

**Building Information Modeling for Masonry  
Phase II Project**

**Project 2, Masonry BIM Benchmark  
Pankow Foundation Grant RGA#01-14**

**Report 2**

**Development and Documentation of Case Studies of Masonry  
Construction Projects**

**delivered to**

**Charles Pankow Foundation  
in support of the  
Building Information Modeling for Masonry Initiative (BIM-M)**

**Georgia Institute of Technology  
School of Architecture  
Digital Building Laboratory**

**T. Russell Gentry, PI  
Charles Eastman, co-PI  
John Haymaker, co-PI  
Bryan Lee, Graduate Research Assistant**

**with students of BC 6550  
Design and Construction Process  
Georgia Institute of Technology**

**David Biggs, BIM-M Coordinator  
Project Manager**

**15 January 2016**

## 1. Executive Summary

This report represents the second deliverable from the Phase II Building Information Modeling for Masonry Benchmark project. It focuses primarily on the seven masonry case studies that were completed as part of the BIM-M Design and Construction Process class that was taught at Georgia Tech in Fall 2014. Students in the class completed in-depth case studies of masonry buildings that included an analysis of the masonry materials, systems, and design and construction processes that were used in the buildings' design and construction. In addition to the case studies, the students received lectures from key stakeholders in the masonry and AEC community.

## 2. Background

In June of 2014, the Digital Building Laboratory (DBL) at the Georgia Institute of Technology developed a framework for the process modeling and documenting of masonry construction projects. This process represented one phase of the ongoing BIM-M project and one part of the initiative that began in January of 2014 to create a benchmark of the implementation of BIM in the masonry industry.

Similar to the implementation of BIM for other building systems, BIM for masonry must first be addressed through the observation, documentation, and development of current industry practices, which is what this Masonry BIM Benchmark project and the associated case studies aim to do. After the initial case study on the EBB over the summer of 2014, we applied a similar process to six more masonry project case studies in the fall course. The class of approximately thirty graduate students was organized into seven teams to conduct case studies of six new, different masonry projects and one continued case study on the EBB. These projects included brick, CMU, and cast-stone masonry.

The students were asked to conduct a comprehensive case study of their projects that would involve the use of the process models in the Systems Modeling Language, or SysML, which allows for the modeling of various diagrams showing structure and process. The case studies are organized by the criteria outlined in the previous report: five phases (Schematic Design, Design Development, Construction Documents, Contractor Coordination, Subcontractor Installation), three masonry types (Brick and CMU, Structural Masonry, Complex Masonry), and three states (Current No-BIM, Current BIM, Future BIM).

For this report, we have included all seven case studies from our fall course:

Case Study	Project	Architect	Mason Contractor	Building Type
1	GT Engineered Biosystems Building	Cooper Carry	Jollay Masonry	Concrete Frame - Brick Veneer on Steel Studs - Interior CMU
2	Emory/Oxford Fleming Hall	Cooper Carry	Pyramid Masonry	Load Bearing Block - Precast Plank, Brick/Stone Exterior
3	Drew Charter School, Senior Academy	Perkins + Will	Cornerstone Masonry	Concrete Frame - Field Stone and Cast Stone over CMU
4	Woodward Academy Humanities Building	Perkins + Will	Cornerstone Masonry	Steel Frame - Brick and Cast Stone on Steel Stud Backup
5	Breckinridge Place	Holt Architects	Dave Trayer Masonry	Load Bearing Block - Precast Plank, Brick/Cast Stone Exterior
6	GCSU Ennis Hall + GT Hinman Hall	Lord Aeck Sargent	Southeastern Restorations	Load Bearing Brick and Stone - Restoration

7	Young Harris, Enotah Hall	Lord Aeck Sargent	Zebra Construction	Load Bearing Block - Precast Plank, Brick Exterior
8	UPenn, Huntsman Hall	KPF	Dan Lepore and Sons	Complex Masonry, Custom Clay Units, Concrete Frame

Figure 2-1. Masonry project case studies for fall course.

These seven case studies span the whole spectrum of material types, BIM states, and project phases that were outlined in previous reports and in the following diagram (see Figure 2-2).

	Schematic Design	Design Development	Construction Documents	Contractor Coordination	Subcontractor Installation
CMU and Brick					
Structural Masonry					
Complex Masonry					
	Future BIM	Future BIM	Future BIM	Future BIM	Future BIM
	Current BIM	Current BIM	Current BIM	Current BIM	Current BIM
	Current No-BIM	Current No-BIM	Current No-BIM	Current No-BIM	Current No-BIM

Figure 2-2. BIM-M Benchmark case study criteria.

Figure 2-3 shows a new visualization guide for understanding the BIM-M Benchmark criteria the organization of case studies. The new tool follows the same structure as before:

- Three masonry project types
- Five project phases
- Three states of BIM implementation

These three, five, and three criteria can be imagined as a 3 x 5 x 3 three-dimensional graph containing a total of 45 cells. Each cubic cell represents a specific project phase of a specific masonry project type of a specific BIM implementation. Our aim is to populate this three-dimensional graph with specific examples from our case studies in order to produce a comprehensive map of the BIM-M criteria.

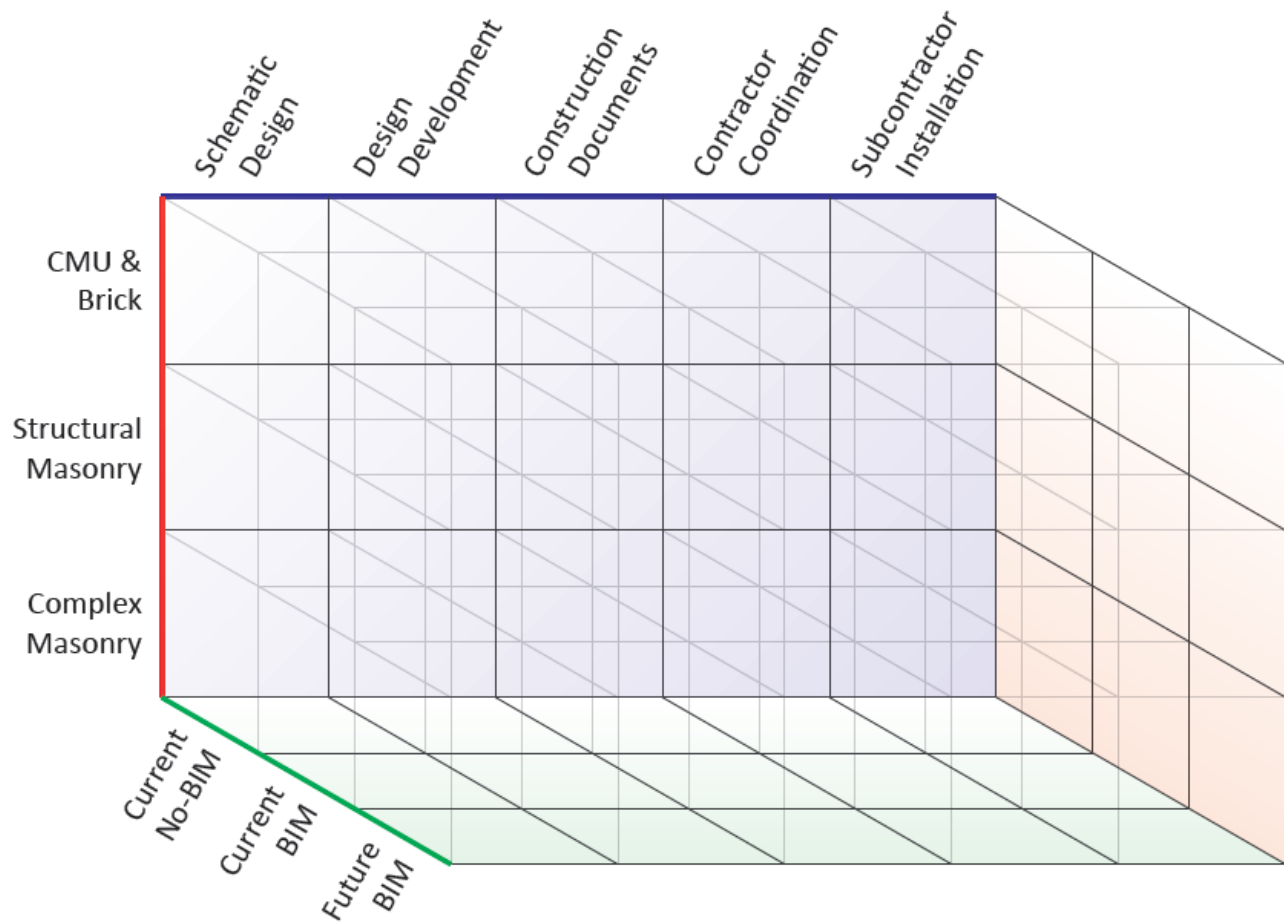


Figure 2-3. New visualization for the BIM-M Benchmark case study criteria.

A goal of this project and the fall course is to explore the future state of BIM in the masonry industry. Many construction processes have been effectively enhanced by BIM and other management tools. These tools have been connected to CAD and other modeling software and building industry databases. By understanding and modeling the masonry workflows in SysML diagrams, we will lay the groundwork for developing BIM tools specifically for the masonry industry. Furthermore, integrating these diagrams with the Masonry Unit Database will further enhance BIM implementation and greatly improve efficiency of the industry.

### 3. Class Process

The class members who completed the case studies came from the Schools of Architecture, Building Construction and Civil Engineering at Georgia Tech. Most of the students were from the School of Building Construction. The title of the course was “Design and Construction Process” and the overall focus was on understanding the interaction between stakeholder responsibilities and viewpoints and the workflows required to design, analyze, detail, procure, plan, coordinate and construct buildings. In the course, the actors in the AECO industry and the workflows might be considered generic, that applicable across a broad range of building systems, but the course also had a significant focus on masonry technology – which was lacking in most members of the class.

The appendix to this document contains the final syllabus used during the semester. It is provided as a blueprint for future classes on masonry construction. During the semester, a number of outside lecturers and

reviewers attended the class, to provide masonry, software and construction knowledge and feedback on the groups' work. These visitors are listed below in rough chronological order of their participation in the course.

1. Rick Fredlund, Cooper Carry Architects, Project Manager on Engineering Biosystems Building  
Lecture on Architects Viewpoint on Masonry Design and Detailing
2. Michael Hasomoh, Holder Construction, Senior Engineer and BIM Manager  
Lecture on BIM Implementation and General / Sub-Contractor Coordination
3. Mark Swanson, International Masonry Institute, Director of Industry Development  
Lecture on Masonry Material and Systems / Modeling of Masonry in BIM
4. Michael Gustafson, Autodesk, Industry Strategy Manager  
Lecture on Structural Engineering Workflows and BIM Coordination
5. Tom Cuneio, President, CADBLOX  
Lecture on Detailing and Modeling of Masonry Systems
6. Bill Pacetti, Jr., President, Tradesmen's Software  
Lecture on Masonry Cost Estimating
7. Matt Jollay, Project Manager, Jollay Masonry  
Review of Student Presentations at Mid-Term, Lecture on Mason Contracting
8. Chad Pyles, Block USA, Sales Manager  
Review of Student Presentations at Mid-Term, Lecture on Masonry Procurement and Cost Estimating
9. Mike Turner, Cornerstone Masonry, Director of Operations  
Review of Student Presentations, End of Term
10. David Biggs, Structural Engineer, BIM-M Coordinator  
Final Reviews
11. Dominic Dowd, National Concrete Masonry Association, Staff Engineer  
Final Reviews
12. Brian Trimble, Brick Industry Association, Vice President  
Final Reviews

In addition to the class participants listed here, all of the architects and many of the structural engineers, masonry suppliers, mason contractors, and general contractors worked with the students on their case study projects.

The short summaries of the individual case-studies are taken from the student group reports, and thus the students themselves are contributors to this document. The students are listed in Table 3-1 below. Their primary self-identified skill set is provided next to their name.

**Table 3-1 Student Teams**

Nivi Arulanandasamy	1	Emory at Oxford Fleming Hall	ARCHITECT
Lauren Dermody			ENGG
Enstin Ethayananth			ENGG
Qi Li			CONSTR
Abiha Ashrafi	2	Drew Charter School Academy	ARCHITECT
Bryce Ginn			CONSTR
Seo-Hun Joseph Lee			ENGG
Sally McEwen			OPERATIONS
Gustavo do Amaral	3	Woodward Academy Humanities Building	ARCHITECT
Yiyuan jia Jia			ENGG
Jeeva Seenivasan			OPERATIONS
Shree Soundiah			OPERATIONS
Jeremy Gentry	4	Breckenridge Place	ARCH CONSTRUCT
Matthew Leonard			CONSTR OPER
Xia Li			ENGG
Luis Torres			CONSTR
Anthony Ranallo	5	Georgia Tech EBB Cast Stone Workflows	ARCHITECT
Dinesh Tarigopula			ENGG
Jeffrey Collins	6	Masonry Restoration: GCSU Ennis Hall and GT Hinman Building	ARCHITECT
Alonzo Self			ARCHITECT
Gigi Tseng			ENGG
Yangyang Wang			CONSTR
Colin Lasch	7	Young Harris College Enotah Hall	OPERATIONS
Maulik Nasit			ENGG
Sheree Srader			OPERATIONS
Sachin Suresh			ENGG

#### 4. Georgia Institute of Technology, Engineered Biosystems Building

##### Project Background

The team assigned to the EBB was tasked with following up on our initial case study of the building to include the cast stone workflows of the project. The cast stone elements were used as parapet caps and window sills

throughout the building (see Figure 4-1). The architect used the aesthetic properties of cast stone to create a more historic brick façade and integrate the overall design language into Georgia Tech’s campus. Georgia Tech’s design and construction standards dictated many of the stylistic elements of the structure’s appearance and essentially required the use of cast stone since the campus is mostly composed of brick buildings with cast stone accents. Figure 4-2 shows the block definition diagram of the cast stone scope.



Figure 4-1. Cast stone elements on the EBB.

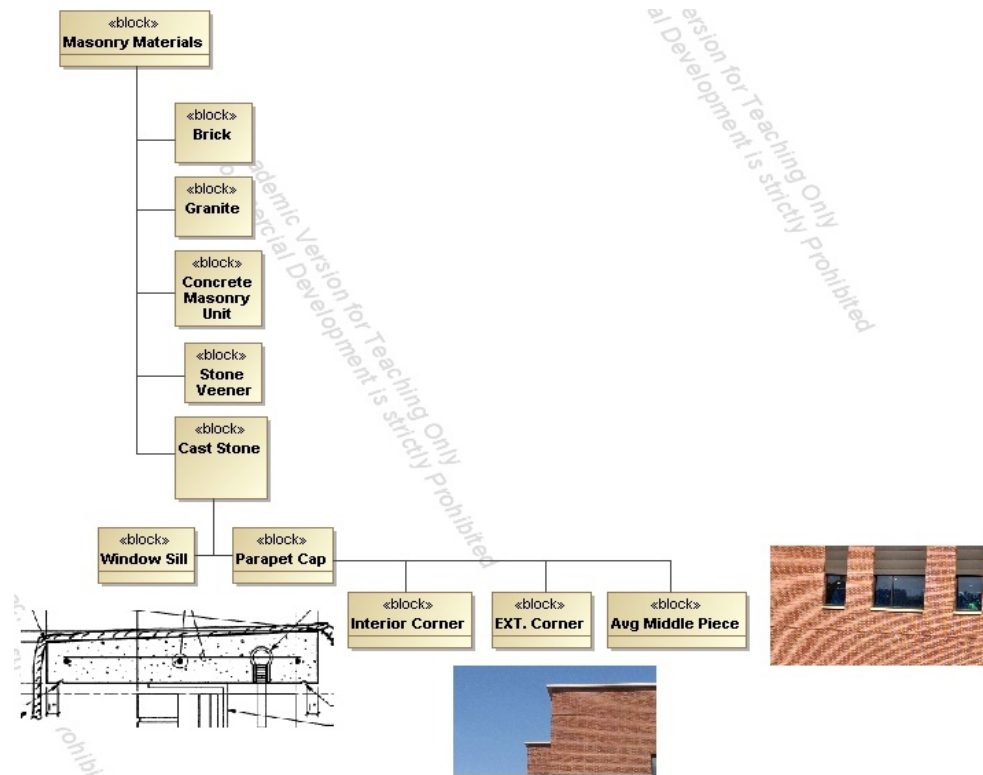


Figure 4-2. EBB cast stone scope diagram

### Stakeholders

This updated stakeholder block diagram (Fig. 4-3) outlines the stakeholders involved in a specifically cast stone workflow on the EBB.

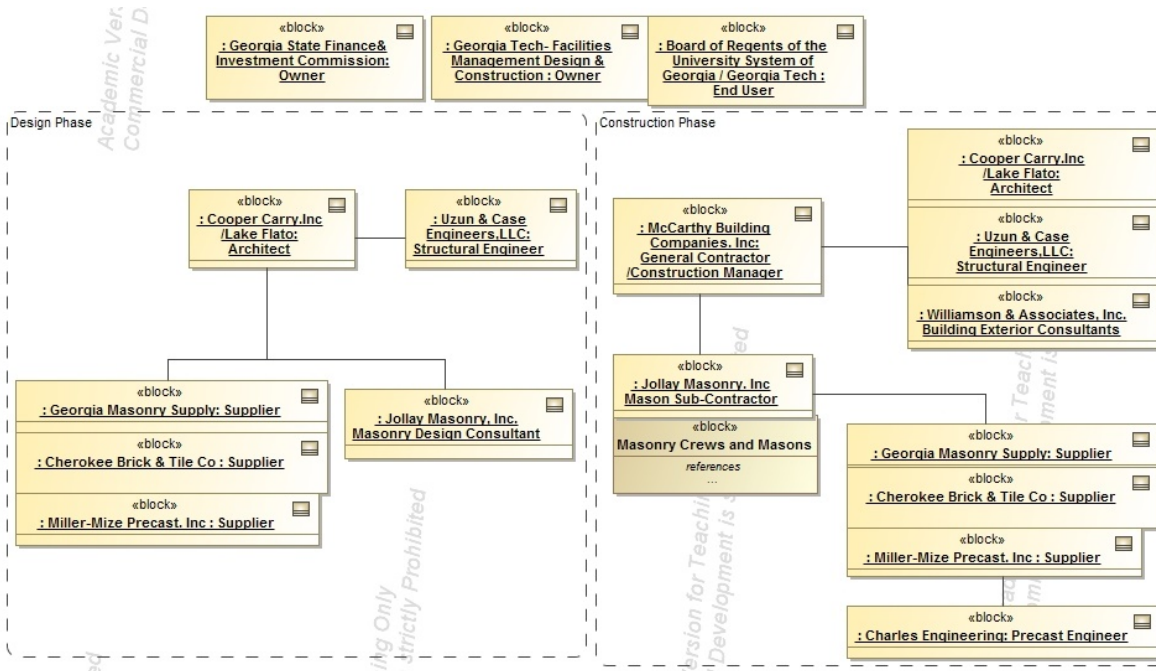


Figure 4-3. Organization of EBB cast stone workflow stakeholders.



It is important to note that the General Contractor, McCarthy, hired a building envelope consultant, Williamson & Associates, to assist with the cast stone process. Essentially anything that impacted the permeability of the structure by disturbing waterproofing was subject to Williamson & Associates' approval, meaning any cast stone requests for information (RFIs) had to go through Williamson & Associates at some point in the process.

Jollay Masonry contracted the cast stone supply out to Miller-Mize Precast for a couple reasons: 1) they had worked with them in the past and had a good experience with their cast stone quality, and 2) more importantly, Miller-Mize is one of the few wet-cast stone manufacturers within the distance required by the LEED sustainability criteria. Though Uzun & Case were the project's structural engineers, the Miller-Mize hired an engineering consultant to approve their shop drawings and any cast stone structural inquiries.

### **Schematic Design Phase**

Cooper Carry sought to make the EBB a modern and innovative landmark on Georgia Tech's campus, while still integrating the historic campus feel. After somewhat easily deciding to include cast stone in the formal language, the schematic design phase only saw very primitive and generic representations of cast stone. Essentially the entirety of the material was captured in the Google Sketch-Up model that Cooper Carry used for form analysis.

### **Design Development Phase**

After completing a schematic design, Cooper Carry began creating more detailed drawings that relate to the location and specific design of the cast stone elements. The representations in the design sheets are only to a certain level of development that does not represent the individual elements of a cast stone placement (see Figure 4-4).

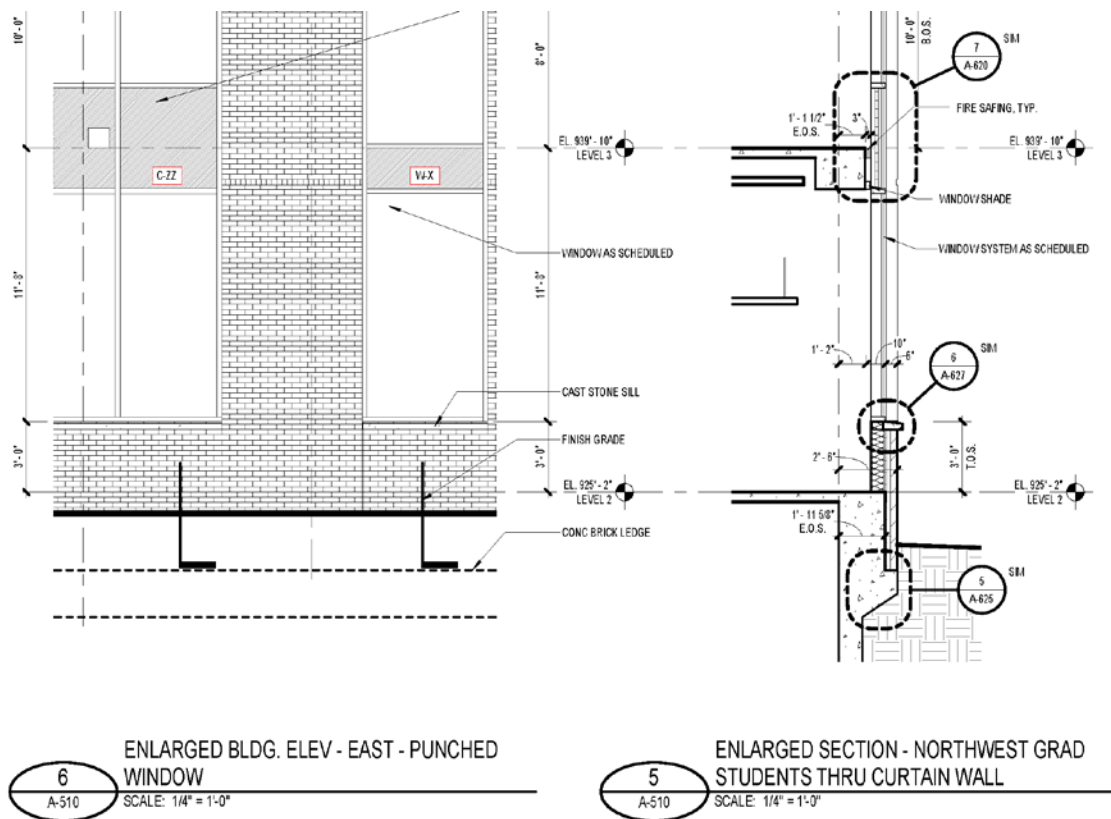


Figure 4-4. Elevation and section of brick wall with cast stone accents.

The responsibility of expertise on the cast stone form gets passed along to each successive recipient through the design and construction process, from the architect, to the general contractor, to the subcontractor, and finally the supplier. The architectural Revit model is complete, however, with references to all materials.

### Construction Documents Phase

Cast stone, for the most part, remained largely unchanged during this phase. Although mockups were built to evaluate the functional and aesthetic aspects of different building sections, these test runs did not result in any changes to the original cast stone design decisions. Considering the fact that all the stakeholders were on-site to review the mockups, we could assume that all stakeholders were content with the cast stone. Though various changes occur to the specifications after mockup reviews (type of mortar, flashing, support, exterior finishing, waterproofing, etc.), none were made to the cast stone at this point.

Due to the relatively small number of actions pertaining to cast stone in the earlier phases of the project, the SysML diagram below ( ) represents a combination of the Schematic Design Phase, Design Development Phase, and Construction Document Phase.

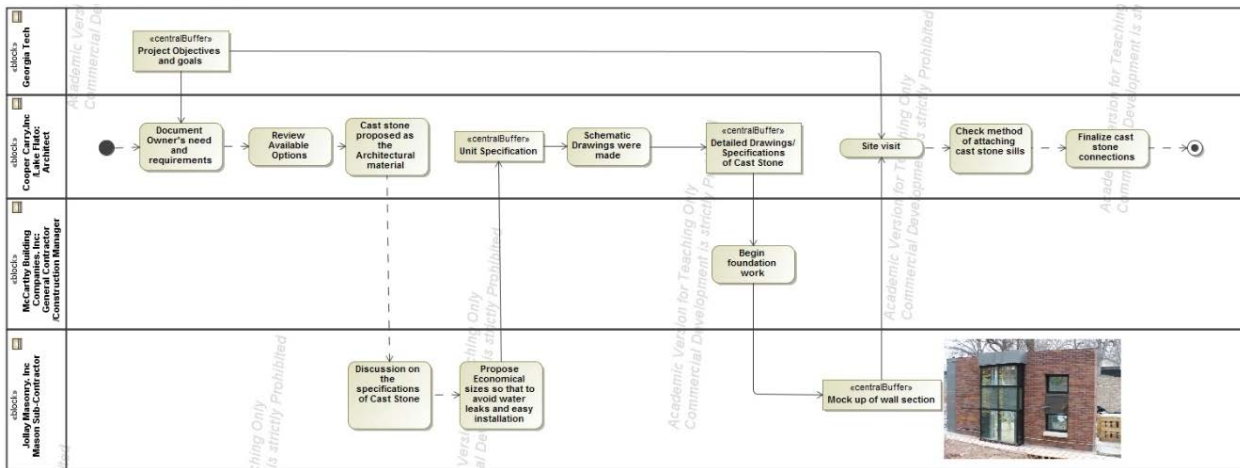


Figure 4-5. Activity diagram of schematic design, design development, and construction documents phases.

At this stage there are fully detailed drawings of cast stone profiles and locations that are included in the construction documents and provided to McCarthy for dispersion to subcontractors.

### Contractor Coordination Phase

Most of the cast stone activity occurs starting in the Contractor Coordination phase. Upon receiving the construction documents, McCarthy forwarded the information to all of their subcontractors, including Jolley Masonry. Jolley then began the procurement process with Miller-Mize. Since this was the first opportunity Miller-Mize had to review the cast stone specifications, they immediately began developing shop drawings. Once completed, the shop drawings were submitted for review to Jolley, who then officially provided the submittal to McCarthy. McCarthy reviewed and forwarded the submittal to Cooper Carry and Uzun & Case. Any important questions that arose as a result of the submittal review were submitted as an RFI. One such RFI from Cooper Carry was regarding the weight of a cast stone parapet cap bearing down on the brick veneer wall. Uzun & Case initially responded with two options: 1) continuously running the thick galvanized steel plate (with weldable reinforcing attached to the concrete stem wall) along the top of the curb, or 2) breaking up this same plate into multiple pieces (Figure 4-6).

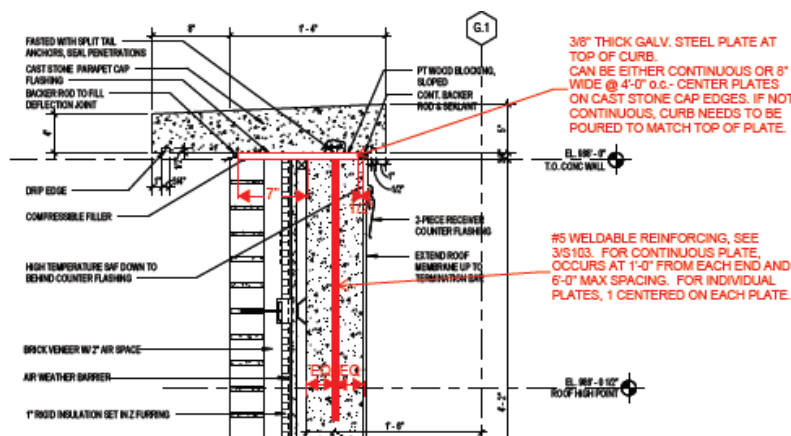


Figure 4-6. RFI initial response.

However, Miller-Mize suggested an alternative which allowed better constructability and didn't change the reinforcement in the wall (Figure 4-7). Uzun & Case had to provide the final approval before McCarthy's acceptance.

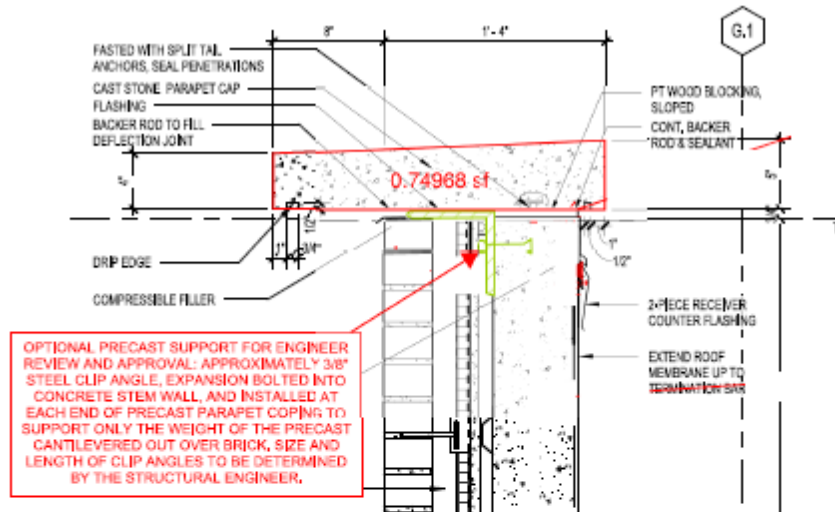


Figure 4-7. RFI alternate response from Miller-Mize.

