.al, 2006) defines BIM as "a data-rich, object-oriented, intelligent, and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility." Valuable information stored in BIM models can be extracted and utilized towards the VP application. The A/E/C industry is still trying to answer various important questions, including what type of information and how much of it should be included in a BIM model, and what are the types of structure/schemes to be used for classification and representation of the information.

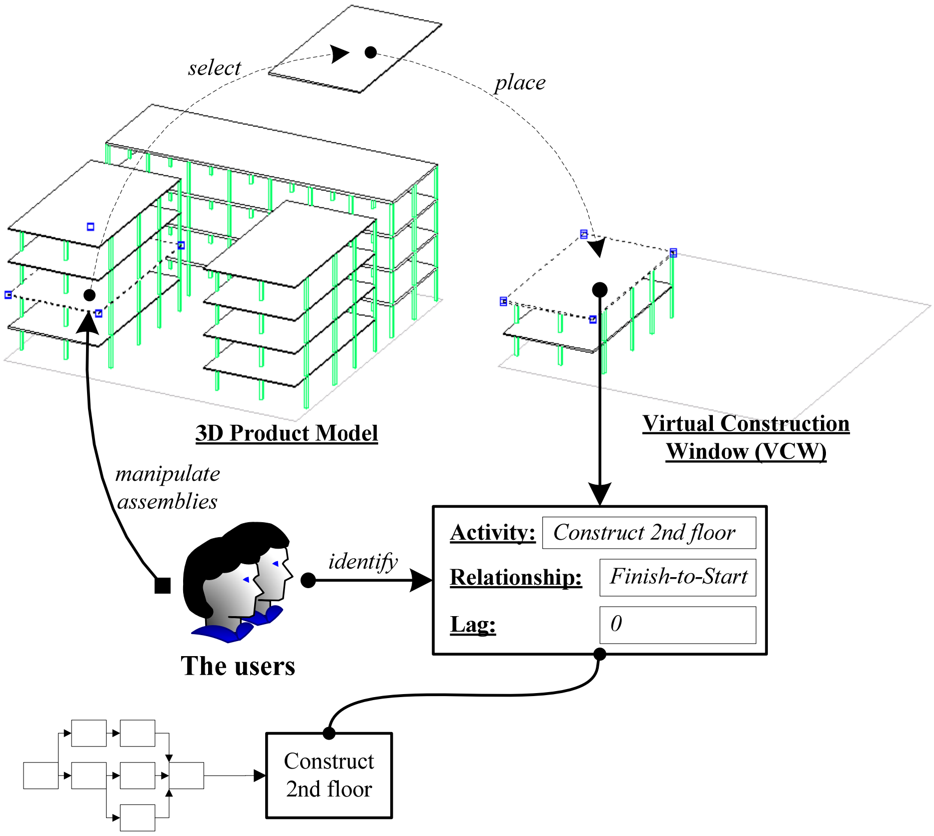
Ongoing research at Virginia Tech is examining some of the shortcomings of current state-of-the-art VP applications and the first generation Virtual Construction Environment (VCE). In response to these shortcomings a 2nd generation Virtual Construction Environment VCE2) framework and prototype are being developed that will allow a construction planner to easily manipulate an A/E generated model for planning work task activities, quickly receive quantities, develop resource allocations and review scheduled tasks through 4-D visualization, bar charts, and activity-on-node diagrams. This paper discusses the original VCE concept, the shortcomings that were identified, and the framework development of the VCE2. A working prototype is also presented.

2. VCE CONCEPT

Waly and Thabet (2002) proposed a Virtual Construction Environment (VCE) framework to assist the user in sequencing construction tasks in a virtual setting. The goal of the VCE is to enable the project team to undertake inexpensive rehearsals of major construction processes and test various execution strategies in a near reality sense. As depicted in Figure 1, the concept of this 1st generation VCE is based on manipulating CAD objects of a 3D product model. CAD objects are sequentially selected, moved and placed in the virtual construction window based on user's perception of the actual order of construction of the project. Relationships and resources are applied in order to get an overall duration for the object and it is placed on the schedule. The VCE would also allow for major equipment placement and planning.