The RFI process was fairly complex and involved several different interacting parties and often multiple relays of information through various stakeholders. Furthermore, they often require much more diagramming and documenting of construction elements that are not represented nor required in the previous phases and documentation (see Figure 4-8).



RFI\_0334

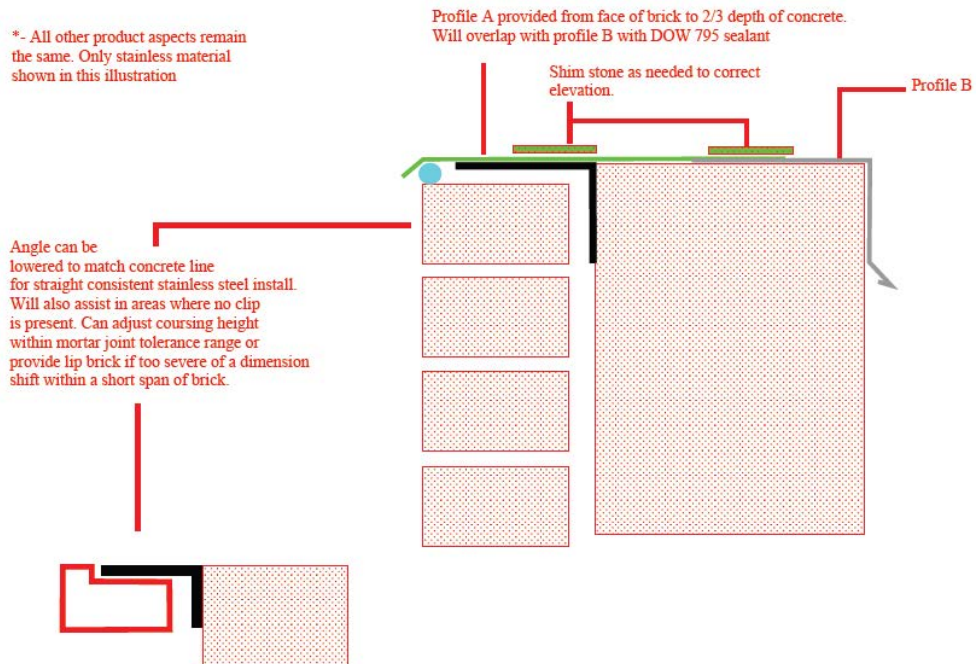


Figure 4-8. RFI response by Jollay Masonry.

Ultimately this information is meant to show both the high amount of modifications that have to be made to the original design drawings, as well as the circuitousness and extreme intricacies of the RFI process in general.

After all issues have been resolved, Miller-Mize altered and finalized the shop drawings, from which they created shop tickets. Figure 4-9 below shows the contractor coordination phase, including the RFIs mentioned above. It also includes this shop drawings revision/shop ticket creation process, as well as the shipment and delivery of the various cast stone batches.

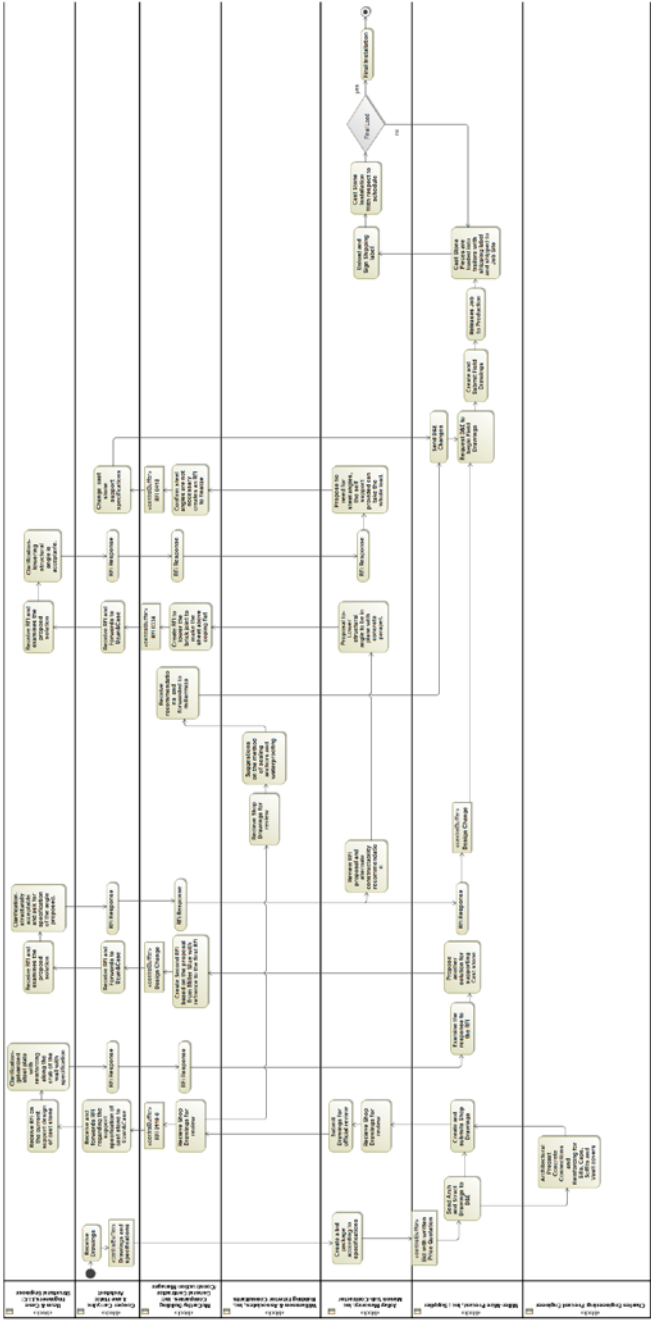


Figure 4-9. Contractor coordination phase.

## Subcontractor Installation Phase

Once the shipment arrived on-site, Jollay signed the shipment and coordinated with the brick masons for on-site storage at a relevant position for future installation. Since the concrete backup wall and all the other supporting structure for the cast stone had already been constructed well in advance, the cast stone arrived on an as needed basis.

The majority of sills on the EBB are “slip sills,” which allowed the cast stone pieces to be installed either before or after the brick façade is installed, but not at the same time due to falling object hazards. Figure 4-10 below shows the subcontractor installation when the brick was installed first. Any gaps between either system were filled in with an adjustment in the size of the mortar bed either at the top or through a few courses.

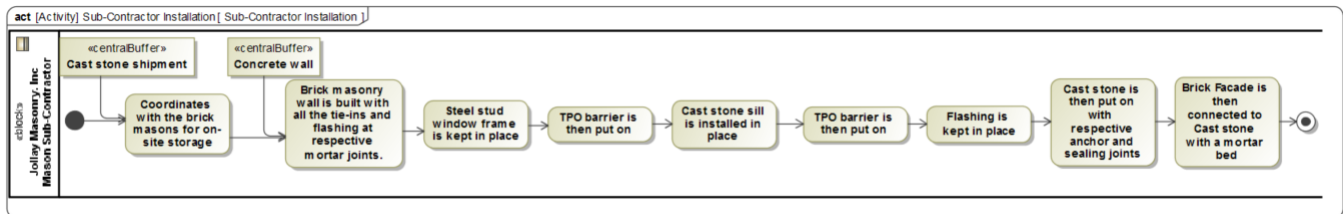


Figure 4-10. Subcontractor installation phase.

As often is the case on similar projects, Jollay had to order extra cast stone pieces for any potential errors such as broken pieces; however, many unused pieces are sitting idle on-site (Figure 4-11). The entire cast stone installation process could benefit from the current and future-state technology of RFID tags. Including an RFID tag in each individual piece of cast has the potential to not only improve site storage issues but also reduce or eliminate the need to order extra pieces. RFID tags would allow the mason subcontractor to request replacement of a specific piece of cast stone only in the event of a breakage rather than ordering them in advance, which would save time and money in procurement. Furthermore, RFID tags could eliminate installation location errors. Instead of constantly referring to the drawings and specifications for placing pieces, workers could simply scan for the RFID which would query the location and other data within a BIM model to streamline installation.



Figure 4-11. Unused, extra cast stone pieces on site.

## Conclusion

Although the nature of cast stone projects usually calls for high levels of customization, projects could still benefit from some method of cataloguing generic elements, processes, or specific metrics, in addition to other non-computational tools. One example is the size limitation of individual cast stone pieces due to weight for easy unaided handling. Such a detail could be incorporated into a BIM model plugin to assist in design and production processes. This could allow earlier and better cost estimation and improve BIM model accuracy. Also, there is the potential added benefit of a more streamlined RFI process by eliminating issues in earlier phases of a project.

## 5. Emory at Oxford, Fleming Hall

### Project Background



Figure 5-1. Fleming Hall (coopercarry.com).

Fleming Hall (Figure 5-1) is a 52,000-square-foot, three story, “L” shaped, LEED Silver certified residence hall for Oxford College at Emory University. It has 106 traditional rooms, shared bathroom facilities within each wing, two study lounges, and two laundry rooms, one in each wing. On the first floor is a large lobby, living room, and lounge space. A tech lounge and a gym facility are on the second floor. On the third floor is a large outdoor roof terrace with views of the Historic Quad. The exterior of the building can be seen in Figure 5-2. The project delivery method was Construction Management at Risk.



Figure 5-2. Exterior of Fleming Hall.

### *Masonry Scope*

Fleming Hall is a load bearing masonry building, and the scope includes Brick, CMU, and granite. These three masonry types all come together at a typical detail of the stone water table (see Figure 5-3).



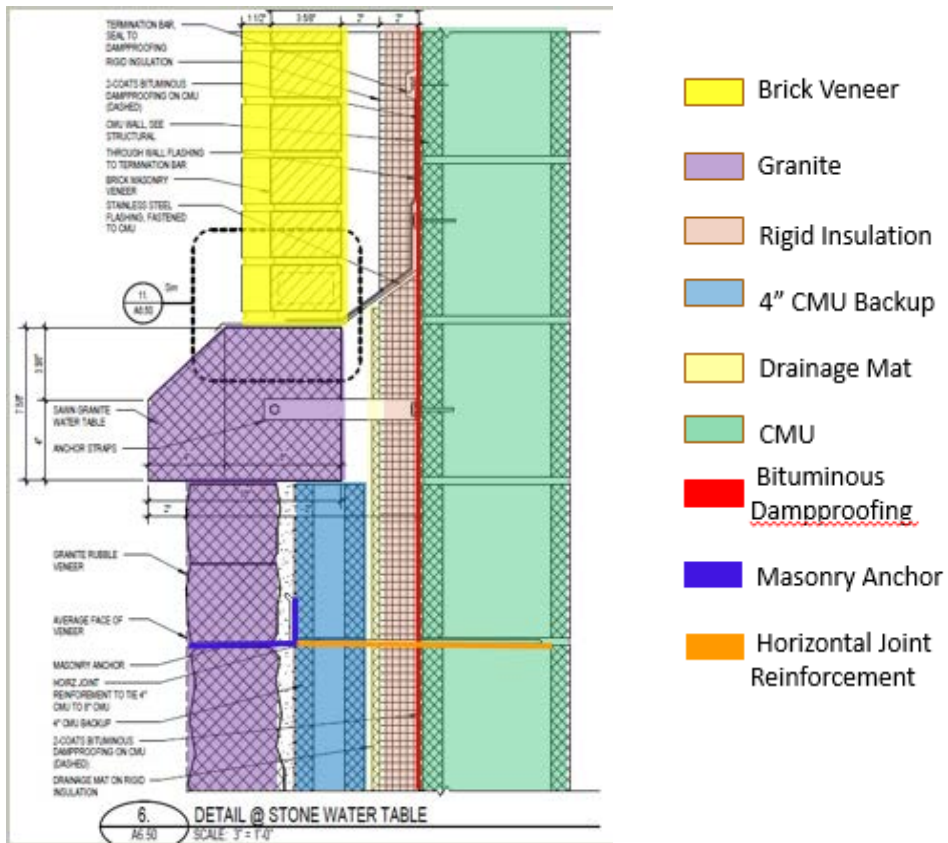


Figure 5-3. Detail of stone water table.

In one area, structural steel beams are used to support a canopy and interact with the granite rubble masonry exterior wall. This can be seen in Figures 5-4 and 5-5.



Figure 5-4. Building system.

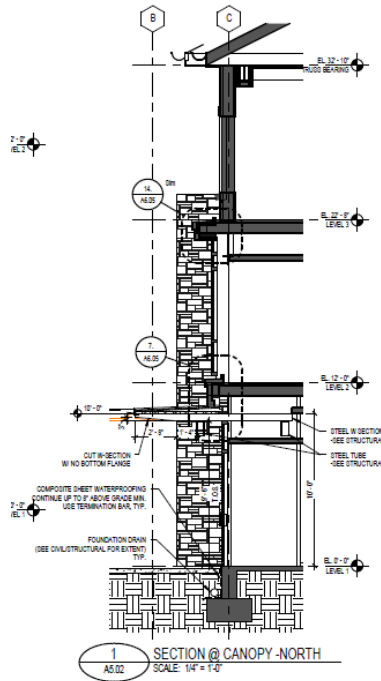


Figure 5-5. Drawing system.

Figure 5-6 shows a block diagram of all materials on the project.

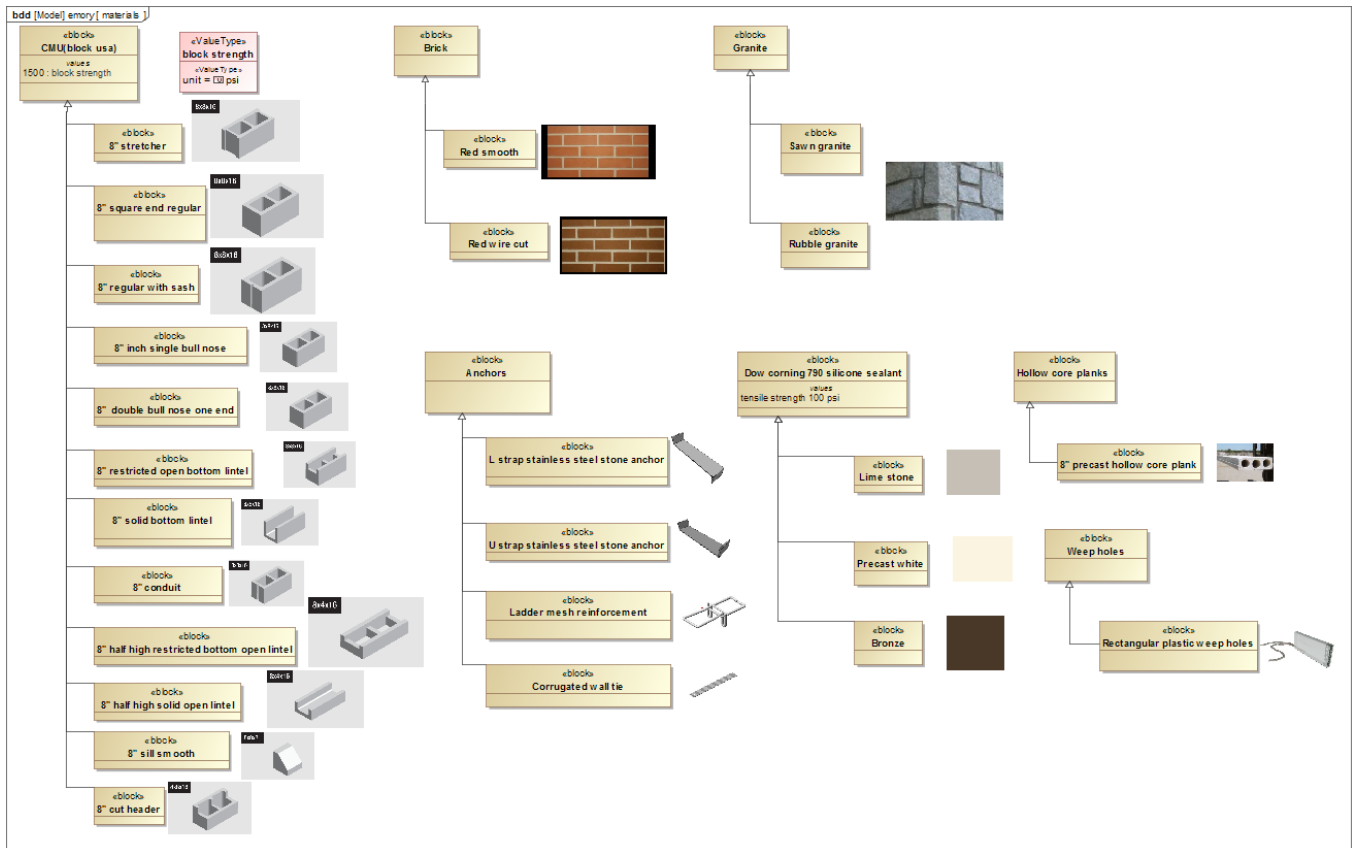


Figure 5-6. Block diagram of masonry scope.

## Stakeholders

Figure 5-7 shows a block diagram of the project stakeholders.

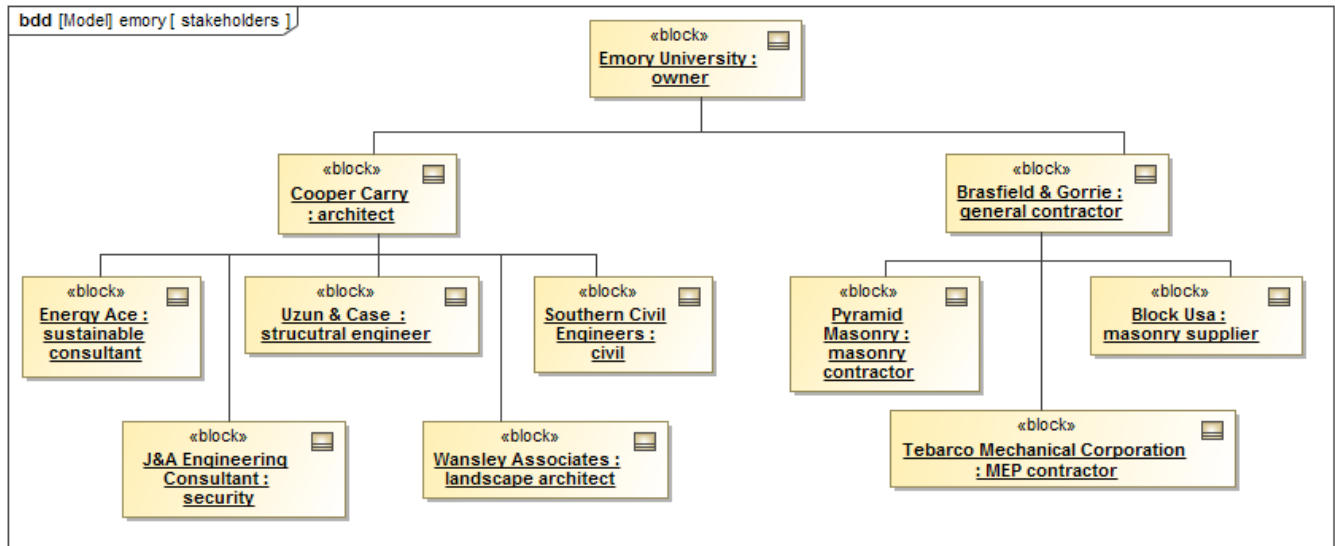


Figure 5-7. Block diagram of project stakeholders.

## Schematic Design Phase

The architect decided to make a conceptual design with the owner's ideas. The conceptual design was made and reviewed by the owner and the architect. Then there was a site visit where the criteria for designing the building were short-listed. The criteria for this building are:

1. The building should match the building across the street
2. The defects in the old building should be corrected
3. The building should be constructed in a short schedule
4. The building should be economical.

After, the architect developed a schematic design based on the criteria, conceptual design and the site visit the architect made. The architect created the schematic design based on the criteria set and they were developed in Revit software. Figure 5-8 shows the beginning of the SysML activity diagram which depicts the schematic design phase.

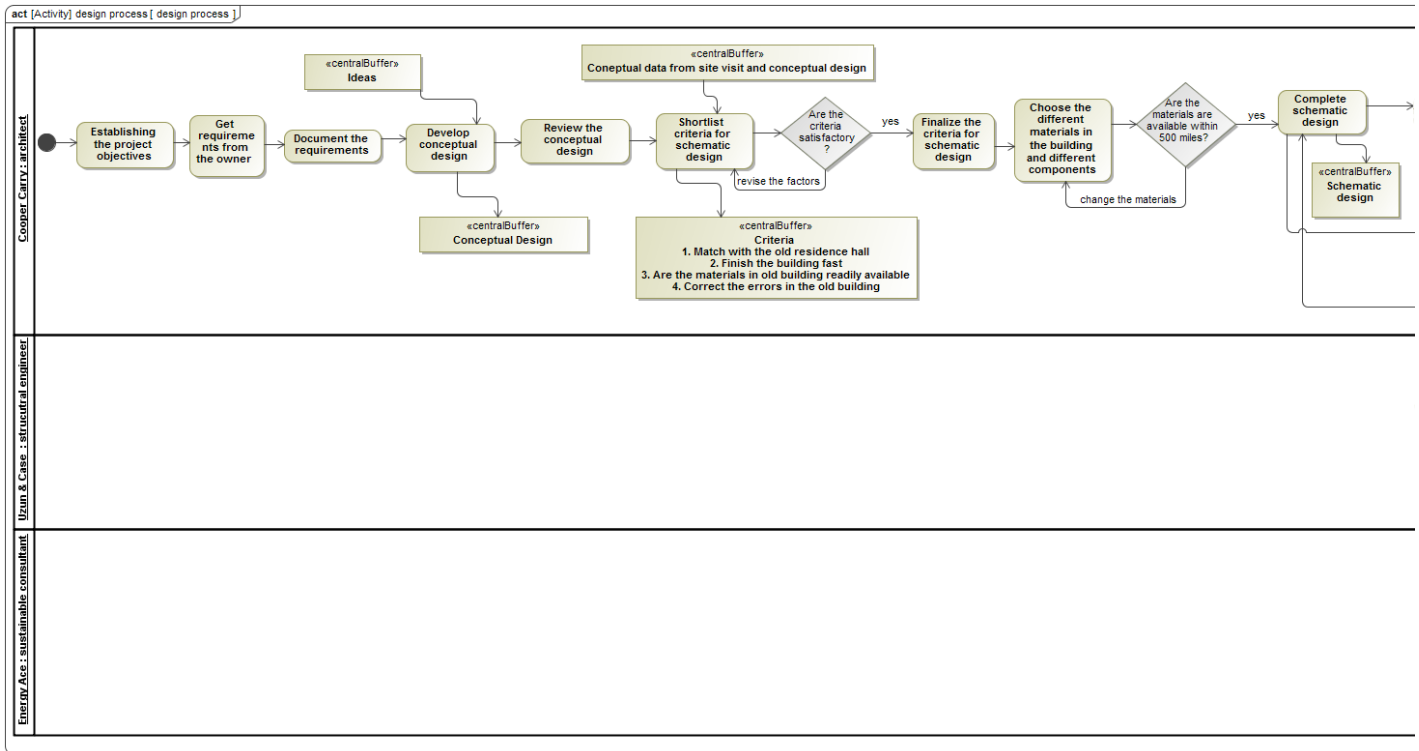


Figure 5-8. Schematic design phase.

## Design Development Phase

The architect then shares the schematic design to the structural engineer, where the model is studied by the structural engineer. The design is then determined to be feasible or not. Any corrections made by the structural engineer is updated in the Revit model and sent to the architect. The architects do a preliminary estimate to make sure that the building is within the budget. If not then they revise some components of the building. The Revit model is also sent to the sustainability consultant to make sure that the building meets the sustainability standards. Figure 5-9 shows the second portion of the diagram outlining this phase.

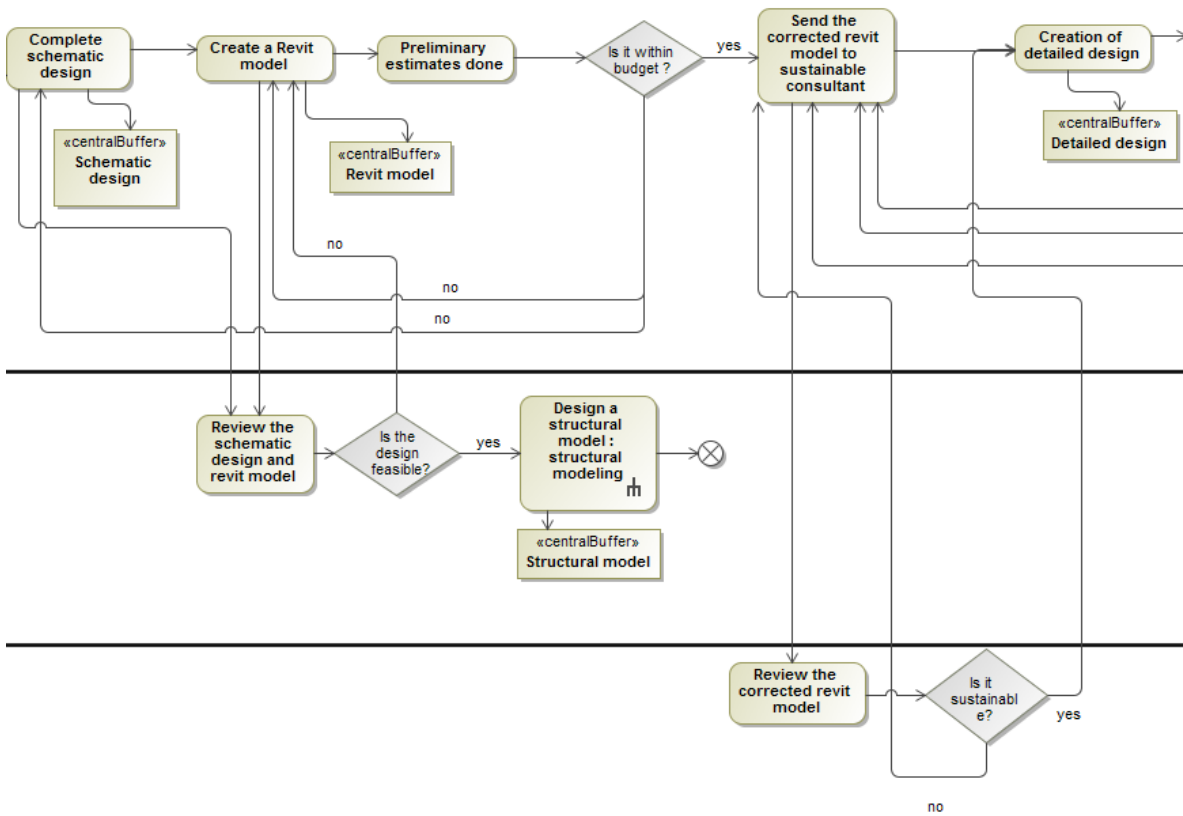


Figure 5-9. Design development phase. Swimlanes are the same as those of Figure 5-8.

### Structural modeling

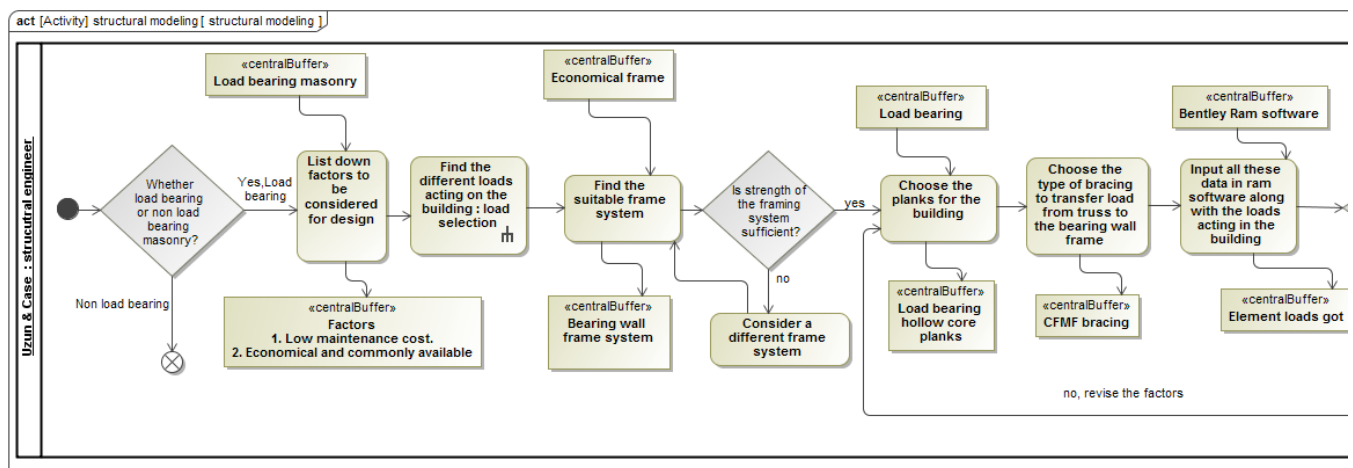


Figure 5-10. Structural modeling: part 1.

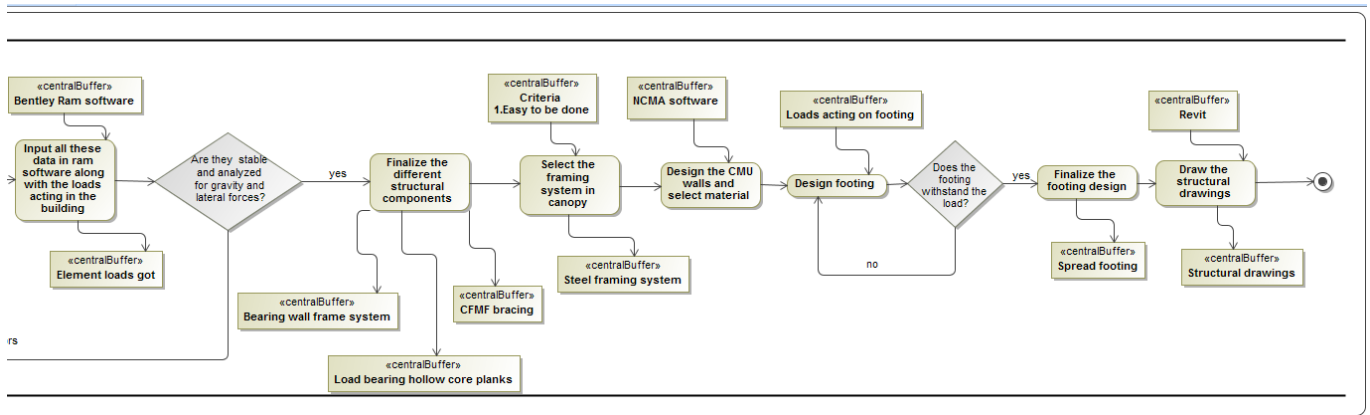


Figure 5-11. Structural modeling: part 2.

The structural engineer first received all of the schematic drawings from the architect and determined whether or not they wanted a load bearing structure. Then, as this building is a load bearing structure, they calculated the loads acting on the building. The loads are calculated based on the building codes and other details, as seen in Figure 5-12.

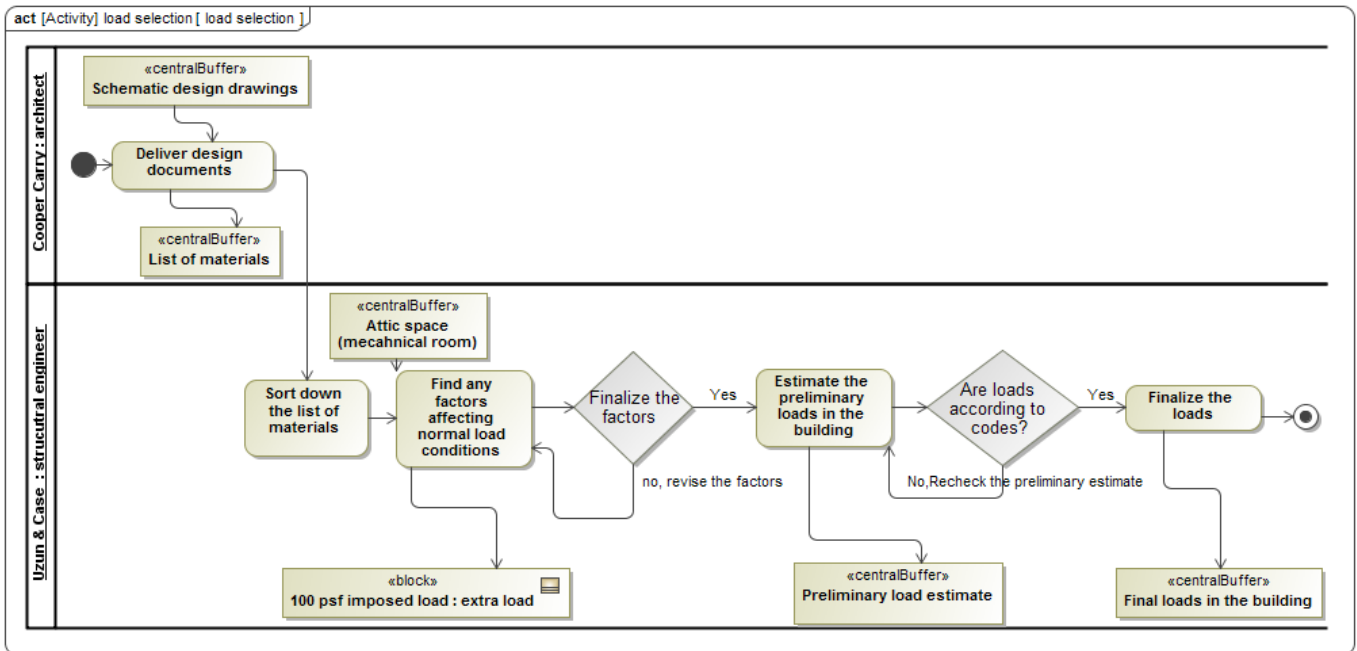


Figure 5-12. Load selection process.

In the Emory Oxford Fleming Hall project, there was a new condition where they had the mechanical room located in the attic space. This added an extra load of 100 psf. Then the live loads of the building were calculated. After calculating the loads acting in the building, they wanted to make the framing system was economical, so they adopted a bearing wall frame system. In addition, they wanted to make sure that the framing system can meet the required loads; it was confirmed that the framing system could withstand all the loads. Next, they chose the planks which need to take the floor loads of the building and they found the planks to be load bearing hollow core planks. After, they wanted be confident the building roof loads are transferred on to the load bearing walls, so they had to use CFMF bracing. The structural design did not need to be

complicated so they chose steel beams to support the planks wherever the planks were not supported by the load bearing walls. These parameters were updated into the Bentley RAM software and were analyzed for lateral and gravity loads. Once this was done, the element loads were received from this software, which is input into the Masonry NCMA software to design the CMU and check them for lateral in plane and out of plane loads. The CMU strength was calculated and the CMU materials and strength was decided. Now the footing was designed to withstand the building loads. The structural drawings were then completed using REVIT.

### Construction Documents Phase

A review of design was then done where the different stakeholders decided whether the design needed to be changed or anything new added in the building. Then the design was refined and reviewed for any ways to reduce waste in the building. If there was any way to reduce the waste in the building, changes were made in the design. Lastly, the building codes were confirmed to have been met while designing the building and documents completed.

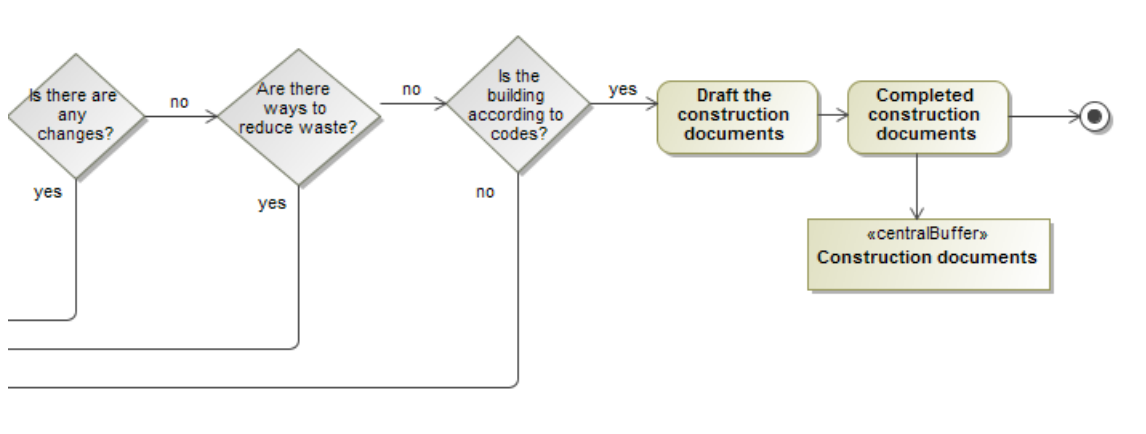


Figure 5-13. Construction documents phase. Taken from the top swimlane of the design phases (schematic design, design development, construction documents).

### Contractor Coordination Phase

#### Procurement Process

The procurement process, which can be seen in Figure 5-14, was started with the architect making a preliminary estimate of the building, where the total materials and quantity takeoff are done.

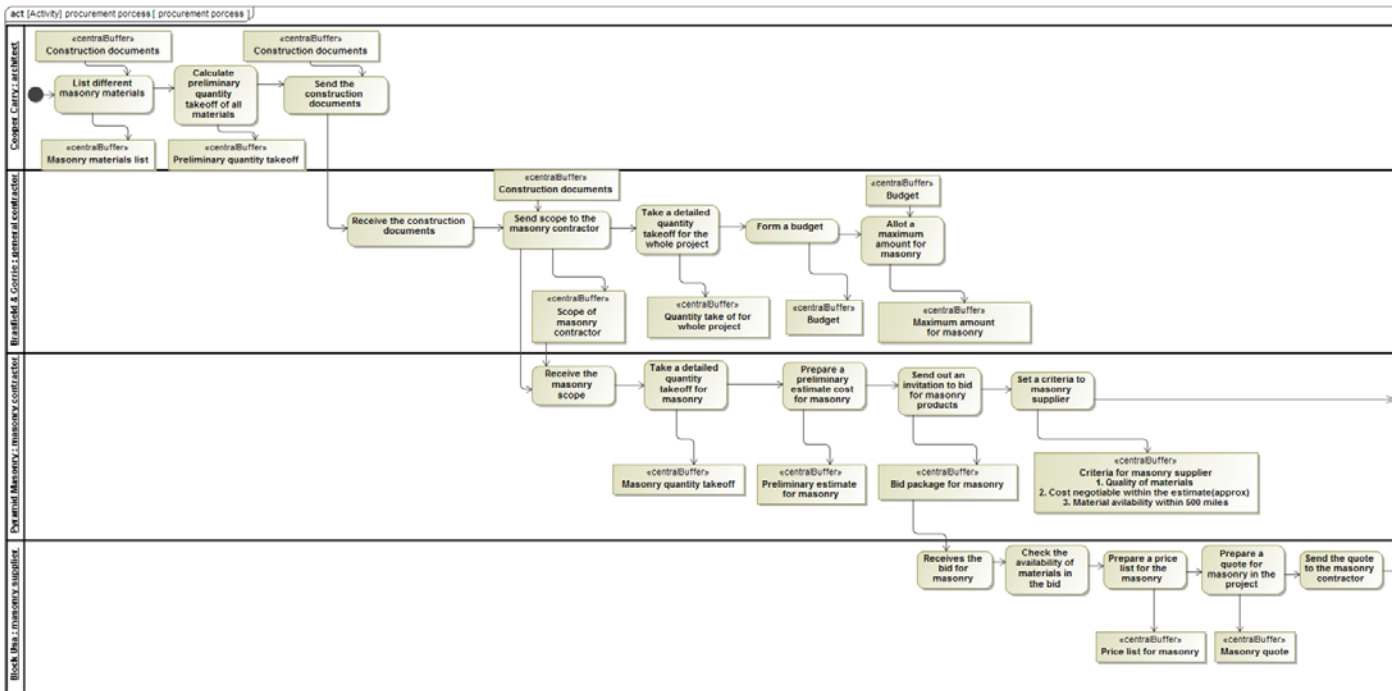


Figure 5-14. Procurement: part 1.

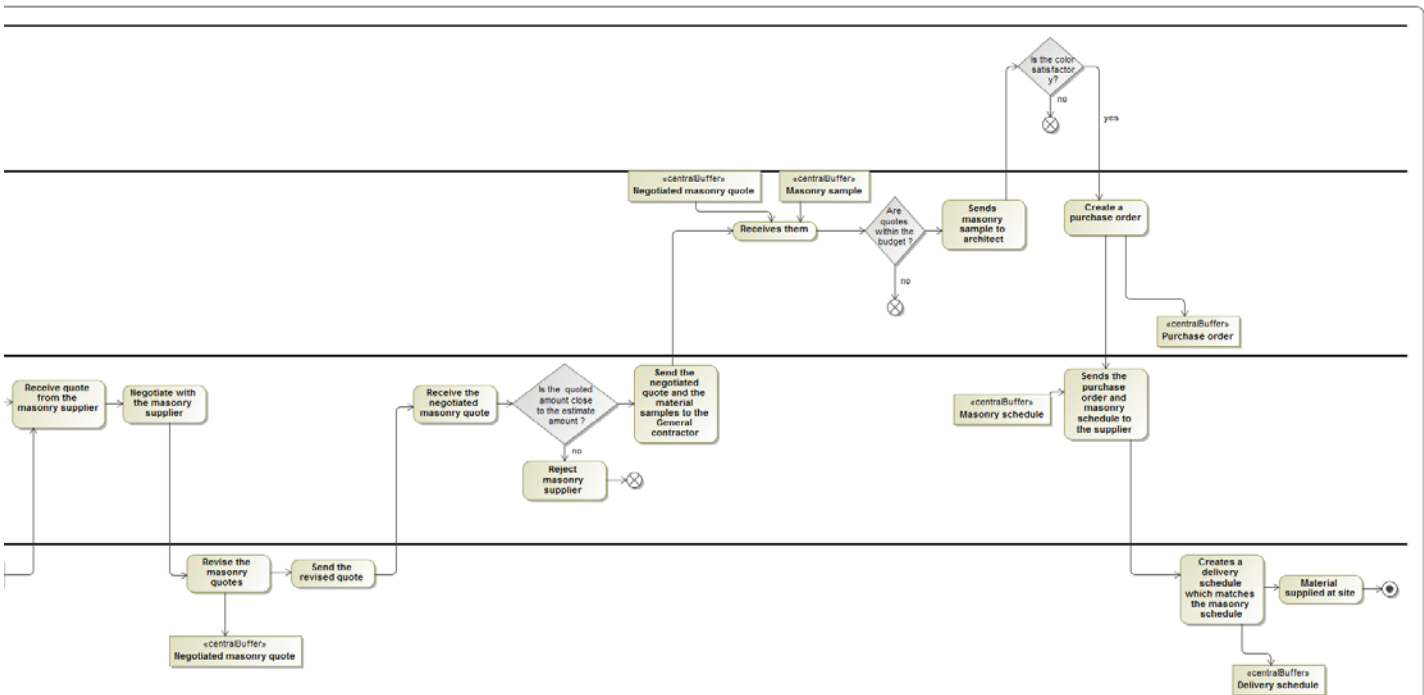


Figure 5-15. Procurement: part 2.

The detailed design was sent to the general contractor where the general contractor studied the design documents and formed a budget for the project. The masonry scope alone was sent to the masonry subcontractor where the masonry contractor took a detail quantity takeoff of the masonry components and completed an estimate for the price of the masonry with assumed rates from old projects. The quantity of the



masonry was then sent to the masonry supplier along with the material specifications. The masonry supplier quoted the rates for the materials along with the estimated time for delivery of each material and sent the price list to the masonry subcontractor, who reviewed the quotes to ensure they were within the budget. Upon budget approval, the materials' proximities were checked to be available within a 500-mile radius. If so, and the masonry materials were satisfactory in specifications, they negotiated with the masonry supplier. The general contractor also had to approve the budget from the supplier selection. Afterwards, the supplier sent some samples to the architect for color verification. After verifying the color to be satisfactory, the purchase order was issued and the masonry schedule was developed. The masonry supplier then formed the delivery schedule, which can match the masonry schedule.

### RFI Process

The RFI process was linear between the masonry contractor, the general contractor and the structural engineer. Figure 5-16 details the RFI process.

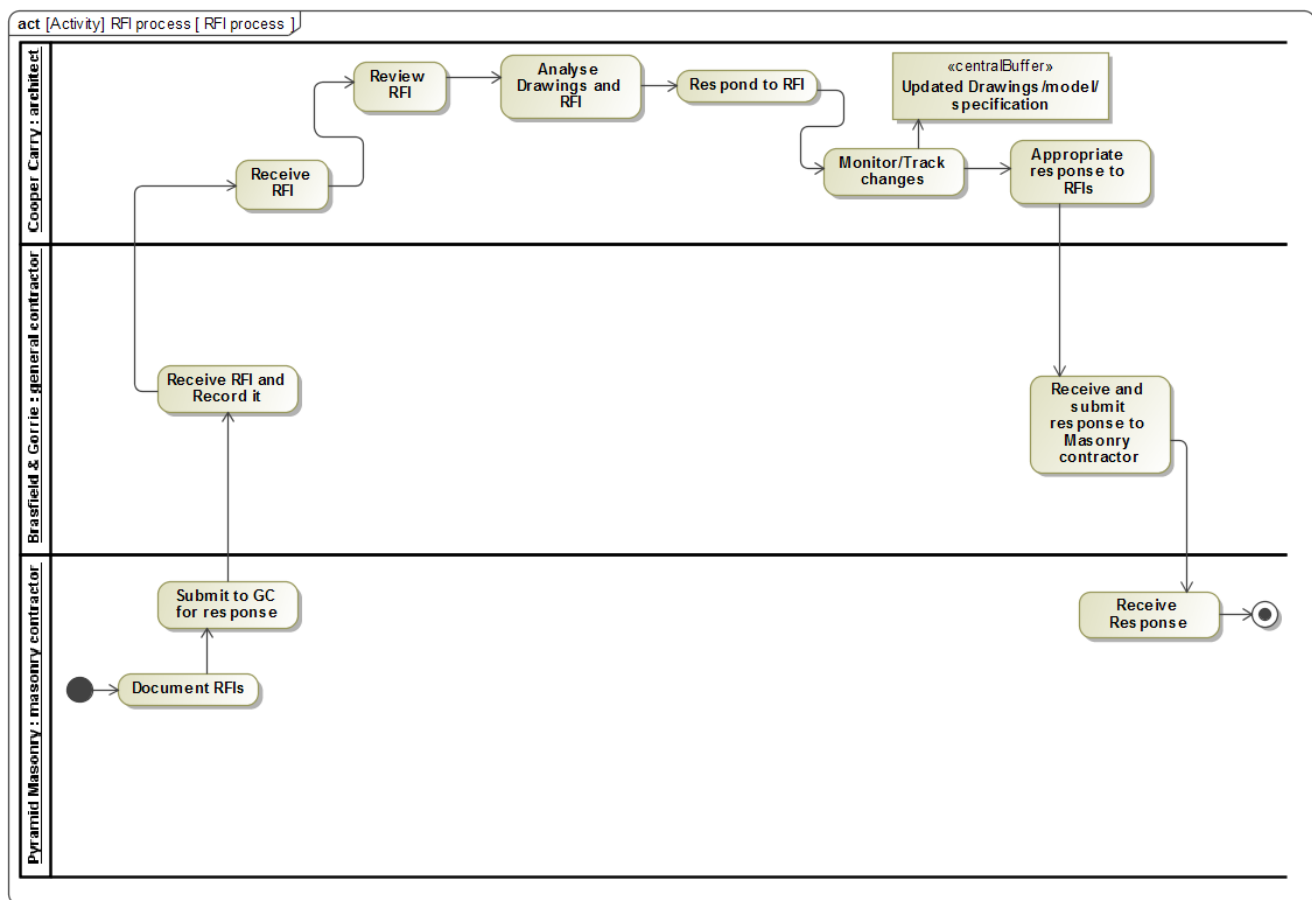


Figure 5-16. RFI process.

### Subcontractor Installation

The CMU installation process was a fairly standard one (see Figure 5-17). Wall heights were determined and scaffolding was placed above five feet to OSHA standards. The CMU laying process can be seen in Figure 5-18. Rebar and spacers were installed, and brick veneer ties were placed over the courses of CMU, after which fasteners and mortar were applied. The damp-proofing process can be seen in Figure 5-19.

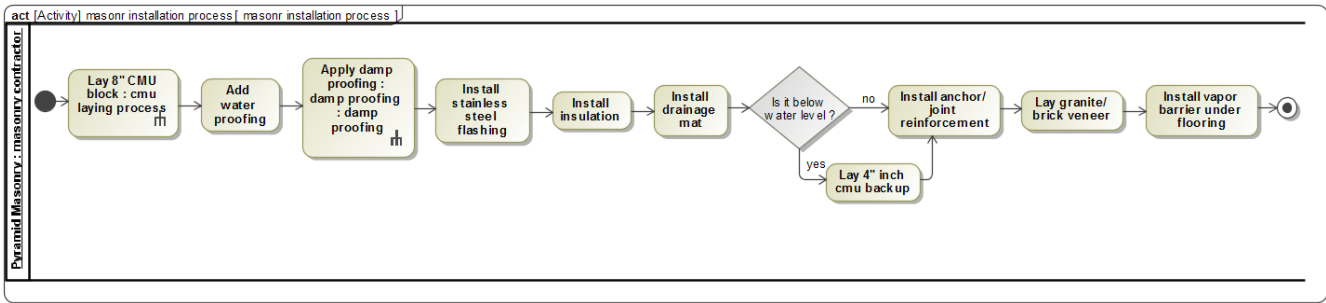


Figure 5-17. Masonry installation process.

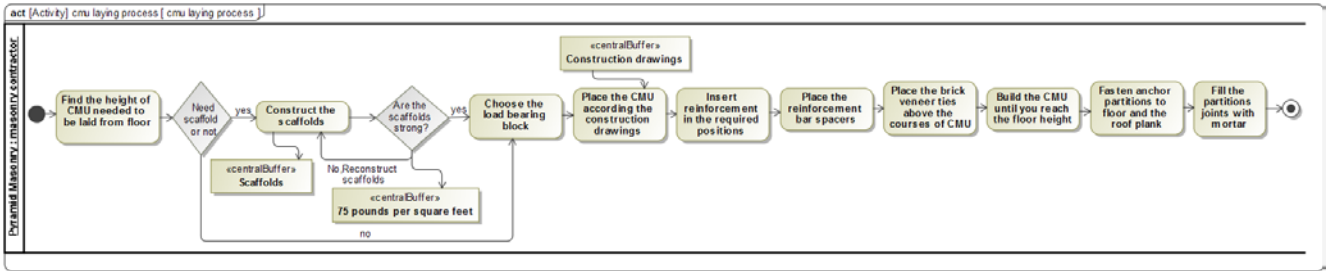


Figure 5-18. Laying the CMU process.

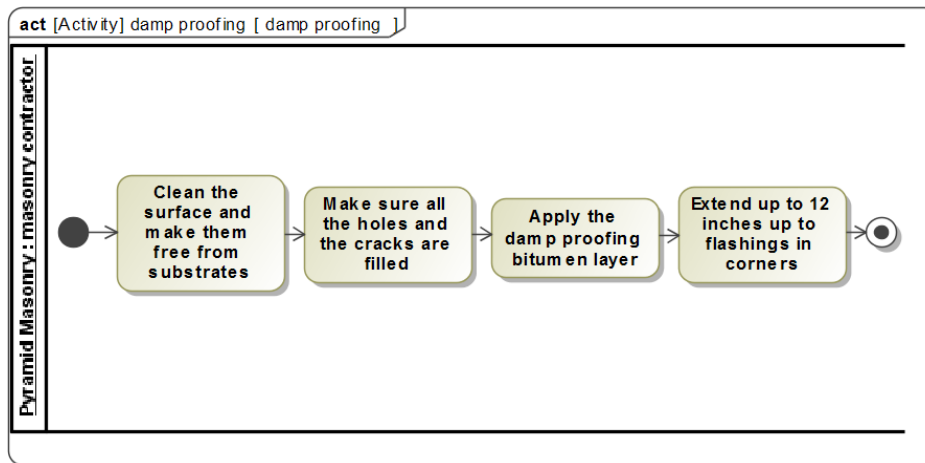


Figure 5-19. Damp-proofing process.

## Future State Processes

### Prefabricated Masonry Walls

The Fleming Hall Project could have greatly benefited from prefabricated masonry walls due to the many issues that were encountered involving weather delays and having to re-cut granite pieces. Each brick panel, whether load bearing or not load bearing, is constructed in a mason contractor’s factory allowing for flexibility in the design allowing for pieces that are more intricate. Usually, brick panel walls are not insulated but they can be. Fleming Hall would have needed to implement prefabricated walls that included insulation. The prefabricated walls could contain RFID tags to assist in tracking the entire process from prefabrication to installation.

## Conclusion

There were a few key aspects that were unique in the design and construction of Fleming Hall. First, multiple inputs during early-stage design led to the selection of load-bearing masonry. Second, the structural engineer felt that the analysis workflow was cumbersome and included a lot of repetitive data input. Third, masonry was constructed in sections to keep the masonry subcontractor busy and ease coordination with the precast plank installer. Lastly, granite pieces were cut off site but this led to some rework needing to be done, which shows that the workflow could use some improvement. Some other issues that arose were the difficulty of coordination with masonry systems, due to the construction of another ongoing project nearby which heavily pulled on the labor force. There were several lessons learned from the mockups (see Figure 5-20), which could provide insights to virtual mockups and BIM systems.

MATERIAL	ITEM
Brick	Confirmed revised dental brick detail (see 4/A5.01)
Cell Vent	Align cell vents at outside edges of window and have one centered in window opening
Cell Vent	Cell vents will be used on the project. Color chosen from samples was "dirty yellow"
Granite Banding	Granite pier to storefront condition: Decision made to stop banding short of storefront and run granite rubble instead so the vertical joint will be uniform along the entire edge of storefront. Decision also made to do this at granite pier to stucco conditions.
Granite Banding	Outward facing piece to be full width of face, have the mortar joint between pieces be on the side face(s) similar to a brick return
Granite Banding	Mortar joint directly above and below the granite band should be 1/2"-3/4" maximum
Granite Banding	Directly below granite cap - drawings show granite banding. Delete this band and have granite rubble extend directly under cap.
Granite Cap	Material confirmed. Team would like vertical height to be larger (6") and keep cap edges flush with rubble below.
Granite Cap	Vertical thickness of cap to be 6" and keep cap edges flush with rubble below
Granite Rubble	Bottom mortar joint of granite piers should be raked so carpet can slide in and not be cut
Granite Rubble	Avoid thin (width) pieces of rubble.
Granite Rubble	Maximum horizontal joint at non-band conditions to be 2/3 of the face

Figure 5-20. Lessons learned from mockups.

## 6. Drew Charter School, Senior Academy

### Background

This 205,800-square-foot, two-story school in the East Lake community currently serves around 1000 students in grades Pre-K to 9<sup>th</sup>. Completed in July 2014, this LEED Gold Certified building includes seven project learning labs, seven state-of-the-art science labs, a 500-seat performing arts center, and two gymnasiums (see Figure 6-1).



Figure 6-1. Drew Charter School.

### Masonry Scope

The school contains two major masonry materials: fieldstone and cast stone. Figure 6-2 below illustrates the location of the masonry details with the fieldstone in green and the cast stone in blue. The fieldstone detail is predominately located on the south face of the building, while the majority of the cast stone is present on the north face where the two gymnasiums and auditorium are located. Neither of the masonry components of this project are load bearing.

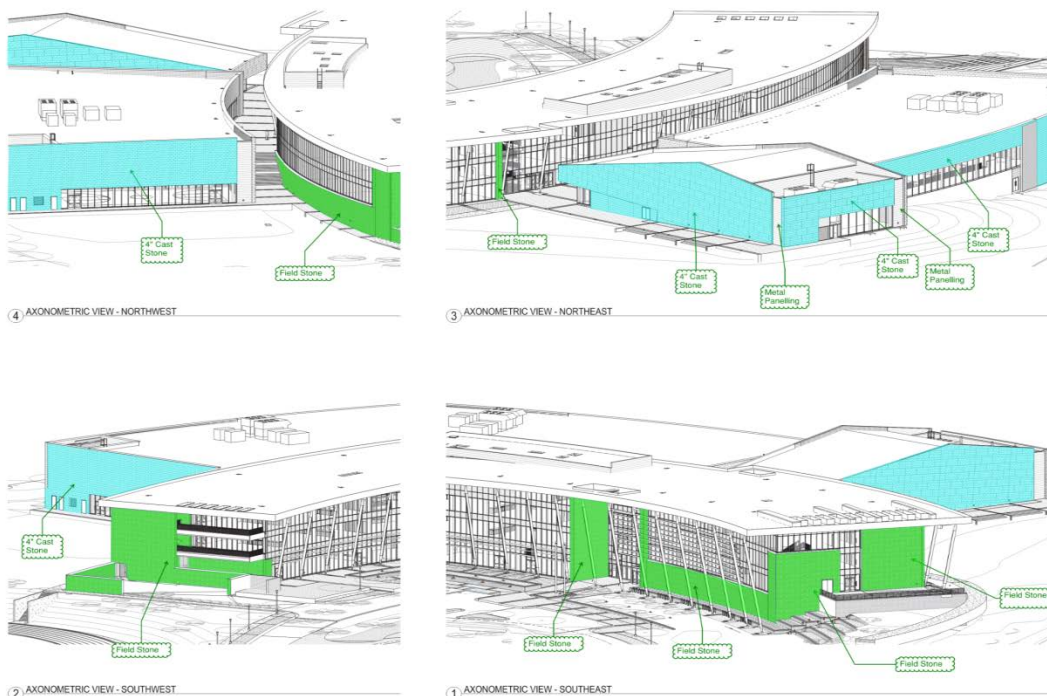


Figure 6-2. Location breakdown of masonry materials.

According to the architect, Perkins + Will, these two masonry materials were chosen in efforts to blend with the surrounding residential neighborhood in the East Lake community. The fieldstone provides a natural and weathered look while the cast stone provides a wood-like appearance that fits with the residential style. The home in Figure 6-3 displays these common features that the design team used to make the school fit in with the adjacent neighborhood.



Figure 6-3. Home in the East Lake community.

### *Stakeholders*

The major project stakeholders for the construction of the Drew Charter School are as follows (see Figure 6-4):

- Architect: Perkins + Will
- General Contractor: JE Dunn Construction
- Structural Engineer: Uzun & Case
- MEP/FP Engineer: Newcomb and Boyd
- Civil Engineer: Pharr Engineering
- Mason Contractor: Cornerstone Masonry
- Field Stone Supplier: Weathered Tennessee Fieldstone
- Cast Stone Supplier: Corbelstone, Inc.