Generated activities corresponding to work tasks are primarily based on the monolithic segments represented by the basic CAD objects. This 1:1 correlation between monolithic BIM components and corresponding monolithic tasks scheduled is not feasible for adequate

Figure 1: VCE 1st generation concept (Waly & Thabet, 2002)



construction planning. If the process of how tasks are derived from CAD objects and the complex interrelationships between the tasks are better understood, the necessary innovative processes and tools can be devised to transform BIM objects to forms more useful for construction. This would close the missing productivity link and advance the state-of-the-art.

The problem with the 1st generation VCE is object granularity. When an architect or engineer designs a model they do not have to consider activity level construction processes. In this sense, the construction planner is presented with a series of monolithic CAD objects that can only represent larger groups of activities (i.e. one CAD object to represent a slab that would involve three separate concrete pours) (Ernstrom et.al., 2006). In order to accurately and easily plan from an A/E created model there is a need to easily modify monolithic graphical objects into objects that represent activities for assembling a project at a detailed (micro) level. The smaller graphical objects that accurately represent the activities allow for inexpensive rehearsals of complex construction sequences to identify flaws in the plan before construction begins.

In response to problems of current planning methods a second generation VCE framework is developed. The second generation VCE address issues of needing an application possible of modifying monolithic CAD objects into a form that properly represents the task level activities being planned. Allowing the user to easily calculate quantities, allocate resources, and determine durations for each activity and inexpensively rehearse construction processes at the work task level. This second generation framework is described in the following sections of this paper.

3. SECOND GENERATION DEVELOPEMENT

In response to the problems of the first generation of the VCE a 2^{nd} generation prototype (VCE2) is developed. The VCE2 allows the user to plan sequences of task level activities by easily manipulating larger objects to accurately represent construction processes, manipulate graphical and non-graphical project information for scheduling, and developed a detailed schedule of activities allowing the user to rehearse and modify planned construction processes.

For development purposes a poured-in-place concrete retaining wall as part of new construction on the Virginia Tech Campus is examined while reworking the VCE2 framework. In a common CAD model one monolithic graphical object would typically represent the wall. This single object does not correlate to construction needs. In order to use this graphical object to represent the analyzed retaining wall construction it needs modification to nine different pieces to represent nine activities (i.e. wall section 1, wall section 2, etc.) with work tasks for constructing each activity (i.e. Interior Formwork, Rebar, etc.). A tool is needed to make these graphical medications. Once the construction planner can modify the object, the system can assist in creating the tasks for each activity, designate resources, calculate durations, and create a detailed schedule.

A decision diagram was created to layout the VCE2 framework for preliminary investigation (Fig. 2). The first step is for the user to input the BIM model of the entire building into the VCE, select the assembly to plan, and define some basic parameters. These parameters include an assembly type, sub-assembly type, and construction type. Currently, these parameters are organized based upon the assembly classifications in “Means Assembly Cost Data” (RSMeans, 1999). Using a BIM model, embedded information related to the assembly, sub-assembly, and construction types can be automatically extracted. The user can review and revise if needed. For the case study assembly the classifications for assembly, sub-assembly, and construction type are “foundations”, “footings and foundation”, and “walls – cast-in-place” respectively.