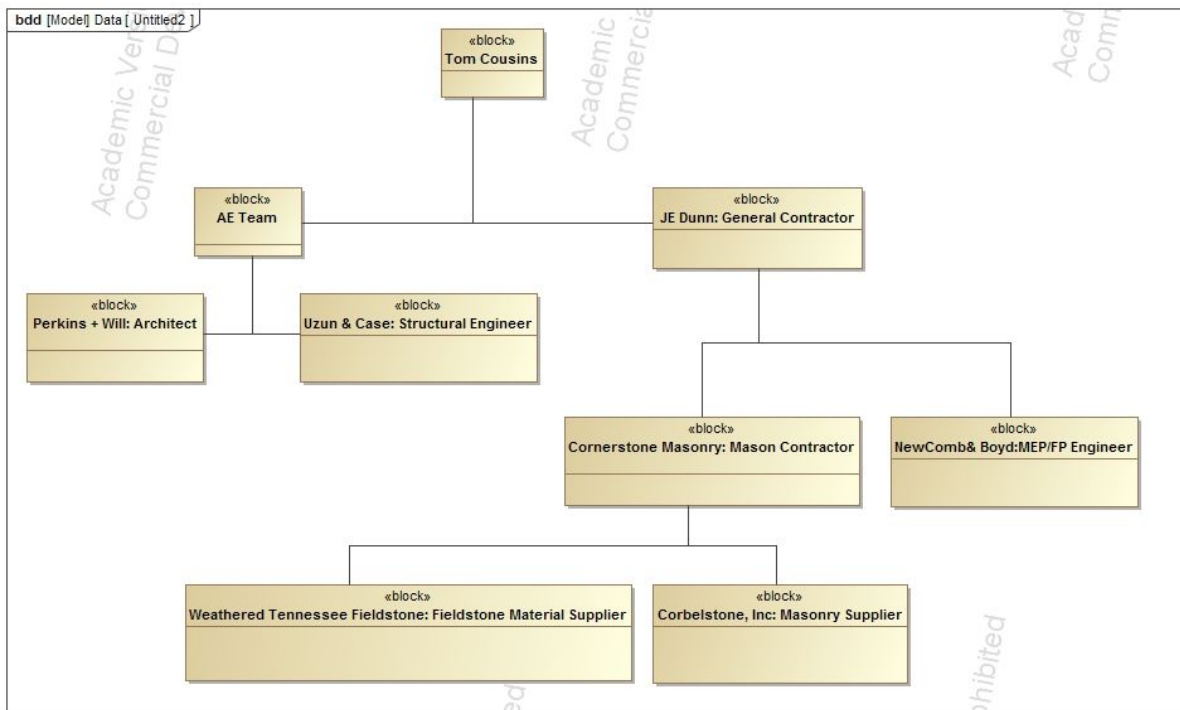


Figure 6-4. Stakeholder SysML diagram.

### Schematic Design Phase – Future State

This project team proposed a future state for the schematic design phase. They propose the role of computer software in selecting ideal masonry subcontractors. This tool would be most applicable in an IPD project where architects and masonry subcontractors would have more potential interaction before construction (see Figures 6-5 and 6-6).

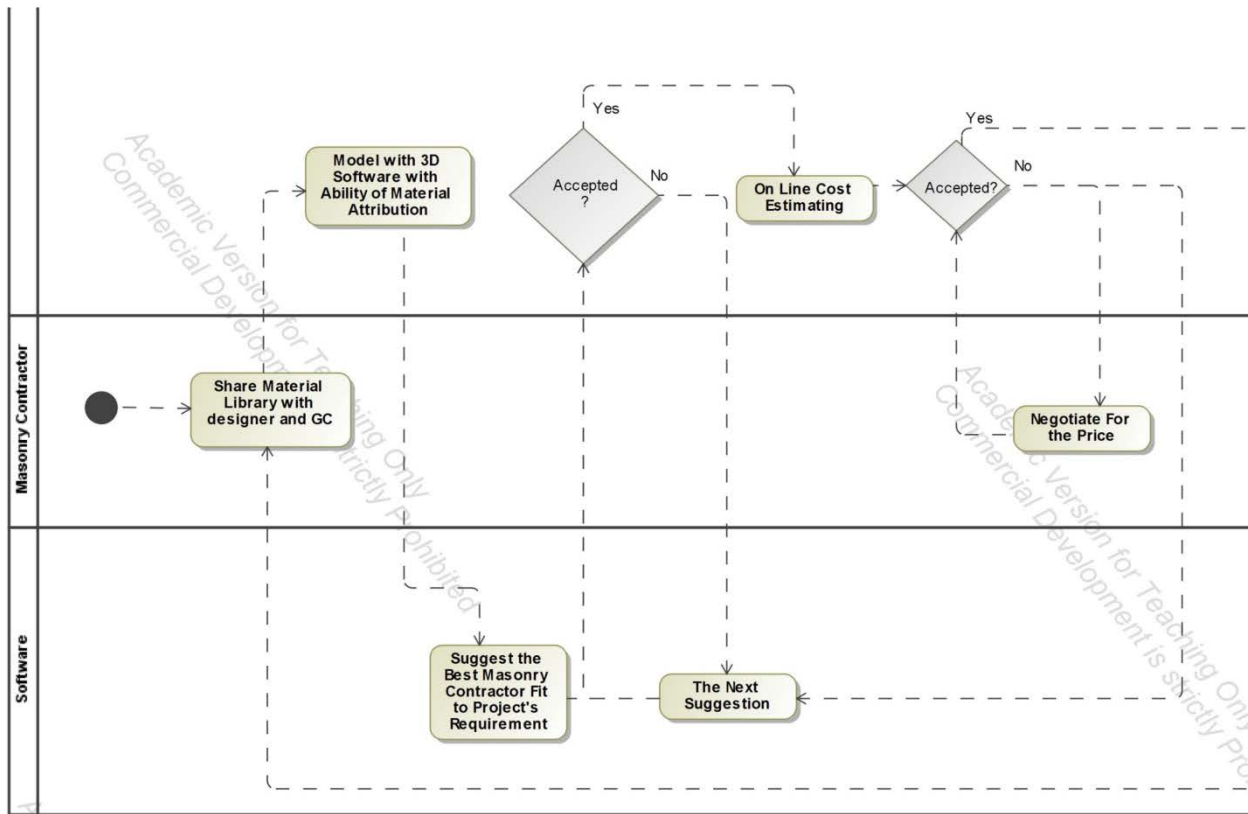


Figure 6-5. Future state of schematic design: part 1.

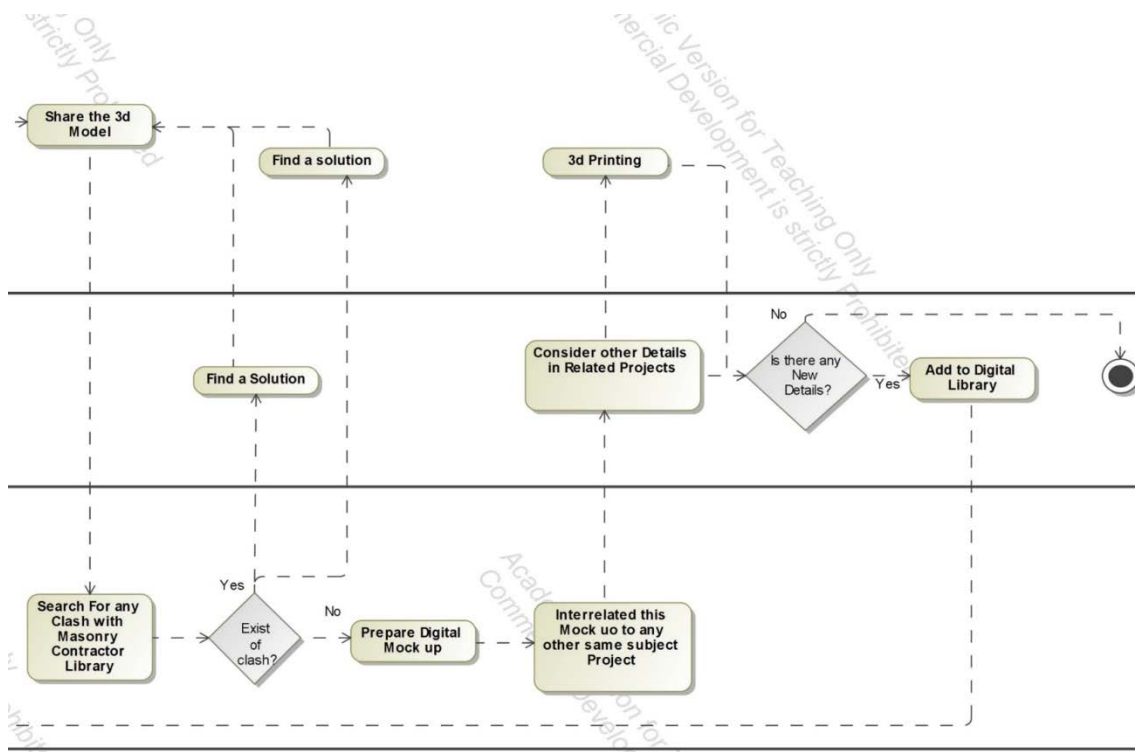


Figure 6-6. Future state of schematic design: part 2.

## Design Development Phase

A design development process is typically led by architect, aided by structural engineer and related contractors (general contractor, masonry contractor and so on). The process typically consists of two different iteration processes which make the design development slower. Especially when the design is not approved by the contractors, the whole process shall be repeated as an inefficient manner (see Figure 6-7).

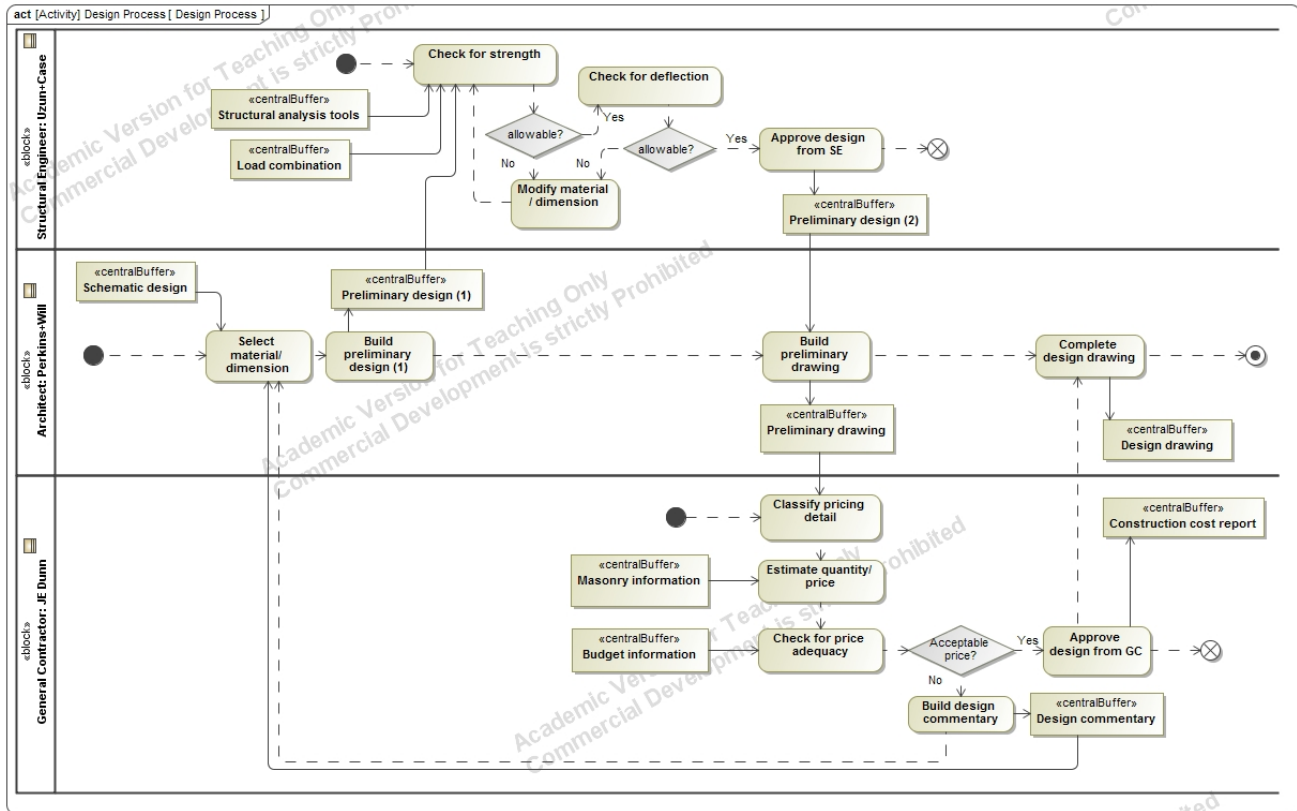


Figure 6-7. Current state of design development phase.

The future state of design development would allow for quicker and fuller communication among stakeholders, so that various processes, such as an RFI would only take a fraction of the current time. This could also reduce the number of errors and coordination issues, further saving time, money, and other resources (see Figure 6-8).



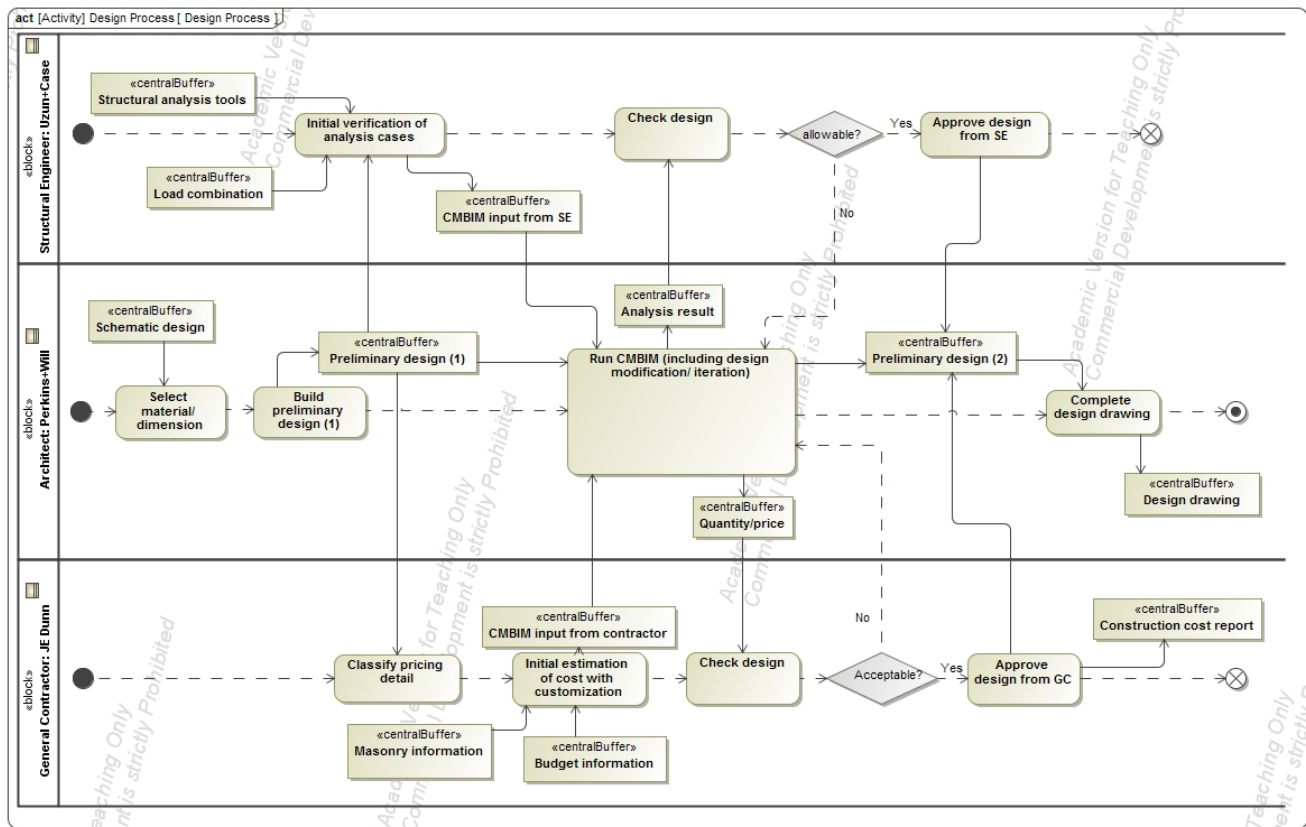


Figure 6-8. Future state of design development phase.

### Subcontractor Installation Phase

In the fieldstone installation process, each rock must be chipped to fit a certain size and shape so that it fits perfectly adjacent to the surrounding stones and satisfies the determined pattern. This is a detail intensive and repetitive process that involves a great deal of coordination between masons, laborers, and stone cutters. Mike Turner of Cornerstone Masonry explained that he provides a 1.5 : 1 laborer/mason ratio for a project of this caliber in order to keep the process moving forward and prepare the appropriate stones. The average trained stone mason lays up to 40 sq. ft. per day. Figure 6-9 illustrates a linear overview of the major activities of the mason contractor (Cornerstone Masonry) while overseeing the installation of the field stone.

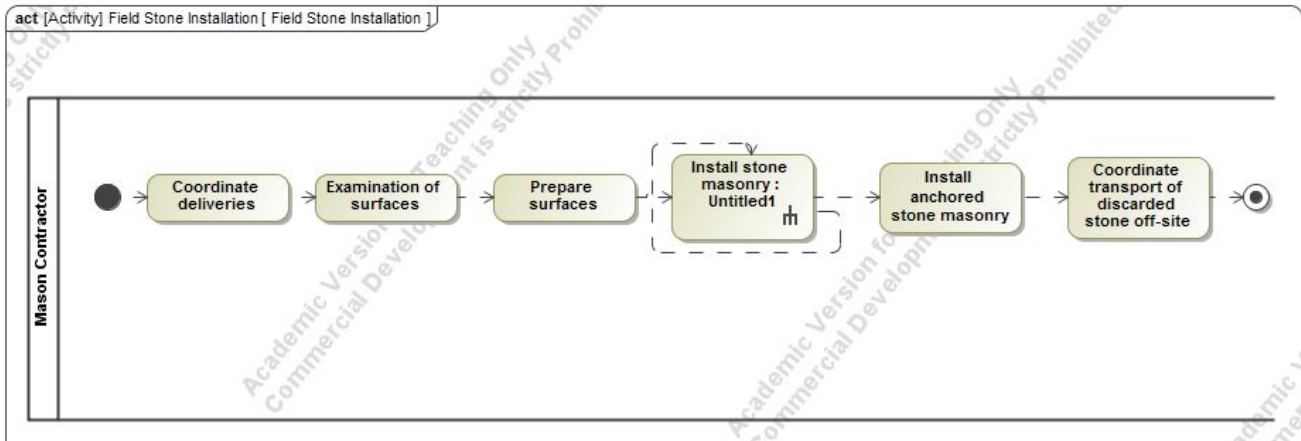


Figure 6-9. Fieldstone installation.

The installation is actually a densely repetitive process; therefore the “Install stone masonry” activity is structured to demonstrate the repetitive nature of this detail and further breakdown the installation process (see Figure 6-10).

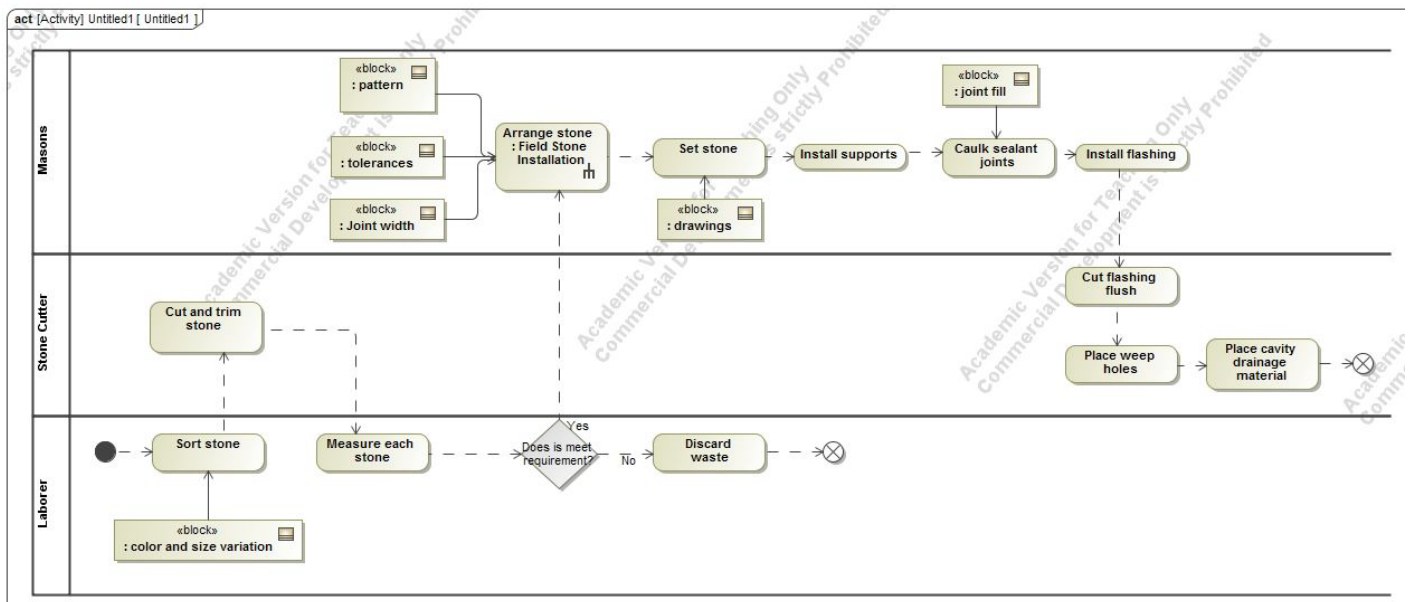


Figure 6-10. Install stone masonry.

The two Block Diagrams below (Figures 6-11 and 6-12) represent the necessary inputs for the activity diagram above, based on the details in the project specifications.

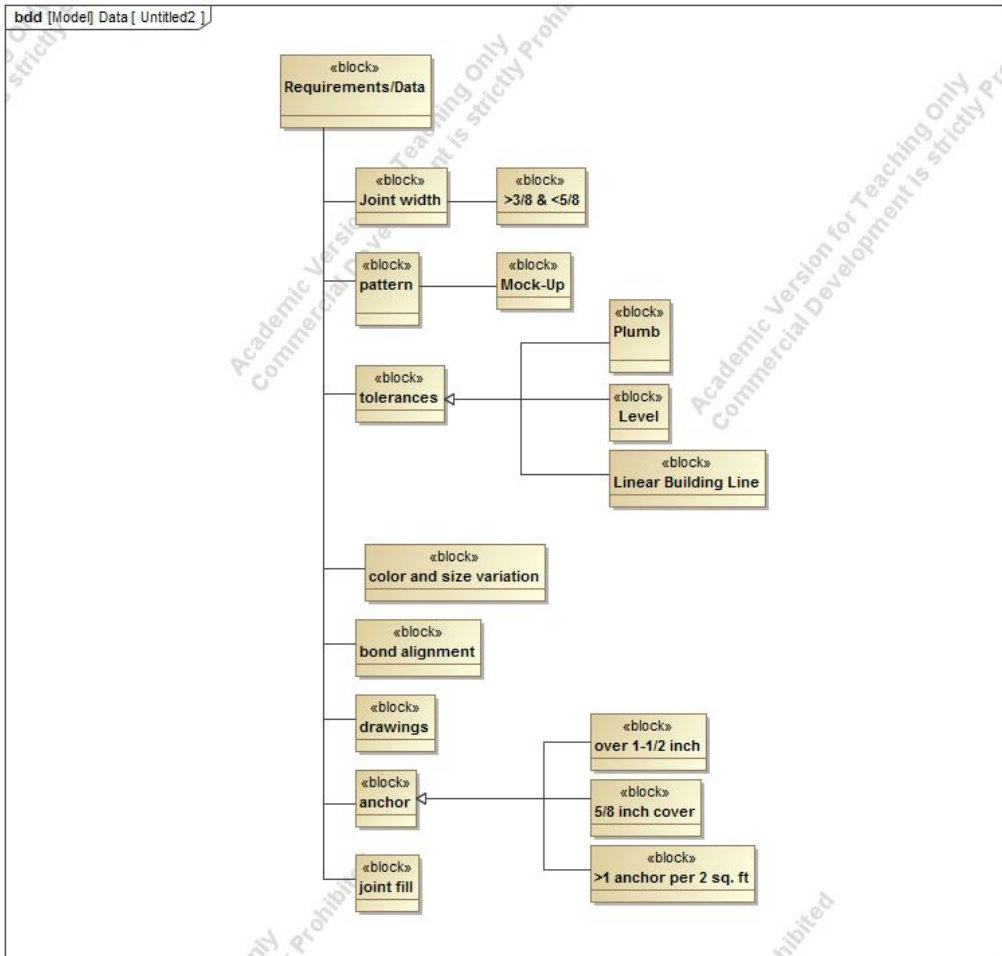


Figure 6-11. Data inputs and requirements for fieldstone.

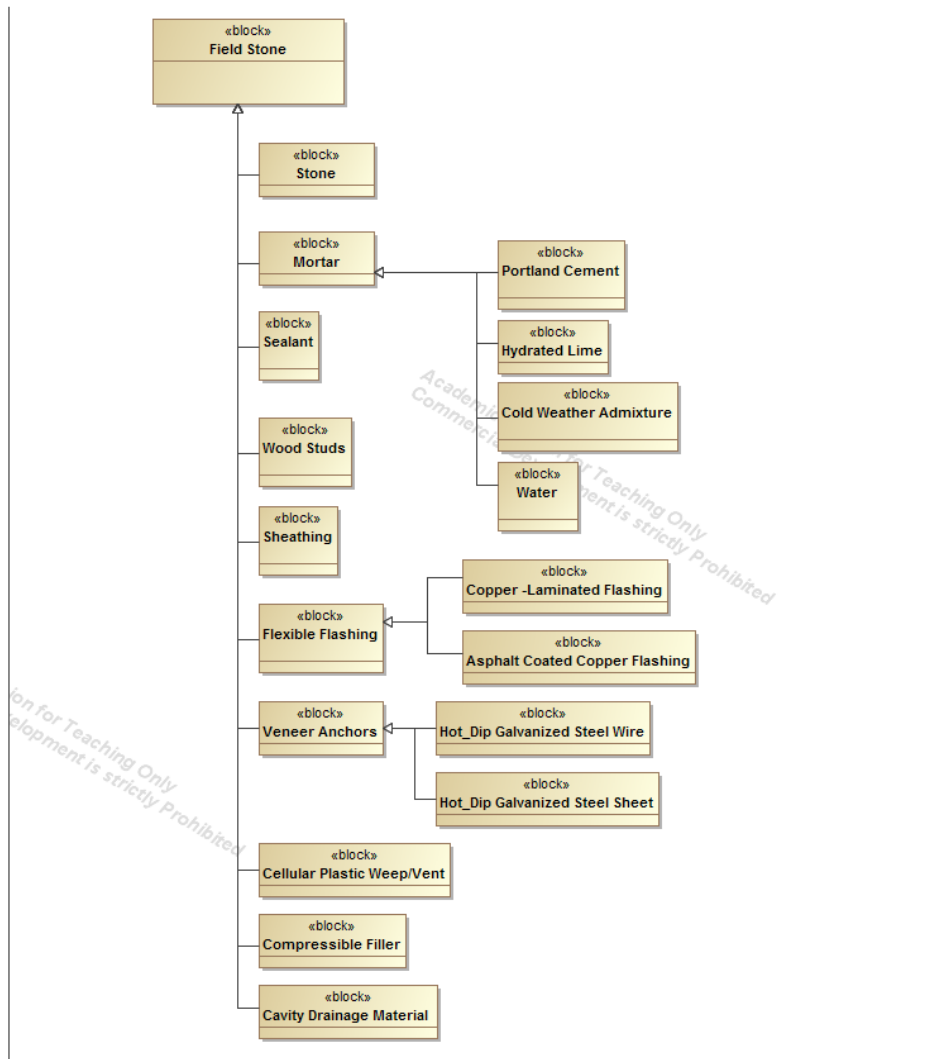


Figure 6-12. Fieldstone materials.

### Potential Future State

After discovering that the discard rate for the fieldstone required in this project was 12% (compared to the normal rate of around 7%) waste reduction proved to be a natural topic for future state discussion. A possible future state for this fieldstone installation process includes the addition of an automated approach of chipping and sorting the stone off-site in order to pre-generate the necessary pieces for installation. Instead of human labor, this approach would involve design computing to produce the stones required by the pattern while still maintaining the desired natural look. In addition, a “best practice” approach involving bar coding each individual stone so that the masons know exactly what they have on-site would help speed up/simplify the actual installation process at the job site. By pre-generating the stone off-site, the frequency for deliveries would decrease and the masons would be guaranteed that the required stones were available throughout the process. Overall, this would reduce waste, costs, and time. Figure 6-13 shows an updated activity diagram involving this potential improvement.

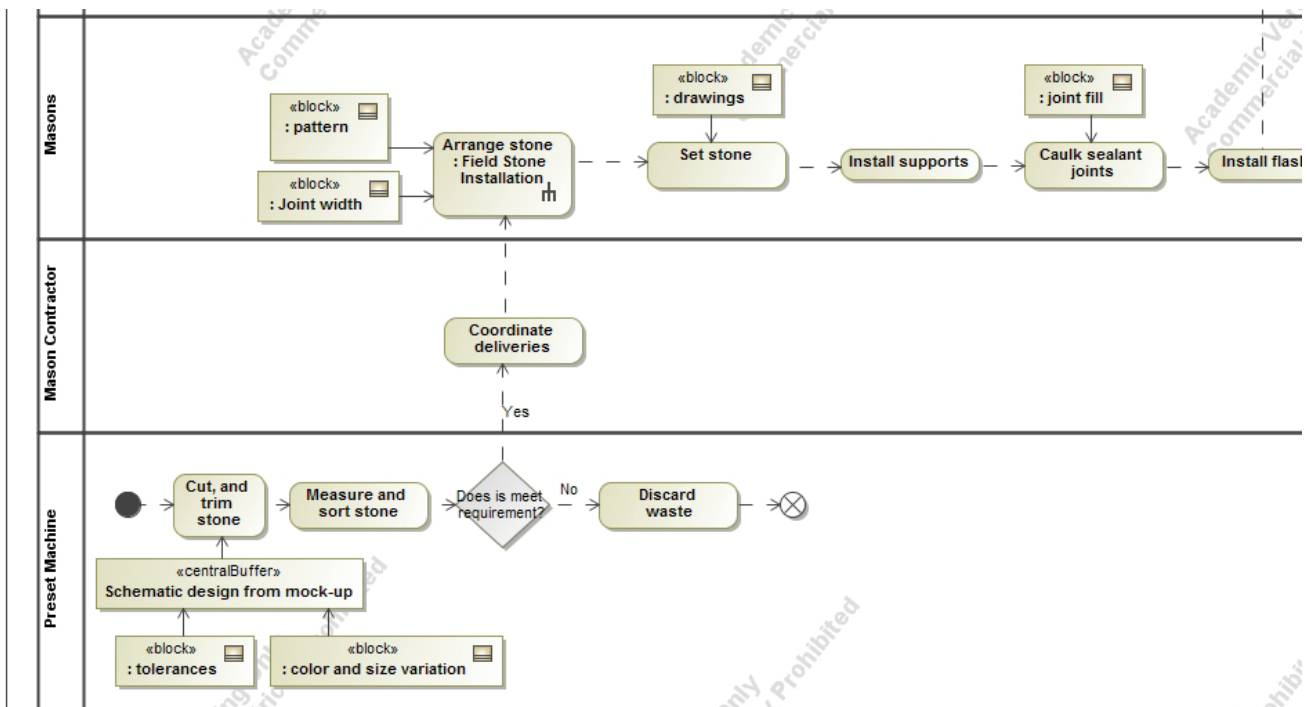


Figure 6-13. Future state of fieldstone installation.

### Cast Stone Workflow

One of more interesting cases of masonry was the cast stone construction on the auditorium. Due to the heavy and brittle nature of cast stone, the material must be handled and installed carefully and is not suitable for load-bearing purposes. To make things more interesting, the architect called for a large cantilevered and angled structure to be made of cast stone (see Figure 6-14).



Figure 6-14. Cast stone installation on auditorium.

Originally, the schematic design plan called for a 4' x 8' block coursing for the wall. However, in design development, after consideration of pricing, logistics, and constructability (one worker can carry only one

block), at the request of the subcontractor, the plan now used a 4x4 coursing of 1' x 2' blocks to mimic the 4' x 8' appearance (see Figure 6-15).



Figure 6-15. Cast stone block modification.

Furthermore, several other factors, such as the angling and cantilever, required further customization and modification for installation (see Figure 6-16).



Figure 6-16. Cast stone features.

## Conclusion

The following is a list of some key points from this case study:

- Drew Charter was originally planned as a school for 10-12th grades but it was changed into 7-12th grades' school - which means the size of the building was increased at schematic design state.
- Four architect firms were asked to build a preliminary design of Drew Charter and competed with given seed money from Owner. Perkins and Will was selected.
- One of the main design concepts was "fitting with neighbor residential area around", so a friendly/warm feeling of masonry texture/material was selected.

- Approximately \$20 per square foot for brick/cast-stone and \$40-50 per square foot for fieldstone. Average cost on Masonry (including construction cost) was approximately \$18-25 per square foot.
- Because of the budget issue, selecting masonry material and size of block were done with discussions among related stakeholders (including architect and masonry manufacturer)
- Cast stone is heavy material due to its high water-content. Initially, 8'x12' size was designed but was changed into 1'x2' size (4" thickness) so that one worker can carry one cast-stone block.
- A design drawing (by Perkins + Will) always came first and a cost estimation (by contractors) followed later. After receiving architect's design, contractors reported the price of material/construction.

## 7. Woodward Academy, Jane Woodruff Hall Humanities Building

### Background



Figure 7-1. Woodruff Hall Humanities Building.

The Woodward Academy is a private school providing education for students from Pre-kindergarten to 12th grade. It is the 3rd largest school in the United States and the largest private school in the continental United States. The school was founded in 1900 and was originally known as Georgia Military Academy. It is located at 1662 Rugby Ave, College Park GA-30337 close to the Atlanta's airport. This school has a long history associated with it and since most buildings were made using masonry systems, the buildings on this campus even today follow the tradition and have masonry finishes. The projected increase in student population led to the birth of this project. The building on focus is the new Jane Woodruff Hall building which mainly houses classes of language and social sciences (see Figure 7-1). The architects on this project were Perkins+Will. They have vast experience in designing schools and have a successful portfolio of projects of similar size and type, which is the primary reason for them to be chosen. The general contractors on record are JE Dunn contractors. The building has been designed for certification with LEED and currently (during the time the report was formulated) the process is being carried out. The total construction cost of the project was \$26.2 million and was completed within 14 months.

### *Masonry Scope*

The masonry selection was oriented by materials of the previous building that existed on site, the Founder's Hall, as well as the other buildings that are present on the school's complex (see Figure 7-2). As the architecture team was investigating and interpreting the documents of the Founder's Hall they discovered that the brick color utilized on the building was named Woodward Blend. That same was selected for the new building since it was the same brick color present on the oldest buildings in the school. Though, at the point of the material selection the architecture team verified with the masonry supplier that the actual brick available under that same name didn't match the colors pattern of the bricks used in the oldest buildings even though they were provide by the same masonry supplier. The main reason for the color discrepancies were the different clay used to manufacture the Woodward brick now and the one used fifty years ago. That way, collaborative meetings were organized between the masonry supplier, the architecture team and the owner representatives in order to choose the brick that met the expectations. The other masonry materials used in the project were cast stone units along the arches, parapet walls and the window coverings and Concrete Masonry Units (CMU). The CMU was used mainly to support the Brick veneer at the base of the building and cast stone was used to replicate the look of the founder's hall building. According to the architect, the entire selection process involved the masonry supplier and the masonry subcontractor.



Figure 7-2. Masonry structures on campus.



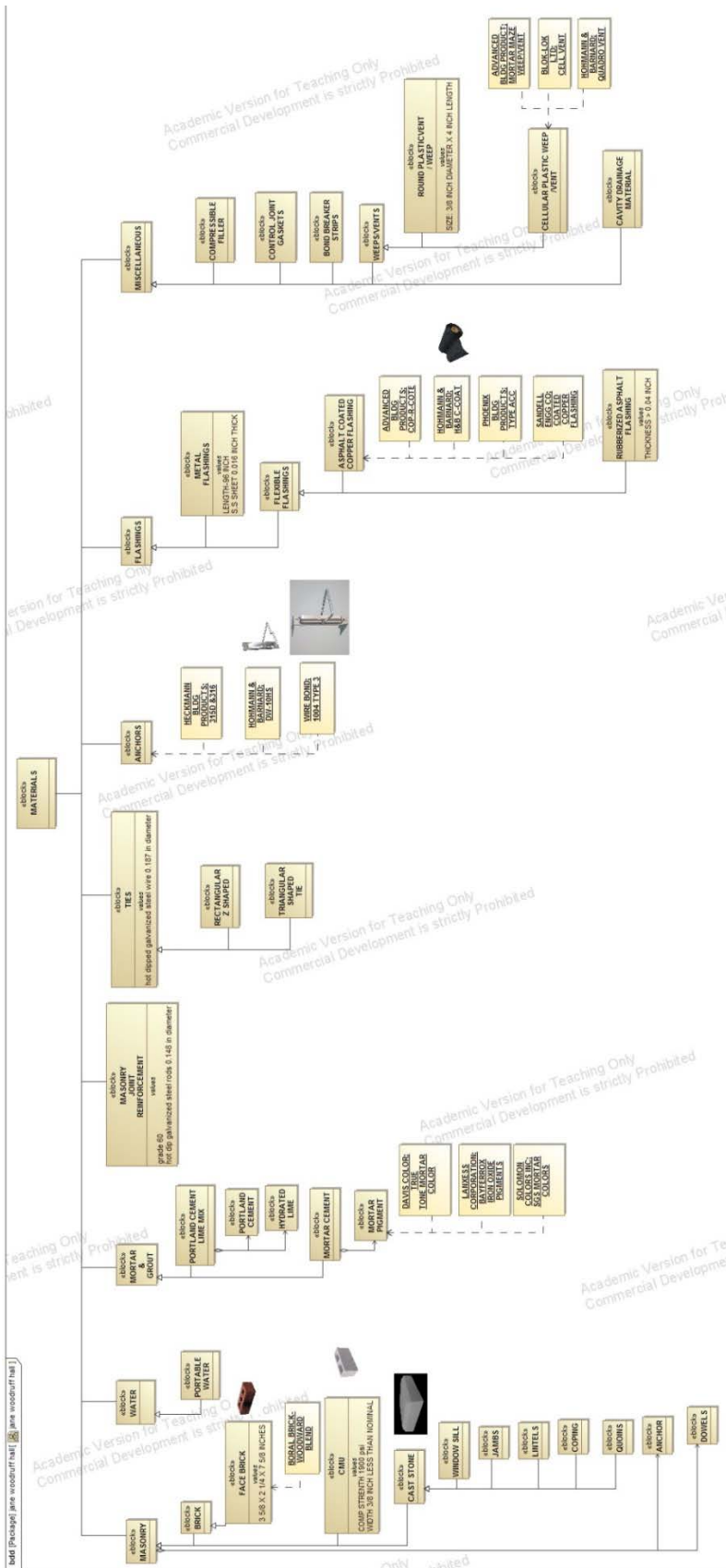


Figure 7-3. Materials diagram.

## Stakeholders

The owner of the project is Woodward Academy. The teams that made the project a success include:

- Je Dunn - General Contractor
- Conway & Owen – MEP Engineers
- Uzun & Case – Structural Engineers
- Cornerstone masonry – Masonry contractor
- Cunningham brick company – Brick suppliers
- Corbel stone – Cast stone suppliers

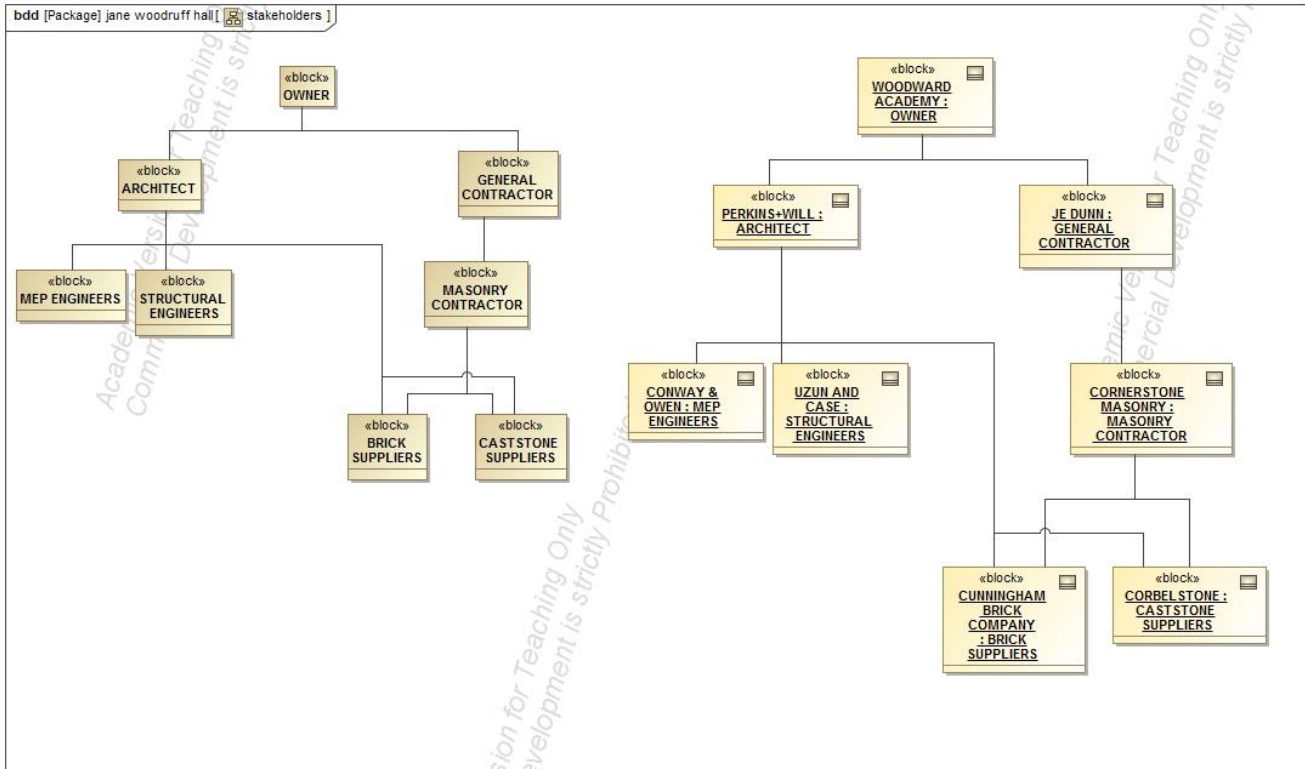


Figure 7-4. Stakeholder diagram.

## Schematic Design Phase

### Material Selection

During the material selection process, the architect looks for the supplier's brick options and the quality are reviewed. Cunningham is the brick supplier for this project.

Compliance attributes: For this project the attributes such as size, color, type and quality of the bricks are being weighed. Then the suppliers location is been evaluated for the proximity and logistic issues. The location of the supplier is checked for within 500 miles and the samples are viewed by the architect to make sure if it is of required quality and quantity.

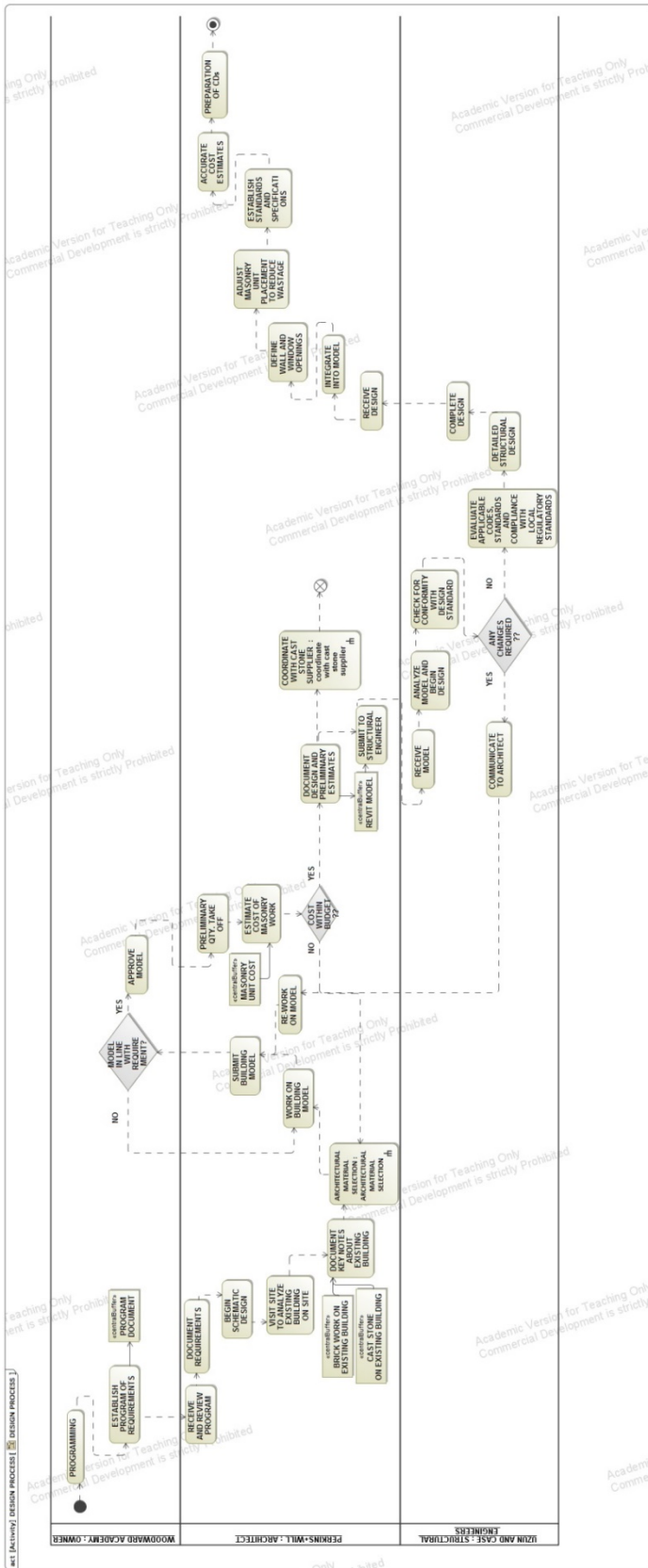


Figure 7-5. Design process.

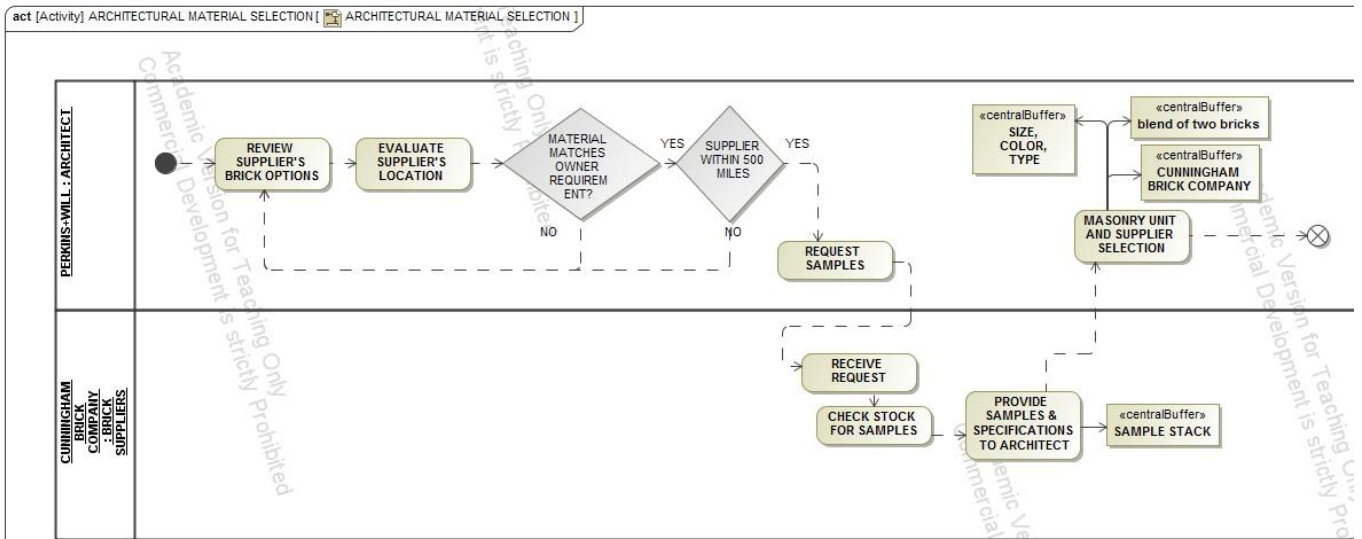


Figure 7-6. Architectural material selection.

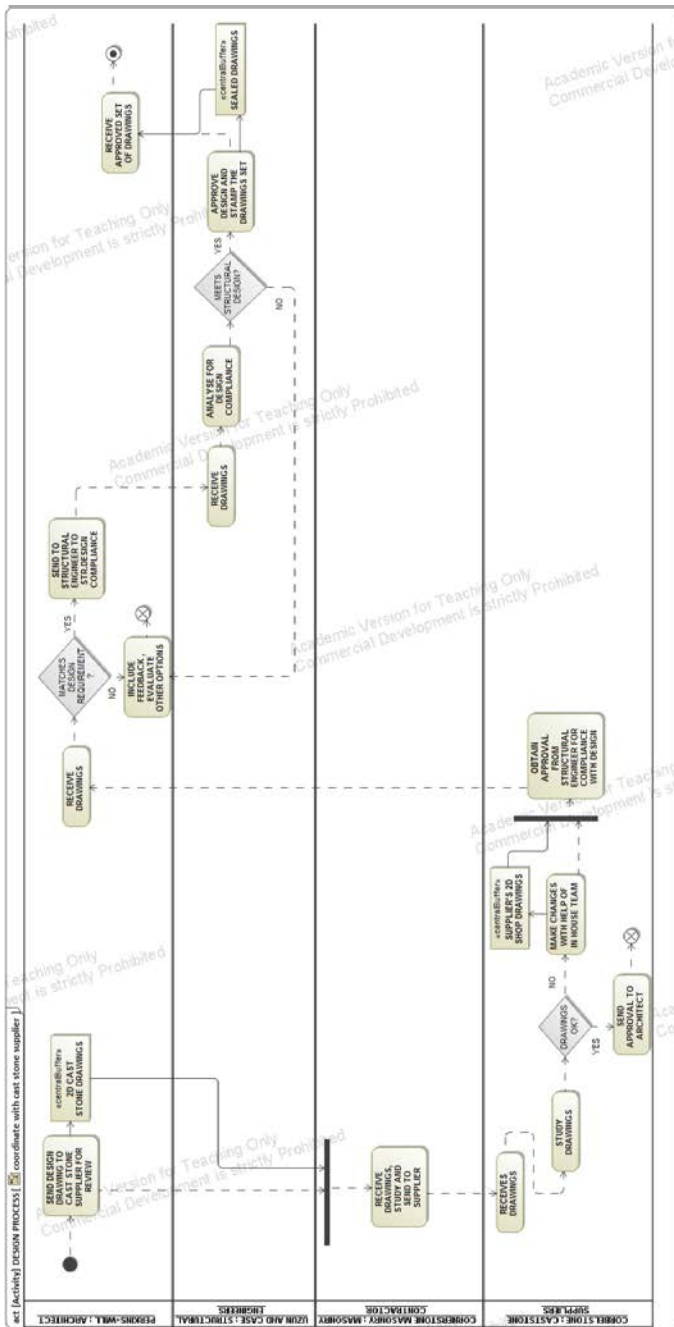


Figure 7-7. Coordinate with cast stone supplier.

Several proposals were made during the design process, one of which was keeping the front wall as a ruin, leaving high costs. The owners approved the proposal with a historical appeal, which interpreted the old buildings on the school complex.

There were two approaches on the main facades, both front and back. Arches would mark the main entrance, and cast stone would be used for detailing on sills, lintels, and copings. By interpreting the old building designs, adjustments were made to the new hall and its proportions.

One interesting point is the use of steel columns and beams as opposed to a CMU backup. After the structural engineer approved the decision, the architect and structural engineer collaborated and exchanged BIM models on a weekly basis.

### **General Contractor Coordination**

The co-ordination process was initiated once the contract was awarded to the General contractor and the masonry contractor was chosen. The General Contractor received the construction documents from the Architect (Perkins + Will) and reviewed the documents to examine if he received all the necessary documents from the Architect as per the contract terms so as to begin the procurement process. He then grouped the drawings and specifications according to the specific needs of the Sub-contractor that he was planning to delegate the job to. In our case study, our prime focus is going to be with the Masonry subcontractor which in our case was Cornerstone Masonry Group (CMG). The General contractor upon grouping the documents, provided the Masonry Sub contractor with all the necessary specifications and drawings so as to enable the Masonry sub-contractor to begin his job. In the meanwhile, the General Contractor also starts establishing their own internal schedule, creates his own BIM model and sets aside roles and responsibilities for other subcontractors. The masonry sub-contractor analyzed the drawings and specifications and sent enquiries to his suppliers to find out if the required type of face brick was available readily or as and when required. Also, simultaneously, the Masonry team extracted preliminary quantities and prepared shop drawings in order to help them carry out the job smoothly on site. In the shop drawings, the masonry team indicated locations for the ties, strap anchors and other accessories that were critical for the installation of the brick veneer. Additionally, during the shop drawing preparation process, if there were any clarifications that were needed to be addressed by the architect, the Masonry sub-contractor would raise an RFI (Request for Information). This RFI would be sent to the JE Dunn, who would then make a record of the RFI and review the RFI and later direct it to the concerned stakeholder which in this case was the architect (Joe) at Perkins + Will. Then Joe analyzed the RFI and addressed the issue and sent it back to the General Contractor with the response, who then sent it to the Masonry contractor after documenting the response. In addition, the same channel was followed for obtaining the shop drawings (prepared by the Masonry contractor) approvals from the architect. Once the Masonry contractor received the approval, he then proceeded with final quantity take off and processed the purchase order for the masonry materials and equipment, the materials being the 4" CMU blocks, Custom made Cast Stone pieces and the Face brick and the equipment being the necessary strap anchors, ties and dowel joints etc. This order was placed with the supplier who was within 500 miles of the project site. The reason for the supplier being within this range was because of the fact that the building was going to be LEED certified and also the ease of logistics. The supplier then processed an internal work order for production of the units that were not available in the inventory and also for purchasing the units that were not available with him internally. Upon production, once the materials are ready and packed in a safe and systematic manner, they were then shipped to the site and were stored in a safe and dry location close to the site and not too far from the point of installation. This ended the Co-ordination and procurement process.

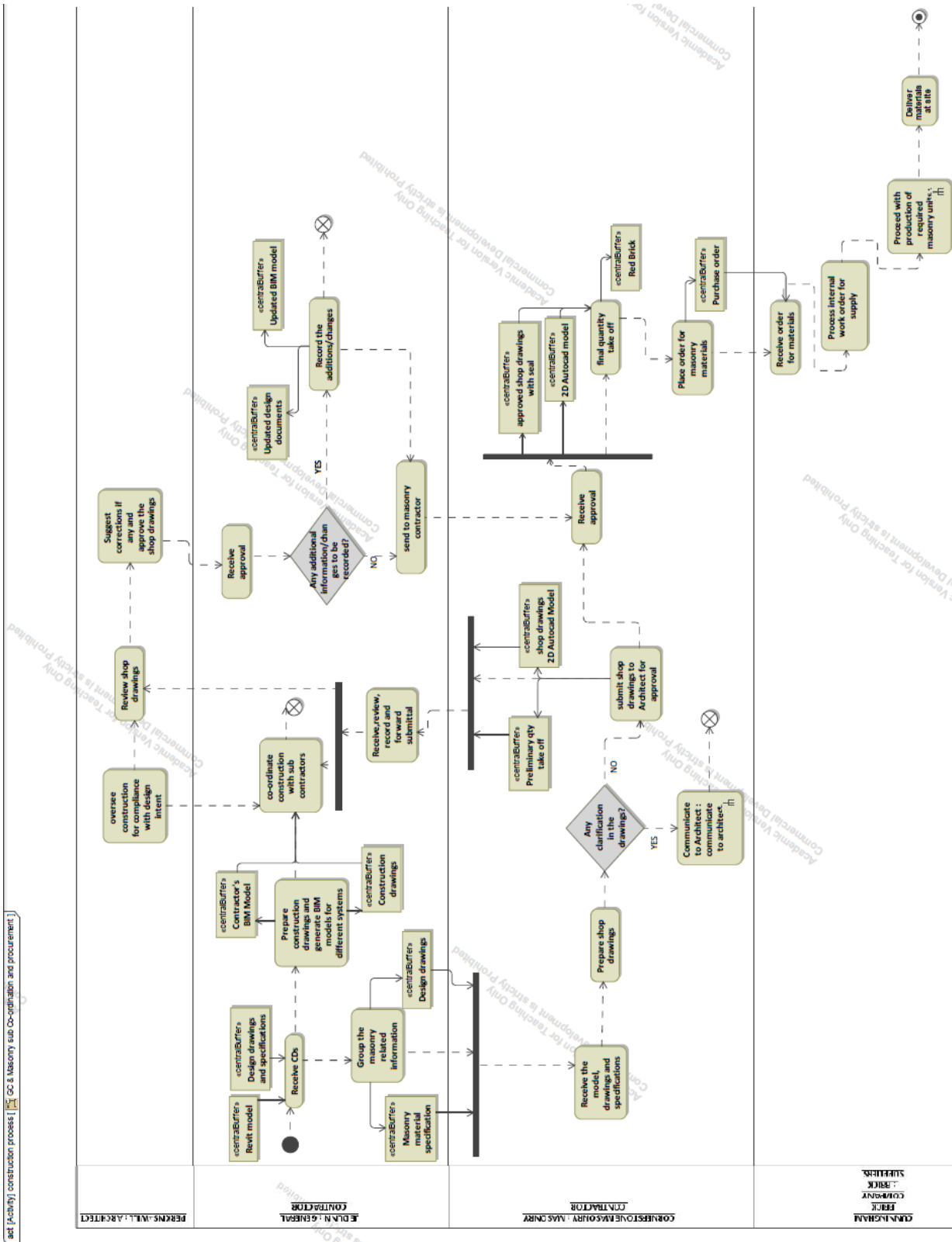


Figure 7-8. General contractor coordination.