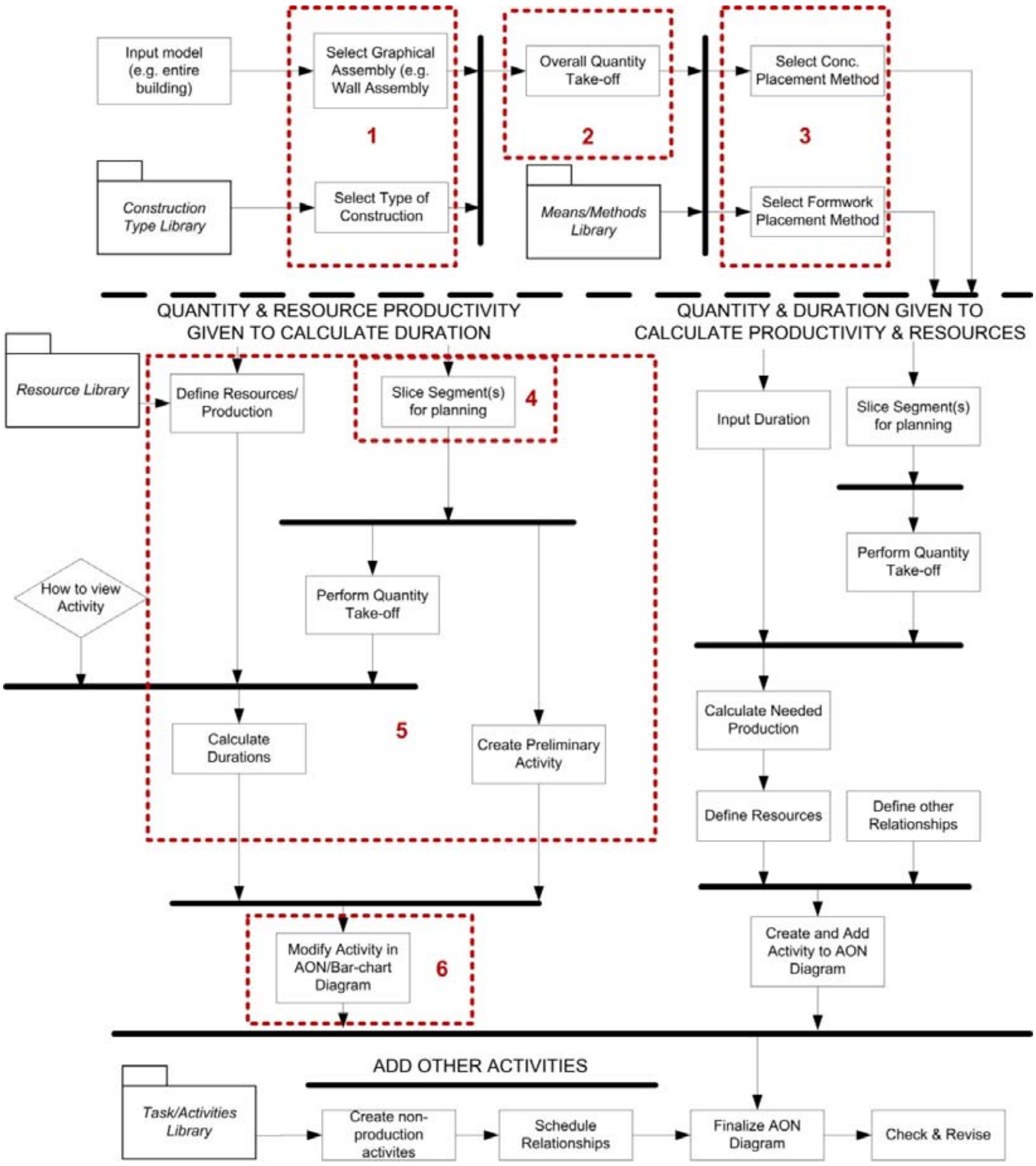


Figure 2: VCE2 Framework

Once the assembly is defined, overall quantities for concrete and formwork are calculated by the application. The quantities are reviewed while defining major means and methods.

The classifications of the assemblies determines which database the system accesses for means and methods of construction to create associated tasks (formwork, rebar, etc.) with each activity. For the “walls – cast-in-place” construction type means and methods for concrete placement and formwork placement are required. The means and methods limit the equipment listed when the resources are allocated by filtering the resource database.

To modify the monolithic assembly into more granular objects suitable for planning, a tool created to slice off a segment is devised. When an section is sliced from the monolithic assembly object, the application creates the activity-on-node (AON) diagram, dependency relationships, quantities of work, resources, production rates, and durations (Fig. 2 – area 5). The process of defining resources and calculating durations can be accomplished one of two ways. The first is to define resources and production rates and have the duration calculated. The second is to assign a duration value, useful if a deadline exists in the planning process, and determine production rates, calculated by dividing quantity by time. Available crews to meet the calculated production rates will be listed for selection. After the activities are formed planned construction sequence is reviewable through various graphical representations (e.g. Gantt charts, AON diagrams, and 4D animations). A prototype mock-up application has been developed as proof of concept of the steps above and described in detail in the following section.