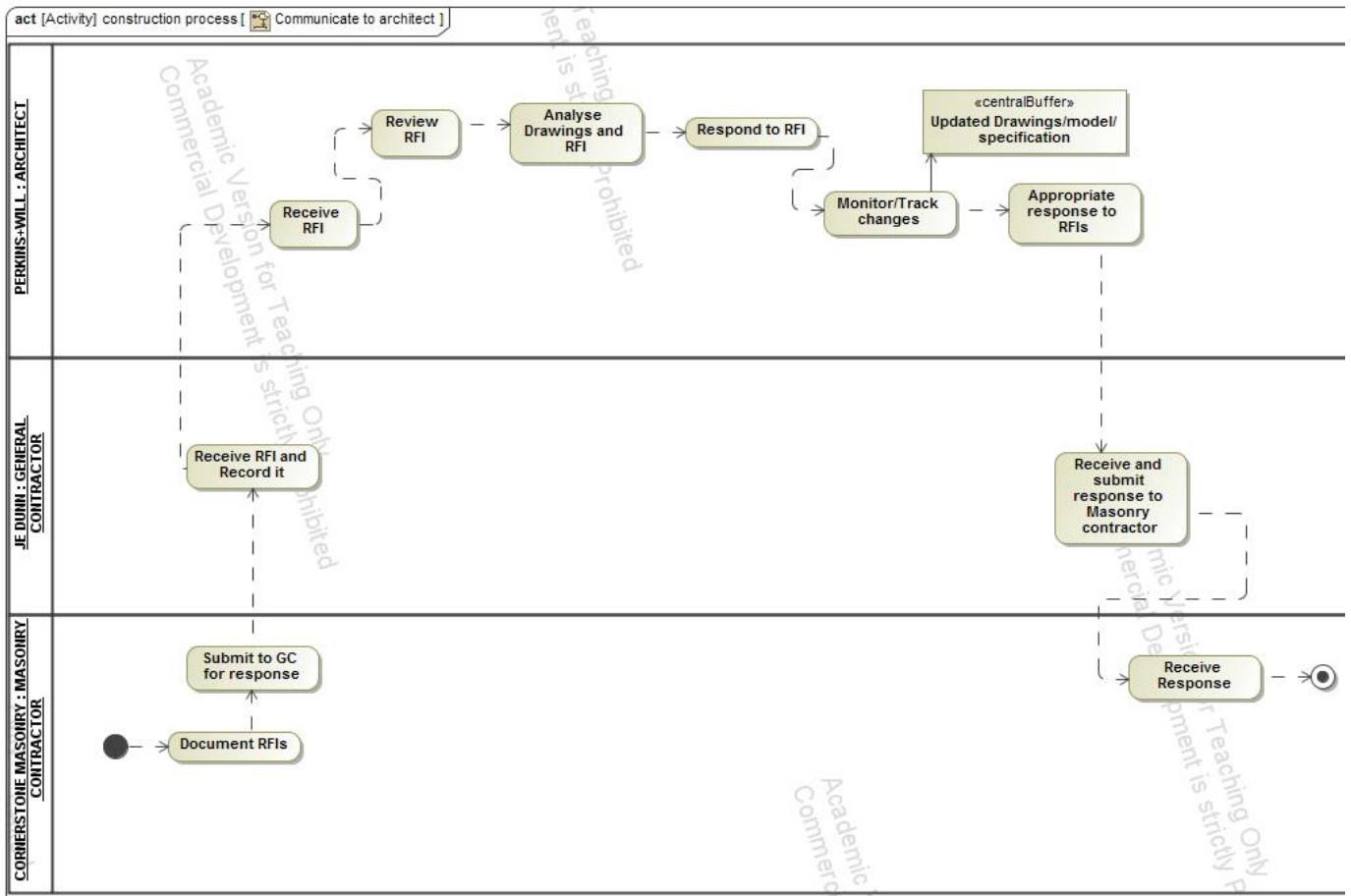


Figure 7-9. Communication to the architect.

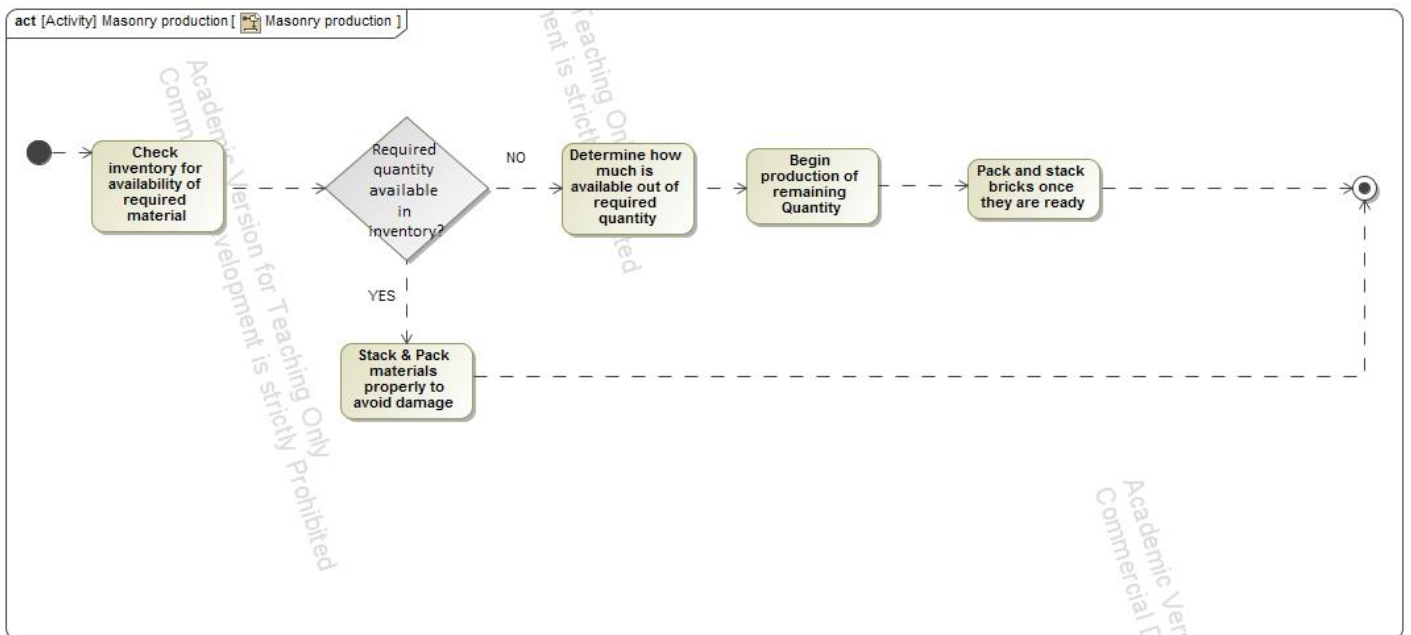


Figure 7-10. Masonry production.



## Subcontractor Installation Phase

The masonry sub- contractor in this case was not only involved during the installation of masonry units above ground, but also below ground. Once the foundation sub-contractor finished pouring the concrete for the foundation and once the concrete was set, the Masonry sub-contractor was brought in to lay the 4” CMU block as support for the Brick veneer to be laid at a later stage. The construction drawings and shop drawings were critical for this phase of the installation process. Then, once the building structure was constructed and the drywall including the water proofing was installed, the Masonry contractor team was brought in, to apply the fluid applied air barrier which acted as a weather protection system in addition to the water proofing and this was followed by the installation of the plastic board insulation which had a thickness of 2 inches. Once that was done, they then installed the ties, anchors and strap anchors (for cast stone) at the location where the steel studs were available. The reason for screwing the ties to the studs was to provide a strong support for the ‘to be installed masonry wall system’. Then a team working under the masonry sub-contractor installed the metal flashings at the ground floor level, the parapet wall level and other locations as specified in the drawings. One end of the flashings were attached to the drywall exterior and the other end was to be laid over the brick course work so as to direct any water that would come in between the drywall and the brick wall to flow out. The flexible flashings were installed in a similar fashion, but along the window openings. These also served the similar purpose. The masons installed the cavity drainage material at the base of the building which acted as a mortar collection device that prevented any mortar that fell in between the brick wall and the drywall from being stagnated at the bottom of the structure. Then, the masons began the brick installation process by first laying a course of mortar and then laying the bricks in a horizontal fashion. The equipment used in the process were the Brick trowel, mortar board and safety jacket to name a few. During this process, the masons also ensured that weeps/vents were installed in between the bricks along the head joints. Additionally, the free end of the flashings were also laid over the layer of brick work to ensure any water that seeped in would flow out of the building without any problem. The masonry sub-contractor did a good job of making sure the brick pieces were laid in such a way that wastage was minimal. This was done by making adjustments during the laying process to ensure modularity in the brick wall. Once the bricks were laid along the ground level, the scaffolding was erected to lay the bricks and the cast stone in the subsequent floor levels. Care was taken in laying the cast stone pieces along the windows, arches and parapet levels as it was a critical component in the aesthetics of design

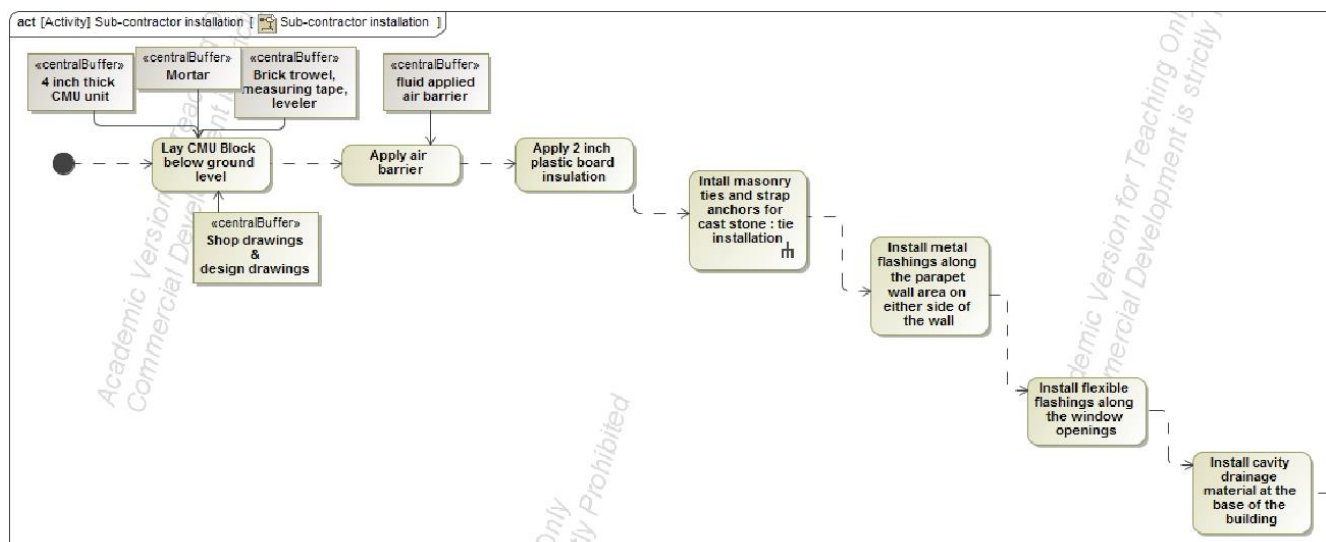


Figure 7-11. Subcontractor installation phase: part 1.

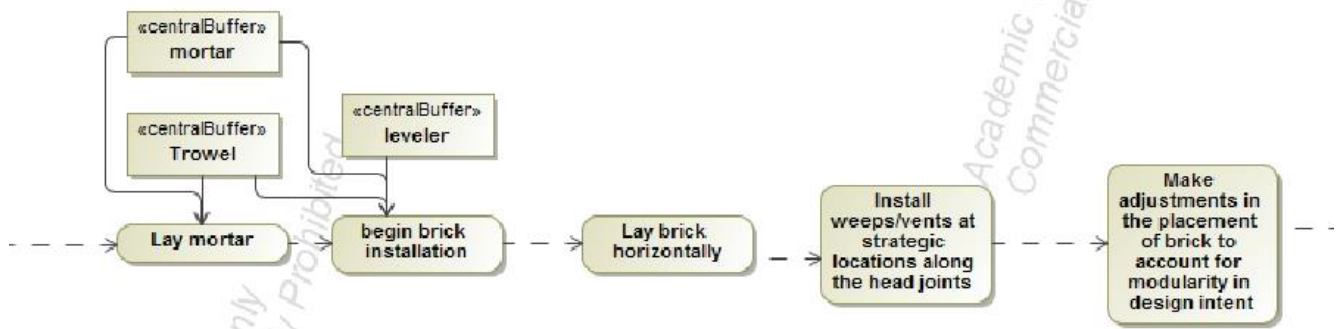


Figure 7-12. Subcontractor installation phase: part 2.

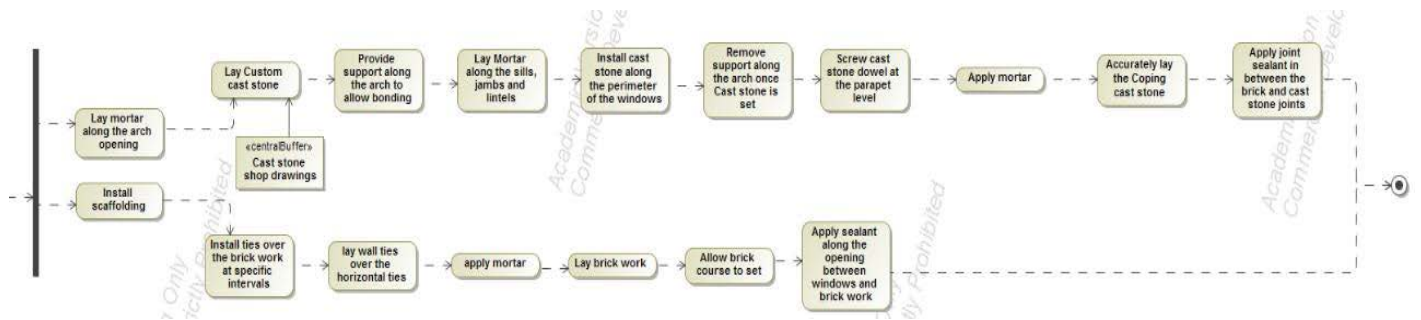


Figure 7-13. Subcontractor installation phase: part 3.

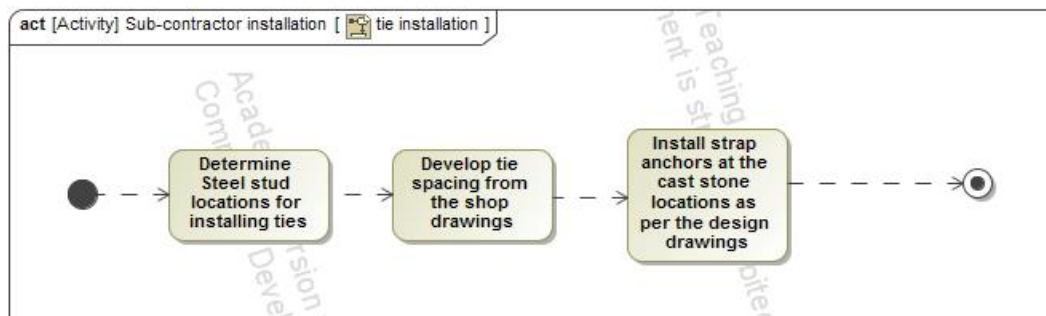


Figure 7-14. Tie installation.

### Future States in Design and Construction

There were several future state suggestions for various aspects of design and construction related to this project:

- A rational decision making methodology of material selection
- Ability to buy additional scope of work / possible improved workflow integration
- Development of parametric masonry families on BIM software
- Schematic design of masonry systems:
  - Determining analysis
  - Energy analysis
  - Structural analysis
  - Integrating with other technologies

## Conclusion

The study about Woodruff Hall had as its main focus the processes that are involved in the designing and construction with masonry. In the perspective of the design phase, this case study evidences the benefits to the whole process when the design team is well trained on the properties of the masonry as a material and for that reason are capable of providing enough documentation and solutions that are adequate to the requirements of a masonry building. The understanding of the masonry unit as a module has a deep impact on the design phase especially in cases similar to the studied building where the masonry peripheral walls were combined with steel structural system. In that specific case coordination between the masonry and the structural system was a crucial aspect to the success of the buildings. Coordination seemed to be the most important word on the masonry universe and with a lot of room to the developments in a manner that it will bring improvements to all trades in the masonry construction workflow. Brick, as a construction material, still have a lot of dependency on the skills and on its interaction with human skills, even with all the efforts made in the construction industry towards automation of its processes, all of the factors that are relevant to a masonry building, from designing to construction, appear to keep this type of future distant from this trade. For that reason, this case study could verify that the coordination of the data about masonry as a material could be the plausible future for the masonry construction as an industry, for designers, contractors and suppliers.

## 8. Breckinridge Place

### Background



Figure 8-1. Breckinridge Place.

Breckenridge Place, a 6-story load bearing masonry building of 60,000 gross square feet, locates at 100 W Seneca St, Ithaca, NY. This historic project pairs state-of-the-art, energy-efficient design and affordability at one of the most desirable locations in the Finger Lakes. Designed by Holt Architects of Ithaca, Breckenridge Place provides 50 units of mixed income, affordable one and two bedroom apartments. As a LEED Platinum project, Breckenridge Place received Gold award, Excellence in Masonry Design & Installation awarded by American Concrete Institute. According to information provided by the architect that led the design efforts, there was an initial decision making process to determine the type of structural system to be used for the project. Two alternatives were assessed:

- Steel Structure
- Load Bearing CMU Block

Finally, the Load Bearing CMU alternative prevailed because:

- **Cost:** The Contractor that was providing pre construction services to the Owner, determined that the cost of this system would be cheaper than suing a Steel Structure.
- **Time:** The plan was to be able to work in dry during the winter season, and this would have not been possible if a steel structure was selected. It basically due the lead time required to fabricate the steel structure.
- **Weather:** Contractor wanted building to be sealed by winter not sure if this would be possible with steel
- **Location:** Downtown Ithaca a lot of history in masonry construction
- **Aesthetics:** Like owners architects bring ideas and vision to design we are responding to the owner’s vision. The design was not client driven we decided early on we wanted to respond the existing environment.

*Masonry Scope*

The six-story load bearing masonry structural system made this project unique from the rest. The masonry scope consists of CMU, brick façade, cast stone sills and base, and granite stone base (see Figure 8-2).

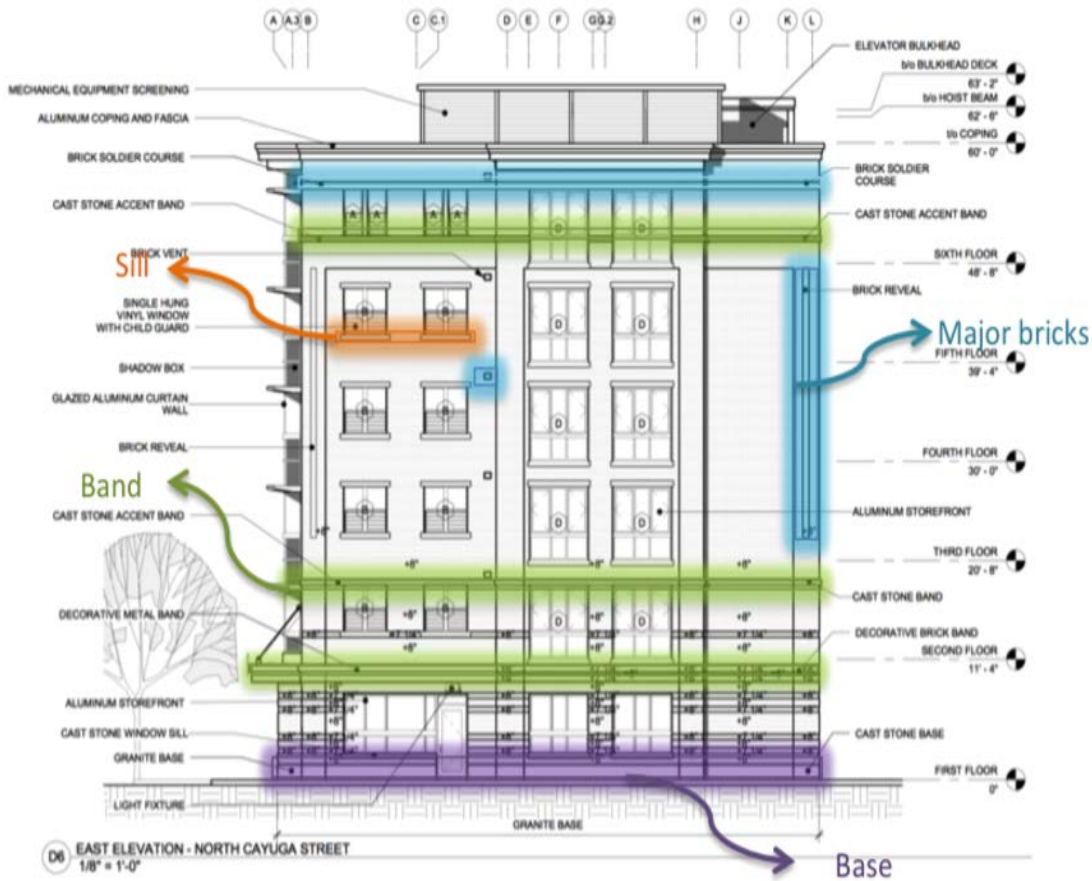


Figure 8-2. View of different masonry elements on building facade.

*Stakeholders*

The stakeholders on this project are given in the following table (see Figure 8-3).

Figure 8-3. Breckenridge Place stakeholders.

<b>Role</b>	<b>Company Name</b>	<b>Responsibilities</b>
Developer	Path Stone Corporation	Owner, Project Integration, Coordination with Occupants
Owner	Ithaca Neighborhood Housing Services	Owner, Project Integration, Coordination with Occupants
Architect	HOLT Architects	Architectural Design
Structural Engineer	Ryan-Biggs Associates	Structural Design
MEP Engineer	Erdman, Anthony & Associates	Mechanical, Electrical and Plumbing Designs
Civil Engineer	T. G. Miller, P.C.	Site Design
Landscape Architect	Trowbridge Wolf Michaels	Landscape
General Contractor	Christa Construction, LLC	Construction Coordination and Oversight
Masonry Contractor	Dave Traver Masonry	Masonry Installation and Coordination
Masonry Producer	Barnes & Cone, Inc.	Provide Masonry Materials

### **Schematic Design Phase**

The Schematic Design Process involves 3 different sub processes:

- Conceptual Design
- Materials Selection
- Cost Estimate Early Stage

The following diagram in Figure 8-4 is a proposed Best Practice / Future State process of this phase.

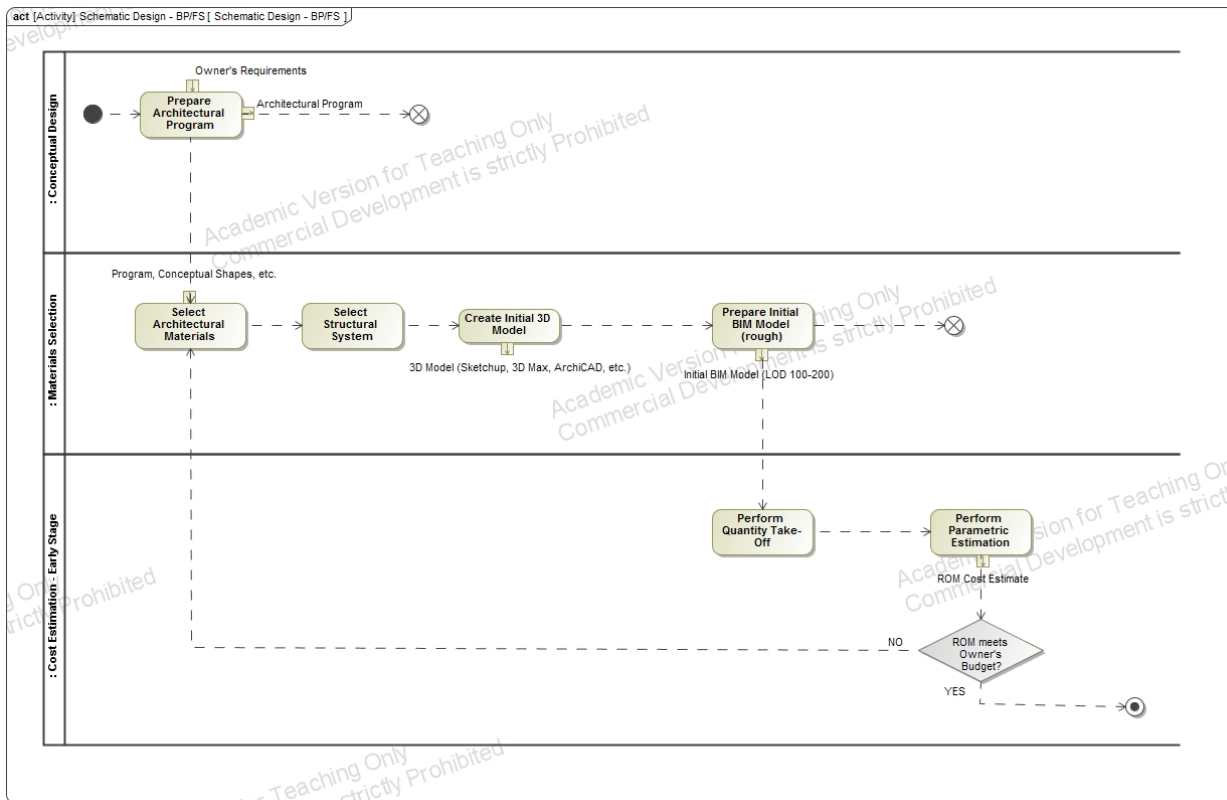


Figure 8-4. Proposed best practice / future state of schematic design phase.

## Design Development Phase

The following diagram is the proposed best practice for the Design Development phase (see Figure 8-5).

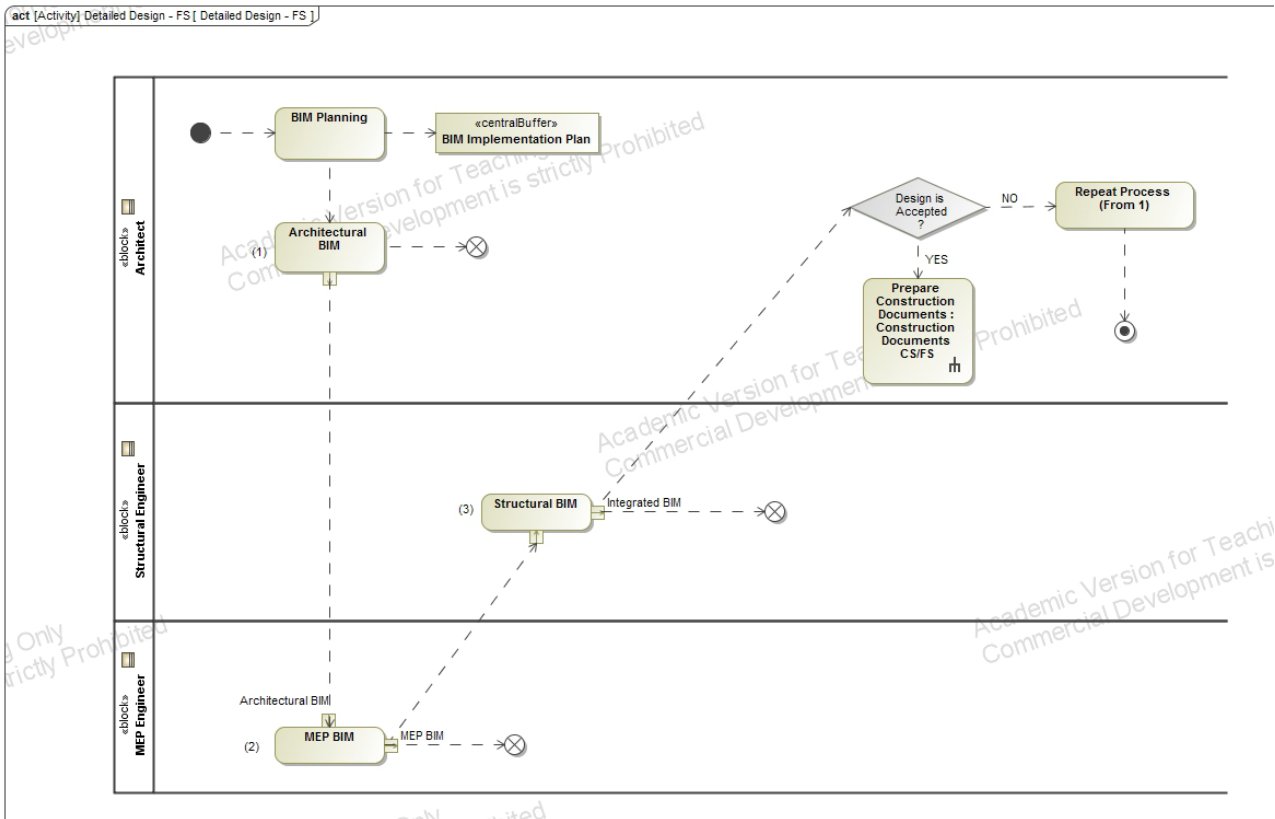


Figure 8-5. Design development phase.