4. APPLICATION PROTOTYPE

The VCE2 mock-up uses Bentley's MicroStation^{TM} and ProjectWise Navigator^{TM} products on a desktop platform running Window's Vista^{TM}. MicroStation, a CAD software application, offers various quarry, modeling, and modification tools useful in the development of the VCE2. MicroStation also allows for development of functions and tools through its compatibility with Microsoft's Visual Basic for Applications (VBA) offering methods of automating processes and references to databases.

The user interface, set within MicroStation, consists of a tool to isolate a planning assembly and an "Information Dashboard," a multipage form where assemblies are defined and quantities, resources, durations, and sequencing information is reviewed. The model is loaded into the environment where the user selects the graphical object(s) that represents the assembly to plan. In this case the graphical object representing the retaining wall is selected. With the graphical objects selected it is isolated by clicking the "isolate" icon which initiates the planning process for that assembly.

When isolated the assembly is then defined on the "Assembly Definition" tab of the "Information Dashboard." This is done through a series of drop down menus populated with categories of assemblies based on RSMeans assembly data. The "Construction Type" menu is populated based on the "Assembly Sub-type" that is selected. The "Assembly Sub-type" menu is populated based on the "Assembly Type" selection. The values that show up within these three menus are derived from information tied to the graphical object assuming the model has intelligence built into it. The user can review and change this information or define this information if the model they are using does not have the information included. Also on this tab of the form the user defines the name for the assembly.

When the assembly is defined and a name is given, the user is able to define major means and methods for concrete, interior formwork, and exterior formwork on the "Means and Methods" tab of the "Information Dashboard" form. Overall quantities are shown to aid the user in understanding the scope of work in selecting the means and methods. The means and methods listed are dependent on the "Construction Type" selected within "Assembly Definition" tab. The drop-down menus are populated based on RSMeans data. Figure 3 depicts the (a) process of isolating a graphical object, (b) defining the assembly, and (c) selecting means and methods.

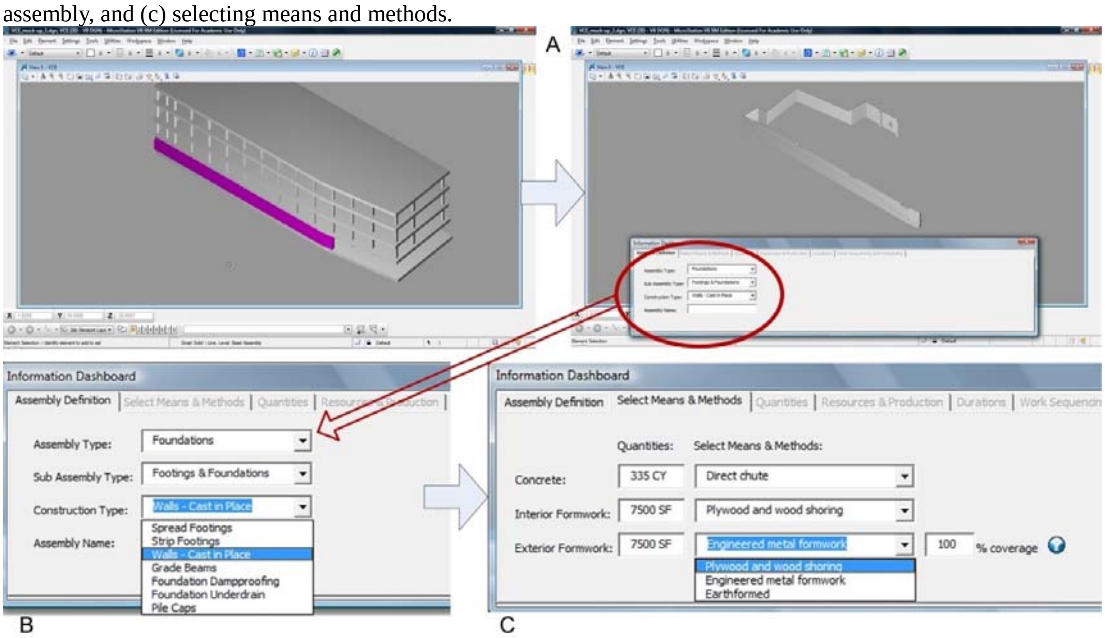


Figure 3: VCE Environment for starting planning process and defining assembly.

After the monolithic graphical object is isolated and basic parameters for planning are in place the graphical object needs modification to correspond to construction activities. This is accomplished with the introduction of a designed tool to allow for slicing a section of the retaining wall assembly from the monolithic graphical object. When the user slices each section of the wall a construction activity is created with the corresponding work tasks (i.e. Interior Formwork, Rebar, etc.). The user then reviews/modifies quantities, resources, durations, and dependency relationships for each activity through the "Planning Center," an interactive graphic user interface (GUI) (Fig. 4).

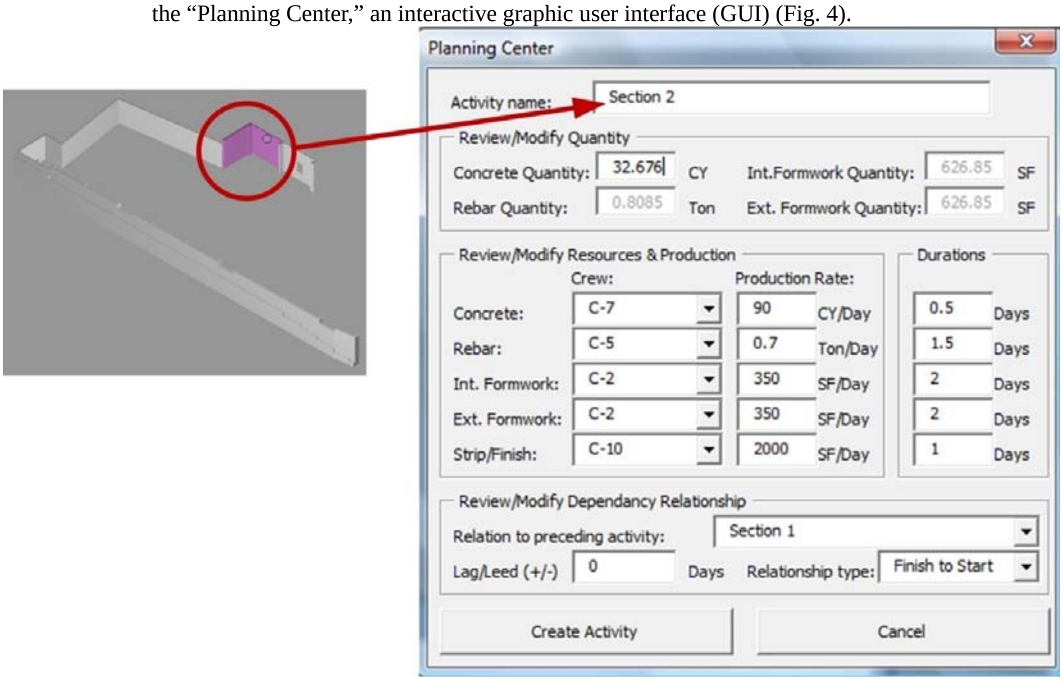


Figure 4: Create activity and assign planning parameters

If the dominant quantity, the concrete in the case of the retaining wall, exceeds or is excessively less than the scope of a typical work package, the user can adjust the quantity value and the system will re-slice the object representing the activity based on the new quantity value. The other quantities (formwork, rebar, etc. for the retaining wall) are automatically recalculated. The "Planning Center" also allows for the review of resources and durations. When inputting resources the user has three options. The first is to select a default crew and production rate from the drop down menus. These are crews that the system has incorporated from the database that were previously defined within the program. The next option is to use a crew and modify its production rate. The last is to design an entirely new crew with its own production rate. If a production rate is changed or a new crew selected, the preview of the duration rate is updated. The user can immediately see how the change affects the duration of work. The user can also input a duration if they need a task or activity completed in a set amount of time and the system will calculate the production rate needed and offer the sets of resources that can manage the production rate. Lastly within the "Planning Center," the user assigns dependency relationships to previously created activities. The default value is a "finish to start" relationship with the activity previously sliced.