### Construction Documents Phase

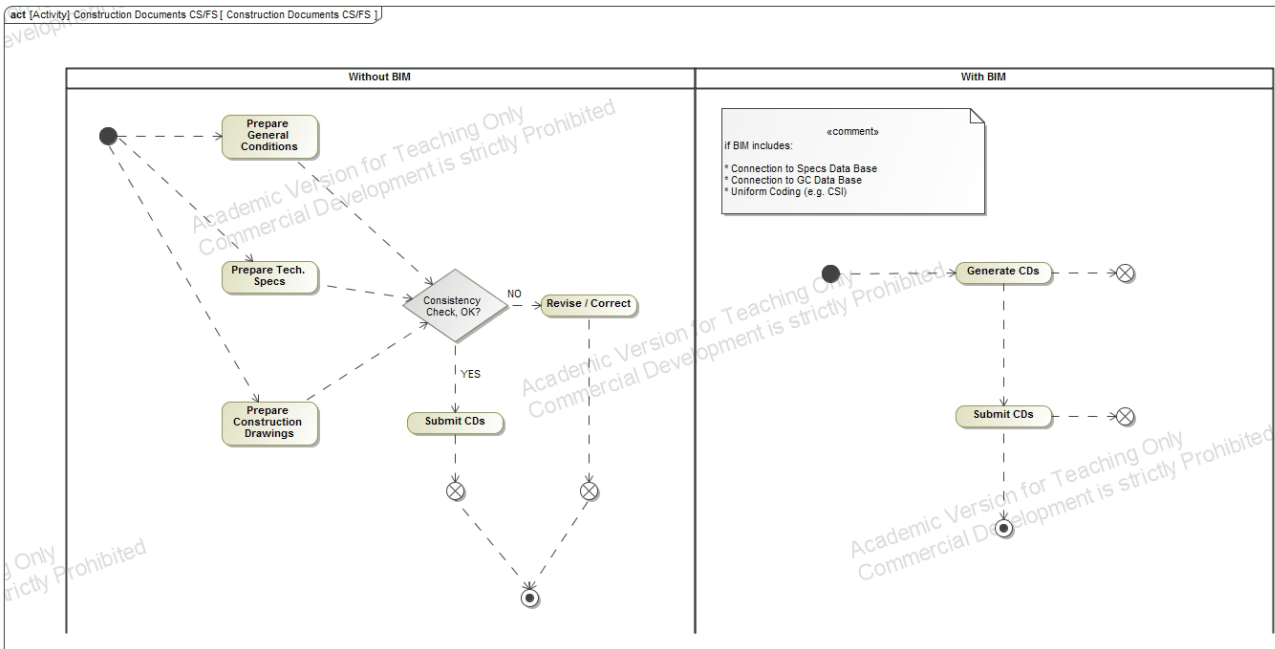


Figure 8-6. Proposed construction documents phase.

### Contractor Coordination Phase

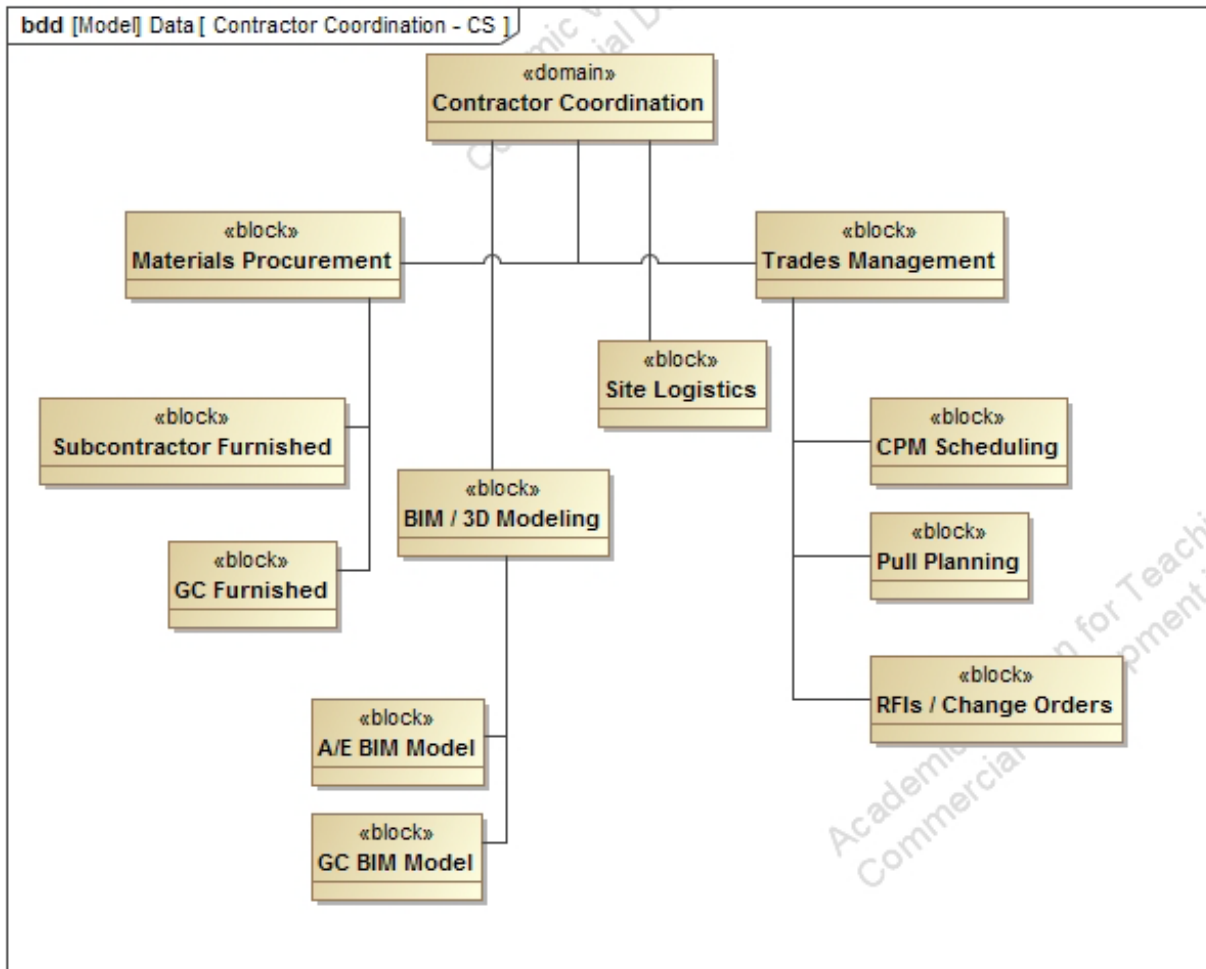


Figure 8-7. Block diagram of elements of contractor coordination.

### *Site Logistics*

This project was built near Ithaca’s downtown district where access and space are very limited. This has direct effect on the storage of materials on site. Furthermore, delivery of materials to site and reception coordination have an added factor that can affect successful construction and project completion.



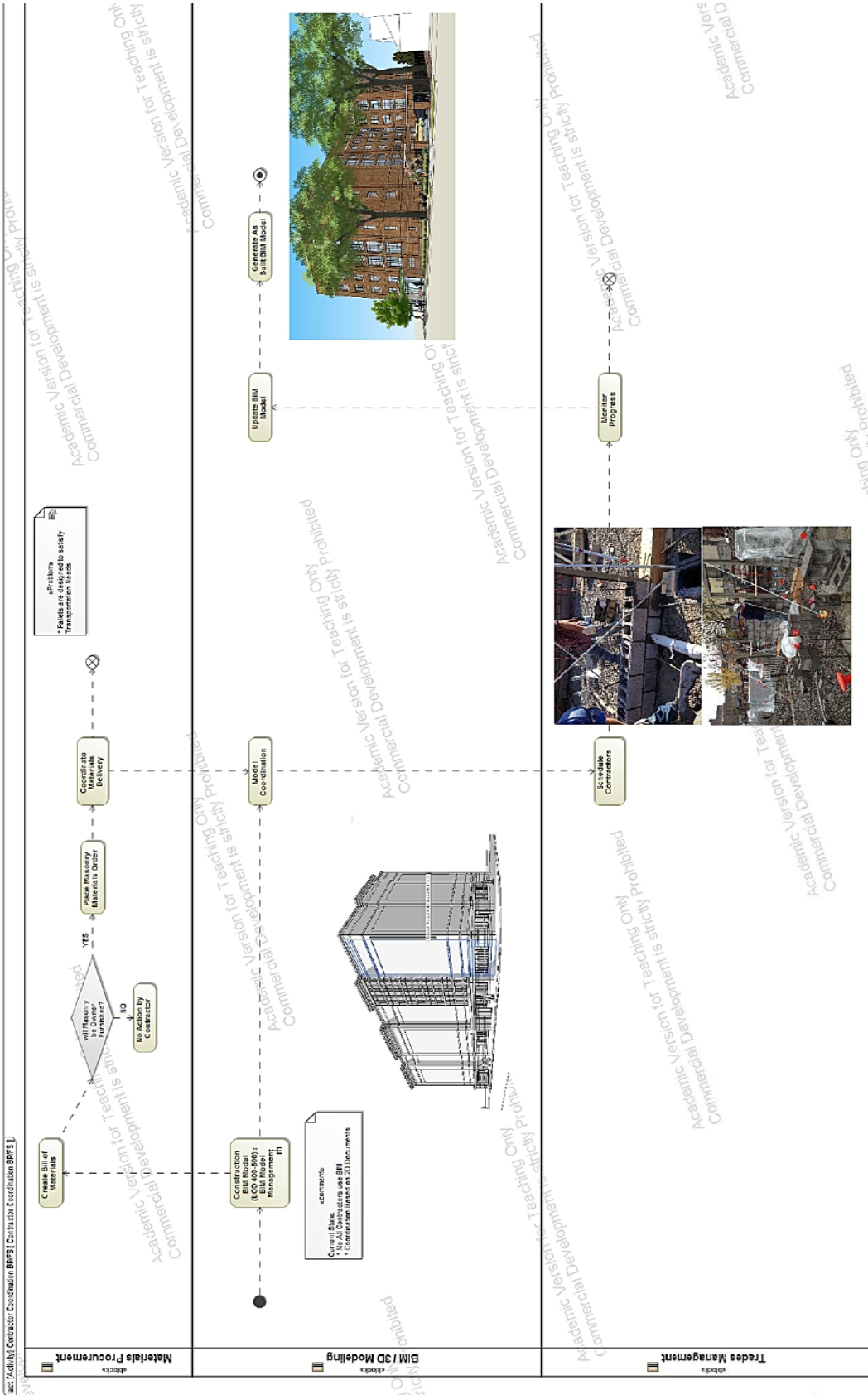
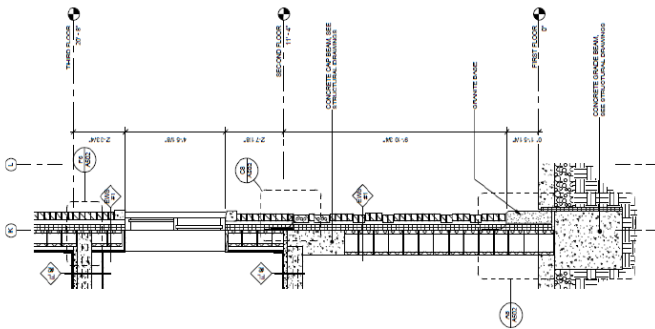


Figure 8-8. Proposed contractor coordination phase.

Punched Windows Wall 1st and 2nd Floor

Wall Type	#	Activity	Division	Installer	Labor	Equipment	Information Required	Coordination Need (Mason Leads)	
Punched Windows Wall 1st and 2nd Floor	<b>Third Floor</b>								
	14	Install Brick	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings		
	13	Install Cast Stone Band	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings		
	Assuming Window Installation After Brick Wall is done								
	12	Install Cast Stone Window Sill	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings		
	11	Install Brick (H=11' to 14')	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings		
	<b>Second Floor</b>								
	10	Install Decorative Brick Band	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings		
	9	Install Brick (H=4 1/2' to 9')	04 - Masonry	Mason	Mason + Helper	Telehandler, Handtools	Specs, Drawings, Shop Drawings	Mason with Other Subs	
	8	Move / Install Scaffold	04 - Masonry	Mason	2 Men Crew	Scaffold, Crane	Specs, Drawings, Shop Drawings	Mason with Concrete Sub	
	7	Install Brick (H=4 1/2')	04 - Masonry	Mason	Mason + Helper	Scaffold, Crane	Specs, Drawings, Shop Drawings	Mason with Concrete Sub	
	6	Cure Grout	03 - Concrete	Concrete / Mason	2 Men Crew	Concrete Mixer, Hand Tools	Specs, Drawings, Shop Drawings	Mason with Concrete Sub	
	5	Place Grout	03 - Concrete	Concrete / Mason	2 Men Crew	Concrete Mixer, Hand Tools	Specs, Drawings, Shop Drawings	Mason with Concrete Sub	
	4	Set Stone Base	04 - Masonry	Mason	2 Men Crew	Hand tools	Specs, Drawings, Shop Drawings	Mason with Thermal Sub	
3	Install Insulation	07 - Thermal & Moisture Protection	Thermal	2 Men Crew	Hammer, Hand tools	Specs, Drawings, Shop Drawings	Mason with Thermal Sub		
2	Install Flashing	07 - Thermal & Moisture Protection	Thermal	1 Laborer	Hand tools	Specs, Drawings, Shop Drawings	Mason with Thermal Sub		
1	CMU Wall Complete	04 - Masonry	Mason	N/A					



(14) BRICKED WINDOWS AT FIRST AND SECOND FLOORS.

Figure 8-9. Proposed work coordination table.

## Subcontractor Installation Phase

The masonry installation requires high degrees of qualification for masons. Some of the many technical challenges that masons face are:

- Maximum height of wall allowed to be built per day
- Cure time of bonding agents (mortar, grout) and associated issues when construction happens during the winter months
- Need for Wall Panels or Mockups to ensure the intent of design can be accomplished

For this project we were informed that a masonry mockup was developed; however, no construction photos of it were sent to the group. Figures 8-10, 11, and 12 shows the elements of a typical installation on the building.

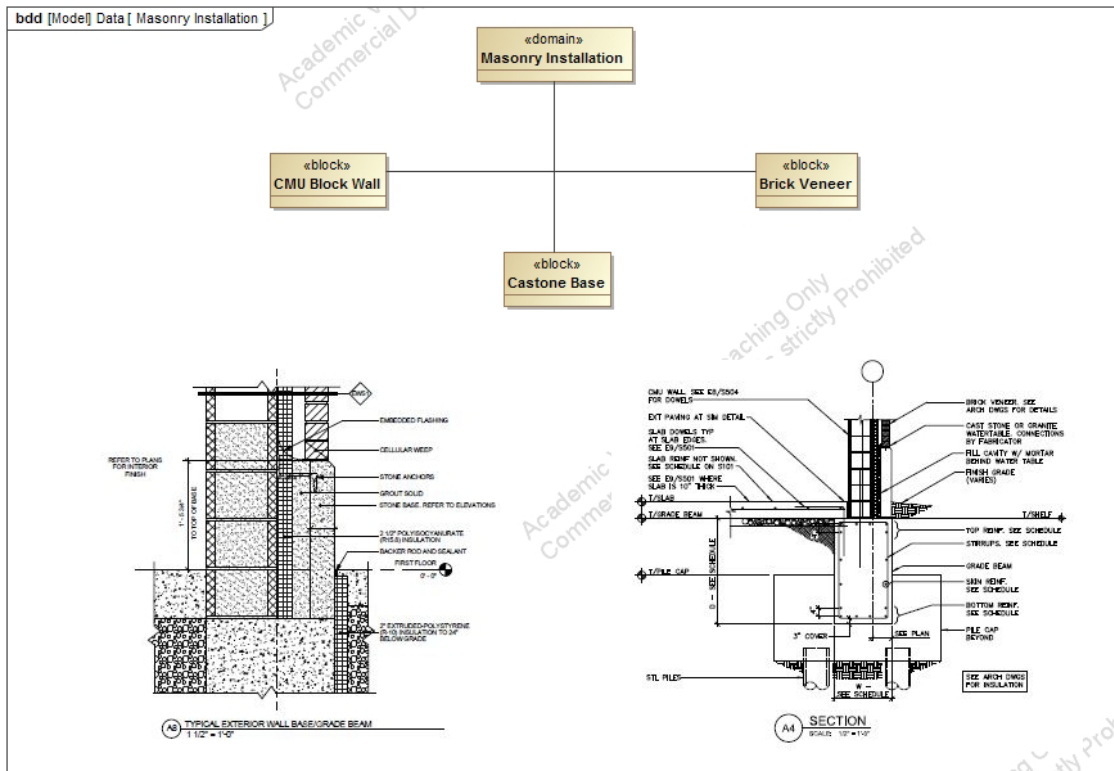


Figure 8-10. Block diagram of construction of southwest corner.

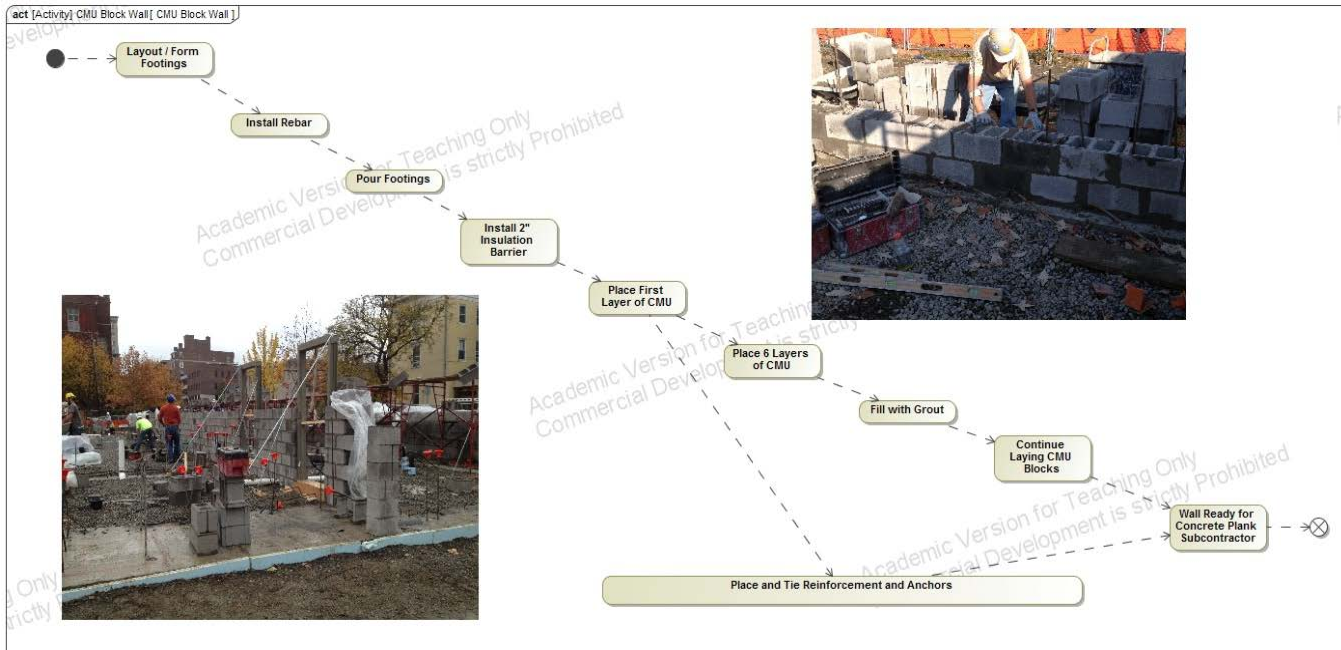


Figure 8-11. Activity diagram of CMU installation on southwest corner.

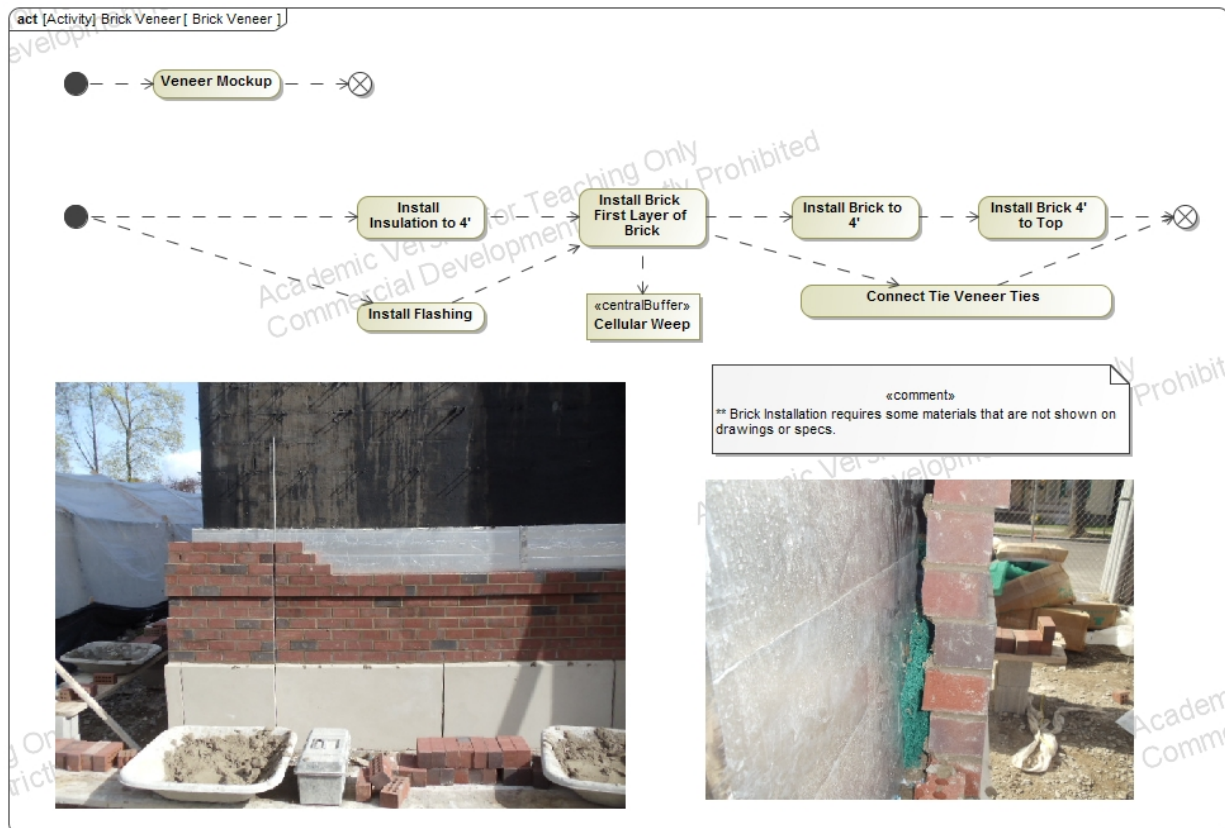


Figure 8-12. Activity diagram of brick veneer installation.

## Conclusion

From this case study, the team identified a few factors that would improve masonry project workflows in a BIM-M future. A proper delivery method that encourages collaboration early on in a project timeline is crucial. From current collaboration, guidelines need to be set in order to efficiently and effectively adopt a BIM for masonry. Although masonry can be complex and more costly than some other building types, masonry construction tends to offer a longer life cycle with less maintenance.

## **9. Georgia Institute of Technology, Hinman Hall / Georgia College & State University, Ennis Hall**

### **Background**

The primary aim of this case study was to explore the methods used to restore masonry systems. The projects included in this study are the Hinman Research Building on the Georgia Institute of Technology campus and the Ennis Hall building on the Georgia College State University campus. The project delivery methodology used for both of these projects was Construction Manager at Risk (CM at Risk). The project delivery was fast-tracked because construction started before the design was complete. The General Contractor was highly involved during all design phases. They provided insight on the renovation process and constructed mockups as required by the Architect. The project team decided to focus primarily on the Hinman Research Building for this case study and use the Ennis Hall project for support on the historic renovation process. Lord, Aeck, and Sargent (LAS) was the Architect of Record (AOR) for both Hinman and Ennis Hall. Ms. Karen Gravel, an architect at LAS, provided information on workflows and tools used to investigate the existing conditions of historic renovation projects.

The Hinman Research Building is 34,500 square feet. The construction cost \$9.5 million and took place from February 2010 to January 2011. It is located at 723 Cherry Street NW. Originally designed by the Public Works Administration circa 1939 as the Research Building, the building consists of a high bay experimental laboratory area flanked by two, two story office wings at the west end. The office wings are connected by a second floor corridor that extends across the west elevation of the laboratory portion of the building. A one-story room, labeled Machine Shop, extends along the south side of the building to the east of south office wing. A three-story addition, designed by Bush-Brown, Gailey, and Heffernan Architects, was constructed along the north side of the building in 1951. Figure 9-1 is an aerial view of the building, illustrating the separate building portions.



Figure 9-1. Aerial view of Hinman Research Building (Microsoft virtual Earth).

### *1939 Original*

The original portion of the Hinman Building is “T”-shaped in plan, with overall dimensions of approximately 108 feet in the north-south direction and 122 feet in the east-west direction. The office wings are about 27 feet tall, while the high bay is almost 50 feet tall. The high bay is a steel-framed structure with steel columns (W14x87) supported by reinforced concrete spread footings. The columns are spaced 16 feet on center in the east-west direction. According to the drawings, wide-flanged steel beams span between the columns (12 feet and 24 feet above the finish floor) to provide horizontal bracing for the columns.

The high-bay portion of the original building is a steel-framed structure with mass brick masonry exterior infill walls. The roof structure over the high bay consists of gypsum panels supported by riveted steel trusses and steel purlins. Multi-ply felt-based roofing covers the gypsum panels. The office wings and machine shop are concrete-framed structures. Built-up roofing covers the low-slope roofs of these areas. The exterior walls of the original portion of the building are mass brick masonry consisting of three wythes of brick, with header courses every eighth course to structurally integrate the masonry wythes. Steel-framed, single pane windows with precast concrete sills provide fenestration for the building. Most of the window openings contain two windows ganged together with a center mullion bolted through the two flanges. The windows in the high-bay portion of the building are fixed. The remaining windows are a mixture of fixed and operable windows. On the office wings, the concrete beam at the perimeter of the roof, and a portion of the second floor, project from the exterior face of the building over the windows (WJE Report, 2009).

### *1951 Addition*

The 1951 addition is an offset “T” in plan, with overall dimensions of about 87 feet in the north-south direction and 150 feet in the east-west direction. The majority of the addition is approximately 40 feet tall. The Bridge portion of the addition is about 26 feet tall. The entire addition is a concrete-framed structure, consisting of cast-in-place concrete columns bearing on concrete spread footing that support the concrete beams, floor, and roof slabs.

The addition is a concrete-framed structure. The exterior walls consist of hollow clay tile back-up walls and brick veneer. The windows are similar to those in the original construction, including the precast concrete elements. As with the original structure, the concrete beam at the perimeter of the roof slab extends over the windows. The low-slope roof is covered with built-up roofing. "The Bridge," is a connector that is a part of the 1951 addition. It connects the 1951 addition and the Calculator Building, which is located on the Northside of the building. Office spaces are along the east side of the Bridge (WJE Report, 2009).

### *Masonry Scope*

The general masonry assemblies used on both projects consist of clay or shale faced bricks (nominal size), 8"x8"x16" Concrete Masonry Units (CMU), mortar (with hydrated-lime), concrete coping, flashing (adhesive backing), and steel anchors. Other considerations in the process are cleaning the existing masonry with proper chemical solutions and constructing mockups during the Design phase. Understanding the material makeup of existing masonry materials through testing is important because it prevents additional or new damage to materials that need to be preserved.

### *Stakeholders*

Figure 9-2 shows a block definition diagram of the stakeholders on the Hinman project.

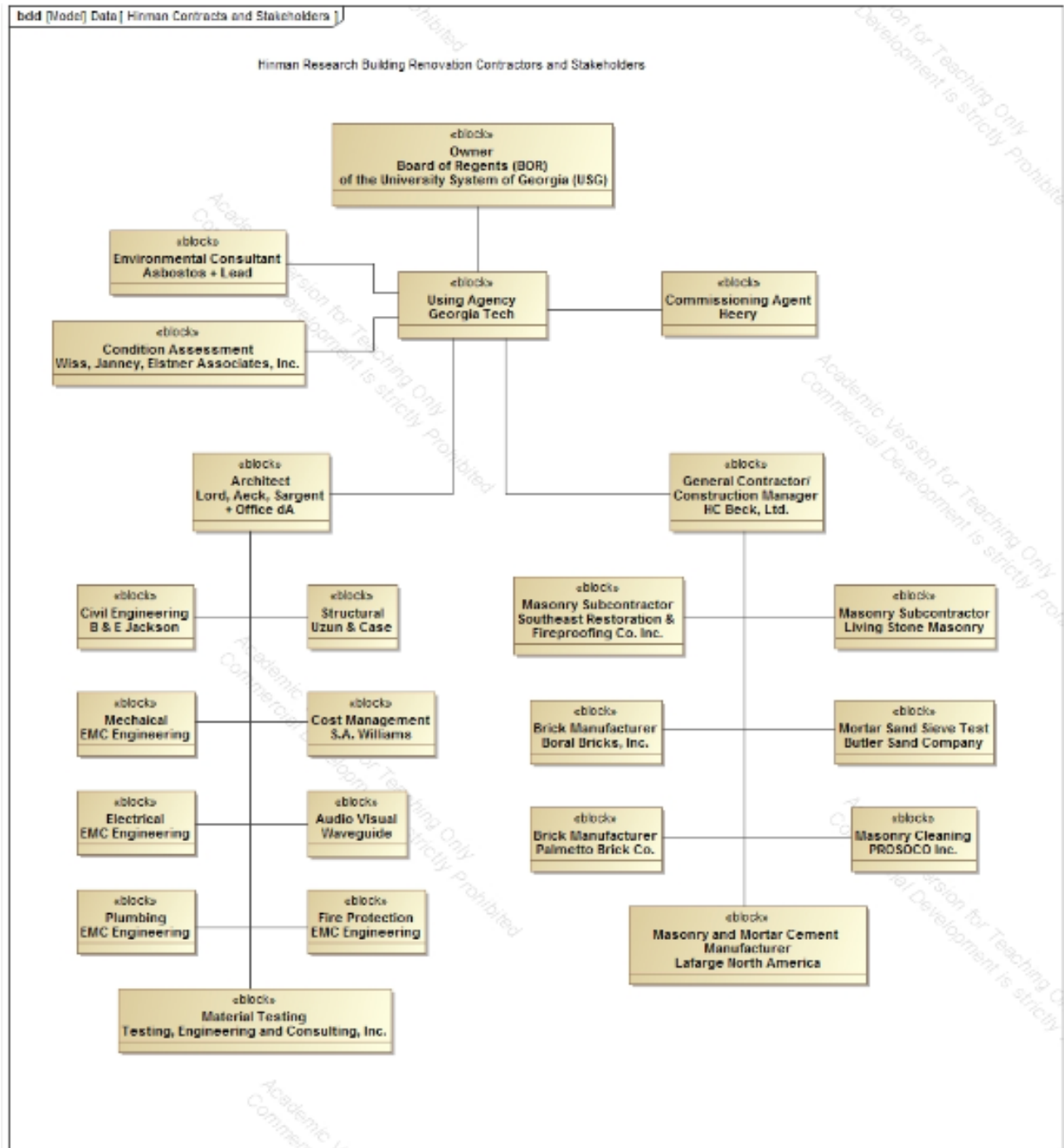


Figure 9-2. Hinman stakeholder diagram.