Once the activity information is selected within the "Planning Center" and approved by the user it is recorded into the "Information Dashboard" under the tabs of "Quantity," "Resources & Production," "Durations," and "Work Sequencing & Scheduling." The user can easily review the information under each tab for each created activity. They can also revise the resources, production rates, and durations with each of the others automatically updated. The "Work Sequencing & Scheduling" tab allows for review of the created AON diagram, Gantt chart, and schedule simulations (Fig 5.).

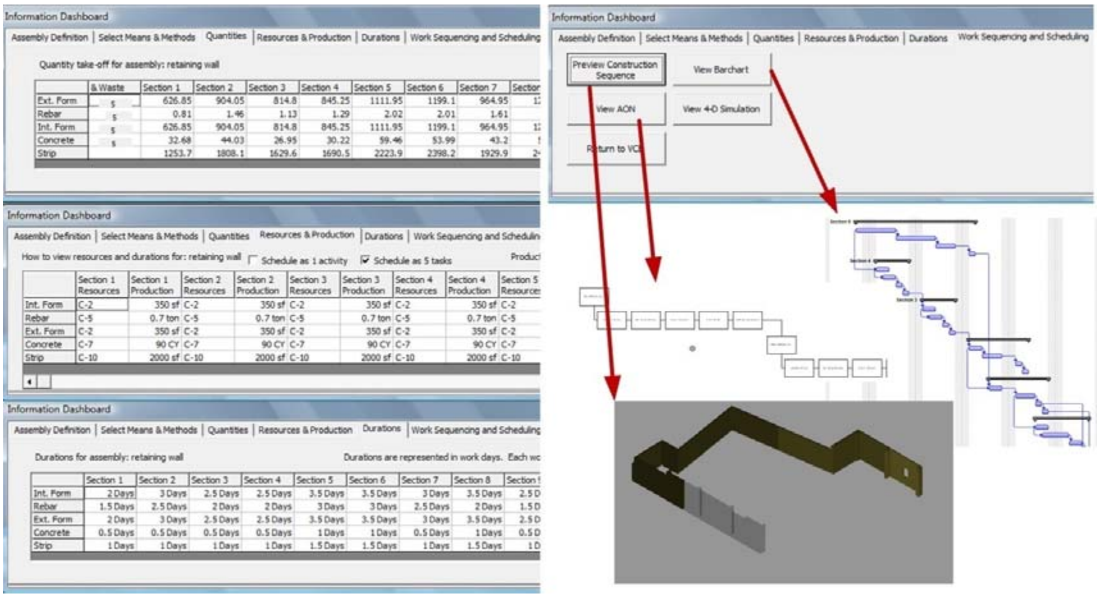


Figure 5: Planning parameters documented and reviewable

5. DISCUSSION

Even though technology and state-of-the-art programs are constantly evolving and making processes easier across industries, the state-of-the-art for construction planning still heavily relies upon tired and true methods. Several factors affect the lack of change within the construction industry when it comes to planning and virtual prototyping. These factors include resistance to trying new methods and refusal to learn new programs but the problems go deeper into the ability of construction programs to easily perform the needed work. Until the programs easily deal with common problems presented to project planners, virtual prototyping in construction planning will not be utilized as state-of-the-art.

The goal of the VCE2 is to examine the full potential of virtual prototyping with the development of tools that allow the user to easily manipulate graphical objects into activities that can represent the planned work tasks. The process discussed above uses the example of a concrete retaining wall for the basis of framework development for the working prototype. A completed program would include means and methods for each construction type based around the developed decision tree and allow for planning of any construction task's durations and resources. A second module of the application would also involve methods for site planning, equipment location, crane reach, work zones, and other non-production planning.

It is hoped that the basic framework of using quantity and resources, or quantity and duration, for graphically planning construction sequences on a micro-level can be expanded to accommodate various other assemblies. Minor variations to the framework would exist but the overall concepts to drive a fully implemented program that can help to eliminate tedious manual processes and take full advantage of digital models already created and in use by design professionals are similar to the developed prototype. With such implementation a fully functional program would better utilize the concepts of virtual prototyping of construction projects through planning and not limited solely to visualizations and clash detections.

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