### *Masonry Execution for Repair, Repointing, Cleaning, and Clay Units Execution*

The documents related to masonry execution of Hinman Research Building are included in the section 04810, 04902, and 04940 of specifications. These three sections are clay masonry units, masonry repair and repointing, and masonry cleaning, and each section lists steps about how to implement the requirements. For example, the steps for masonry repair and repointing are examination, protection, temporary shim support, removing anchors, repointing mortar joints, removal and resetting of loose or damaged brick, dismantling and reconstruction of existing masonry, cleaning, and curing (see Figure 9-3).



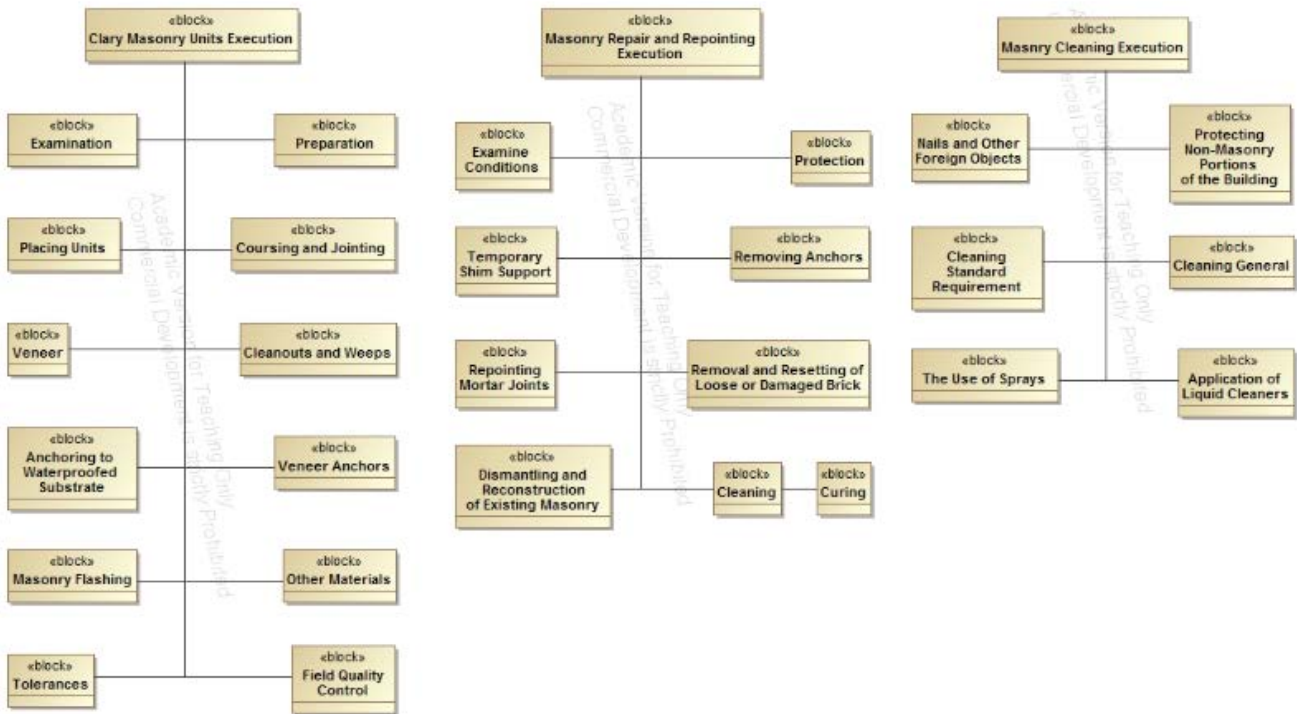


Figure 9-3. Masonry execution diagram.

### Hinman Building Conditions Assessment

According to the interview of Mr. Gary Petherick, the Owner’s Project Manager of Hinman Research Building, the Georgia Institute of Technology requested that Wiss, Janney, Elstner Associates, Inc (WJE) perform a conditions assessment before a Design Team was selected. The purpose of the assessment was to evaluate the condition of the building envelope and structural systems, develop a preliminary scope of repairs required for these systems, and provide an order-of-magnitude opinion of probable cost for the required repairs, for use by the Georgia Institute of Technology and the architect selected for the renovation design, for budgeting purposes.

LAS located areas that required re-pointing and repair to concrete elements such as eyebrows and sills. LAS also did condition assessments for construction process. Ms. Gravel had punch list items and field reports after she visited the field from May 2010 to December 2010. The field reports with photos showed the process of construction (Interview with Ms. Karen Gravel, October 29th, 2014).

"The condition survey of the exterior included a visual survey of the exterior of the entire building from the ground using binoculars, and a close-up survey of selected portions of the south and east elevations from a boom lift. In addition, WJE made exploratory openings at selected locations in order to observe concealed conditions. The elevations are provided a graphical summary of the conditions observed on the exterior of the building" (WJE Report, 2009). The following figures are photos of the condition assessment performed.



Figure 9-4. Typical deteriorated mortar joints on south elevation of High Bay.



Figure 9-5. Stained area on east elevation of High Bay.



Figure 9-6. Crack and displaced brick masonry at north end of east elevation of High Bay.



Figure 9-7. Poor installation of brick courses in curved portion of east elevation of High Bay



Figure 9-8. Abandoned anchor holes in east elevation of High Bay.



Figure 9-9. Failed sealants at anchor bolt and plate elevation of High Bay.

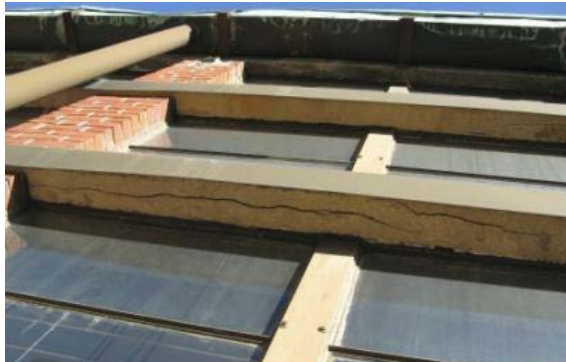


Figure 9-10. Cracked/delaminated concrete sills on High Bay



Figure 9-11. Exposed rebar that is now corroded because of material failure.



Figure 9-12. Transverse crack near midspan of curved concrete beam on east elevation of High Bay.



Figure 9-13. Overview of large spall at south end of curved concrete beam.

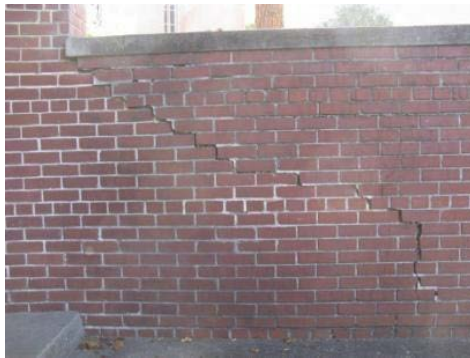


Figure 9-14. Overview of crack in retaining wall on West elevation of North Office Wing.



Figure 9-15. Displacement at the retaining wall.



Figure 9-16. Failed expansion joint.



Figure 9-17. Damaged spalling brick at the end of a lintel.



Figure 9-18. Spalled concrete sill.



Figure 9-19. Spalled areas at the East elevation of the South office wing.

Graphical summary of conditions observed on the EBB.

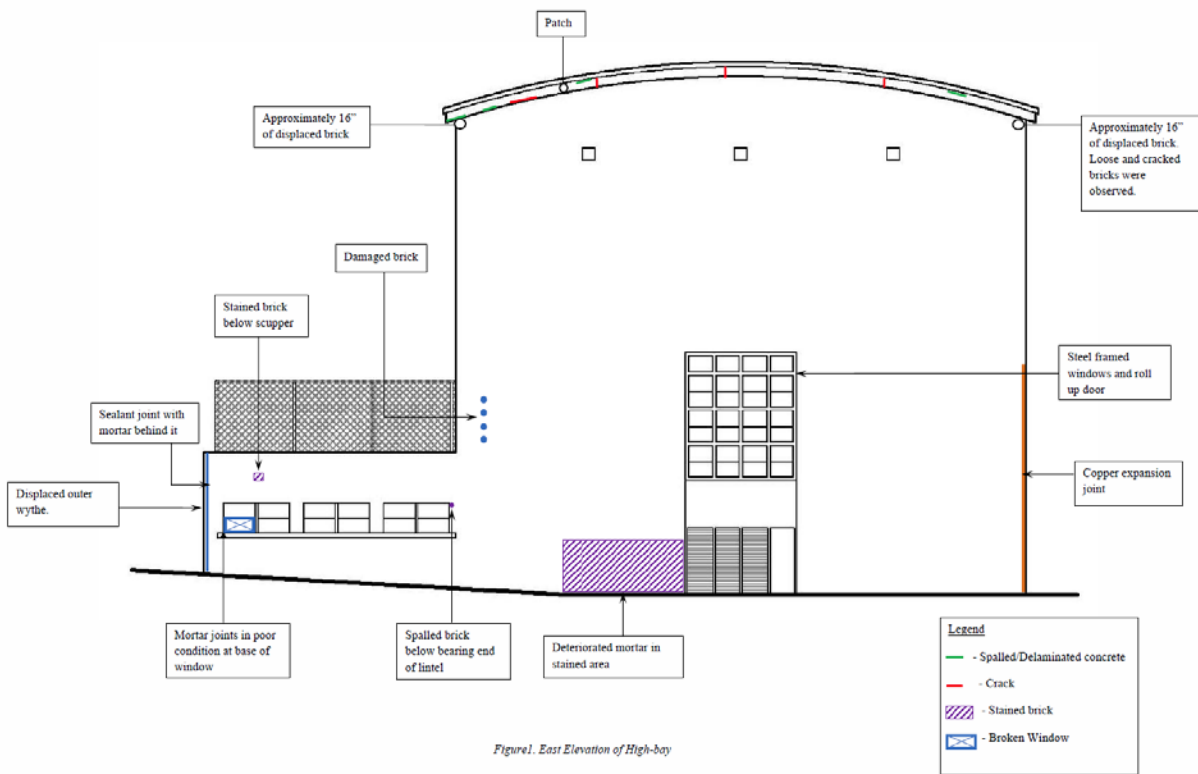


Figure 1. East Elevation of High-bay

Figure 9-20. Noted elevations for repair.

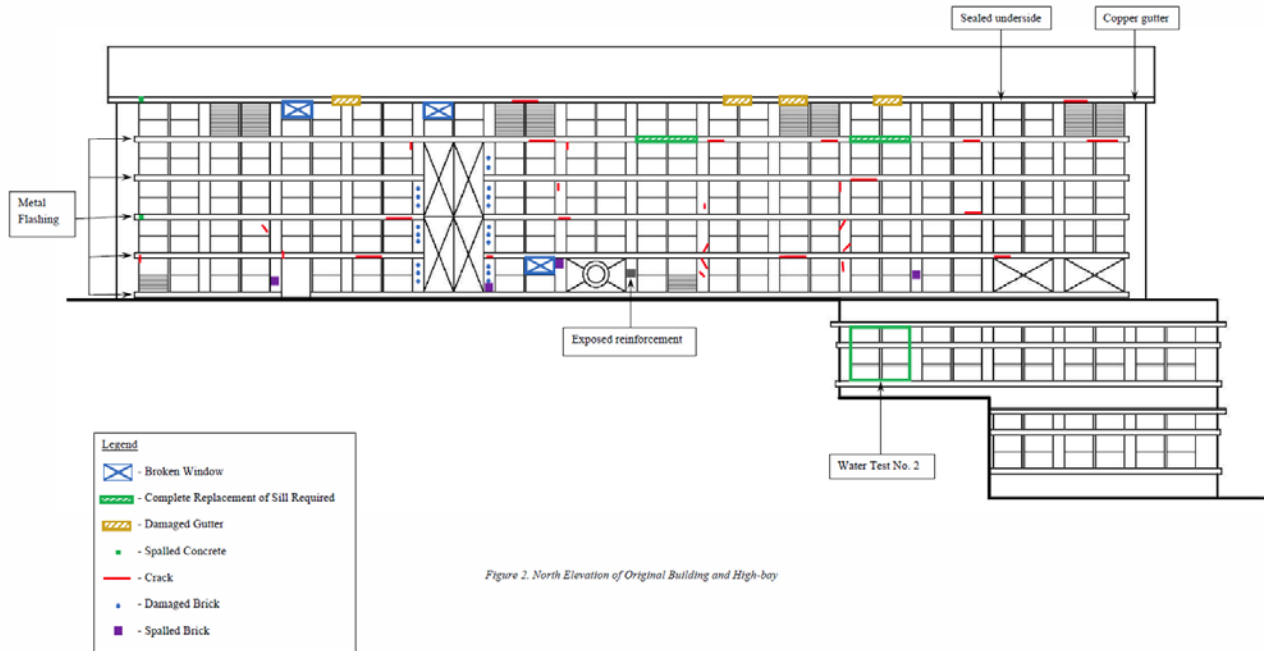


Figure 9-21. Noted elevations for repair.



Figure 9-22. Noted elevations for repair.

*Exploratory Openings*



Figure 9-23. Exploratory opening.

This exploratory opening was made in one of the masonry piers below one of the concrete sills on the south elevation of the high bay. The opening was made to observe the exterior surfaces of the window flange and steel column, the conditions of the inner wythes of masonry, and the underside of the concrete sill concealed within the masonry wall (see Figure 9-23).



Figure 9-24. Exploratory opening.

This exploratory opening was made near the west end of the south elevation of the Addition (Figure 9-24). The opening was made to verify the presence of masonry ties detected and to evaluate possible causes of the adjacent cracks in the brick veneer.





Figure 9-25. Exploratory opening.

This exploratory opening was made at the West end of the concrete beam above the windows on the south elevation of the Addition (Figure 9-25). The opening was made to determine the as-built construction of the spandrel beam as it projects from the face of the wall.



Figure 9-26. Exploratory opening.

This exploratory opening was made at the West end of the intermediate concrete windowsill on the south elevation of the Addition. The opening was made to determine the as-built construction of the concrete sill and adjacent elements.



Figure 9-27. Exploratory opening.

This exploratory opening was made at the shelf angle location on the southeast corner of the Addition. The purpose of the inspection opening was to evaluate the as-built construction and condition of the shelf angles at this location.

### **BIM Model**

The BIM Model was successfully created and used on the Hinman Research Building Renovation Project (see Figures 9-28 and 9-29). The adoption of BIM exemplified the high degree of collaboration between the design

team and the construction manager. The HC Beck Group adopted the architect’s BIM model and used it for construction purposes. The construction BIM Model combined the laser scans of space with seamlessly achieve the project design within the construction budget and schedule. The Beck Group also created intelligent models to support the design, fabrication, and installation of architectural millwork.

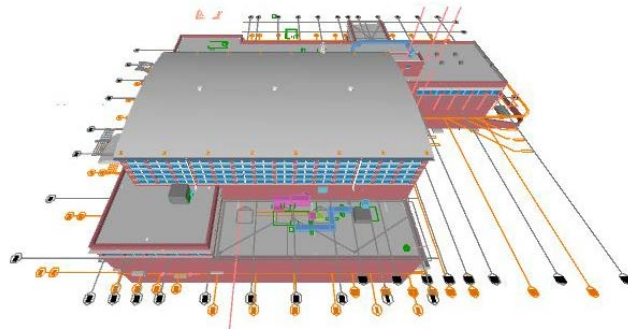


Figure 9-28. Construction BIM model for masonry renovation.

After the completion of the Hinman project, the general contractor (HC Beck) provided the Owner with a complete BIM model in Autodesk® Revit Architecture. This model will enable the Georgia Institute of Technology Facilities Department to monitor the building’s performance throughout the building’s life cycle.

**Project Execution**

The Design Team employed a manual approach for collecting building information for both projects. This method entails the architect printing plans and elevations in tabloid format. Then going to the project site to document as-is conditions of the building, by making notes on the printouts, in addition to take hundreds of photographs. The information noted on the drawings then had to be integrated into the BIM model. This is an area for improvement because work is duplicated.

The challenge of using a BIM model on a historic renovation project is the model might not be accurate. The reason for this is there are numerous unique conditions that cannot be precisely modeled, if a manual method is used for data collection. Ms. Gravel also had to develop a method for identifying areas that required work. The solution was to place symbols on the building’s façade that would pinpoint the type of work that needs to be performed. The location of the symbols did not represent exact point of the work but gave a general area of 25 square feet (see Figure 9-29).

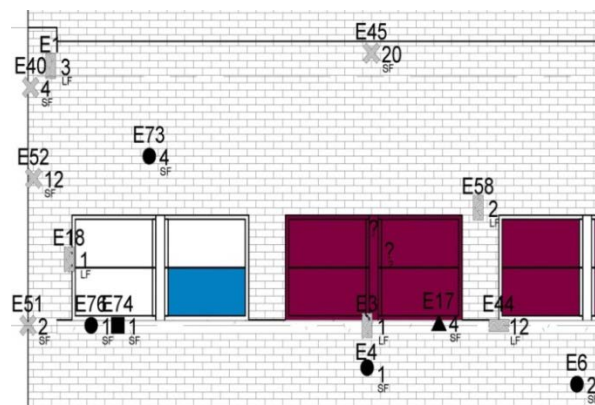


Figure 9-29. Illustration of symbols used to locate damaged areas on building facade.

LAS required that the General Contractor provide mockups of the materials and techniques used in the renovation. The mockups were provide during the Design phase of the project. The architect and owner were able to make more decisions that are accurate on the materials selected to match new materials with the existing brick and mortar. Further, tests on the existing materials were performed to determine the exact makeup of the materials used in the original construction (see Figure 9-30).

In addition, we learned the overall process of the Hinman Research project through interviewing Gary Petherick, the Senior Project Manager of Hinman Research Building of Georgia Tech. He provided significant information to help our team for finishing the Hinman project. In addition, through the interview, we could be able to understand the process from the beginning phase - Programming/ Planning to the end Occupancy Phase of the Hinman Research Building.

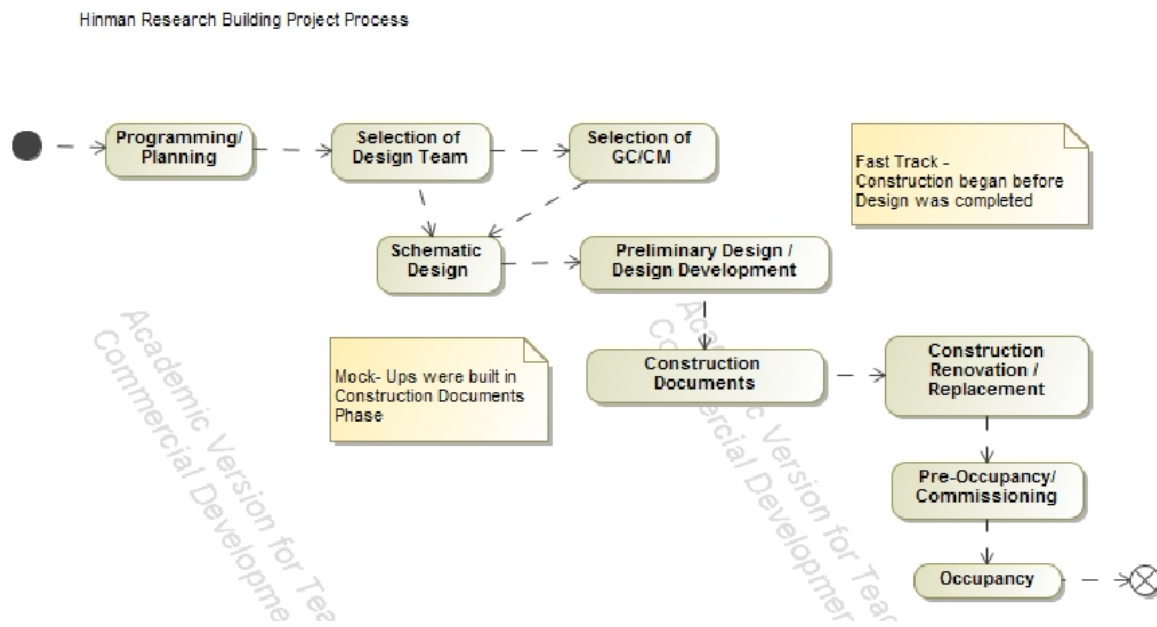


Figure 9-30. Process model for project development.

From Owner’s view, there were several benefits to choosing CM at Risk as the delivery method. First, early selection of the General Contractor would allow the GC to provide preconstruction services. This enhanced the collaboration and improved the communication among the Owner, the Architect, and the General Contractor. Second, the overlapping (fast-tracking) process of design and construction phase could shorten the schedule and save money. Third, transparency is enhanced, because all costs and fees are in the open, the owner can better control budget and cost details as well as increase the project predictability.

This team chose to distinguish certain sub-phases as their own phase and determined the following: Programming/ Planning Phase, Selection of Design Team Phase, Selection of GC/CM Phase, Schematic Design Phase, Preliminary Design (Design Development) Phase, Construction Documents Phase, Construction Phase, Pre-Occupancy / Commissioning Phase, and Occupancy Phase.

Planning Process of Hinman Research Building

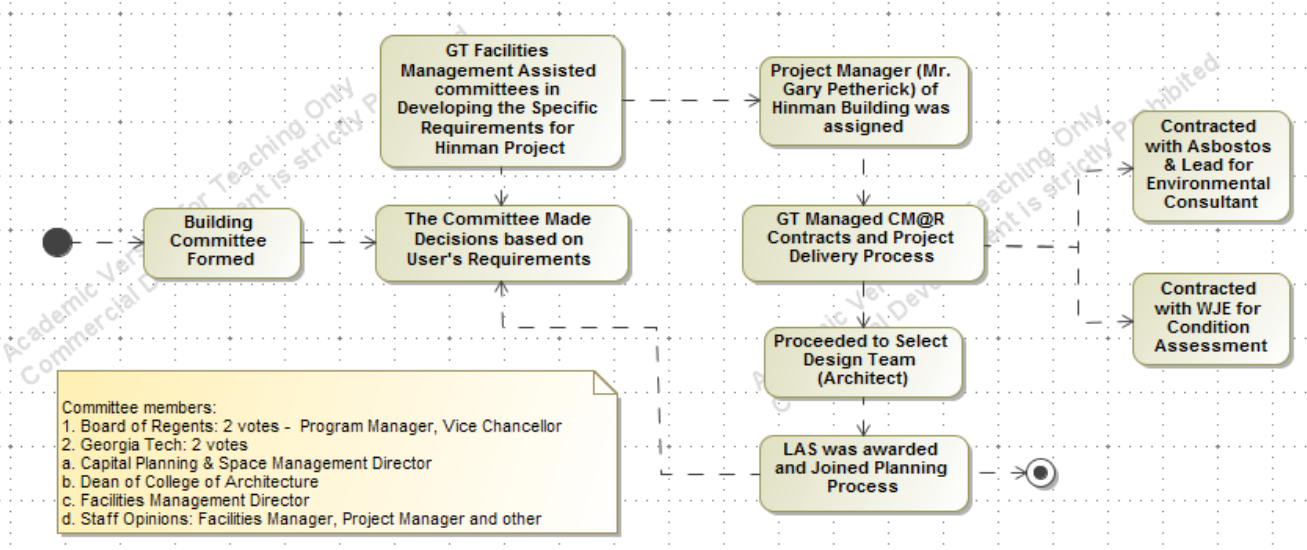


Figure 9-31. Programming and planning phase.

### Programming / Planning Phase

During the planning Phase, the building committee formed. Georgia Tech belongs to University System of Georgia, and Board of Regents (BOR) is the Owner and Georgia Tech the using agency, so the BOR has two votes and Georgia Tech has two votes to form the Building Committee. The Committee members are formed from Program Manager and Vice Chancellor of BOR, and Capital Planning and Space Management Director, Dean of College of Architecture, Facilities Director, Manager, Project Manager, and other staff from GT. Furthermore, the committee decided to have design team to involve in the project earlier, so they selected the Architect to participate in the programming. The scope of the project is “To rehabilitate, adapt and expand the capacity of the historically significant Hinman Building in a way that: 1) Recognizes, preserves, and rehabilitates the features of the building that give it its character, 2) Satisfies the programmatic objectives of the College of Architecture and Georgia Tech, and 3) Produces flexible and functional space that encourages interaction and collaboration for the College of Architecture”.

Design Team Selection Process of Hinman Research Building

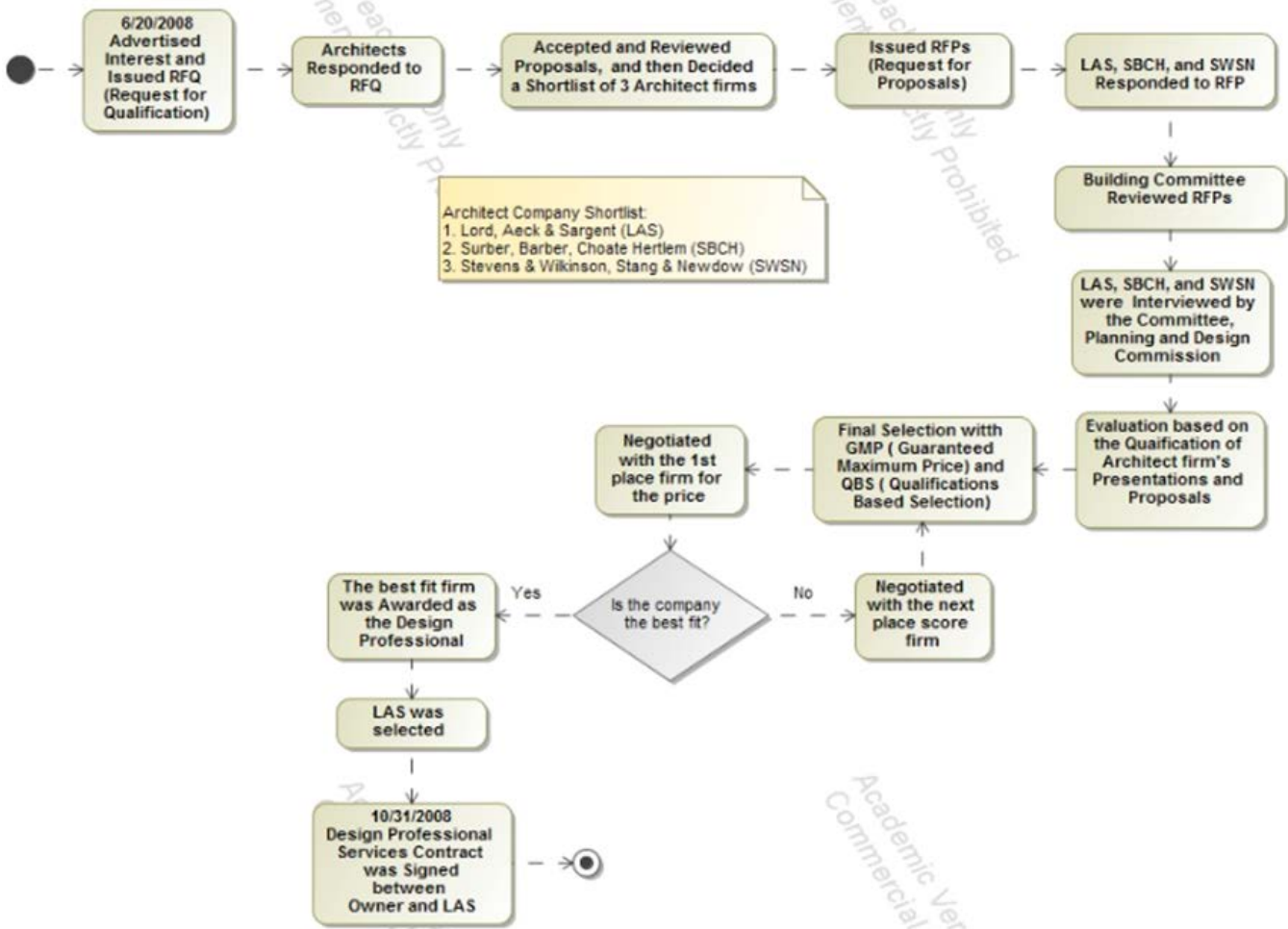


Figure 9-32. Design team selection phase.

### Design Team Selection Phase

The selection of design team was based on Qualifications Based Selection (QBS) procurement option. The process began with a Request for Qualification (RFQ), and then issued a Request for Proposals (RFP). During RFQ step, three firms were chosen based on the company’s qualifications and expertise. These three companies were Surber, Barber, Choate & Hertlein, P.C.(SBCH), Stevens & Wilkinson Stang & Newdow, Inc.(SWSN), and Lord, Aeck, & Sargent, Inc.(LAS). After the shortlist has been decided, the owner issued RFP, and the three firms responded to RFP. The committee then reviewed the shortlisted firms and had them to participate in interviews or presentations to the committee. Finally, after the three firms’ proposals had been evaluated and interviewed, the selection committee did a final group ranking and selected the design team, LAS.

### GC/CM Selection Phase

The process of selecting General Contractor / Construction Manager was similar to the Design Team selection process. The shortlists were HC Beck, Hardon, and New South. The awarded contractor was HC Beck Group.

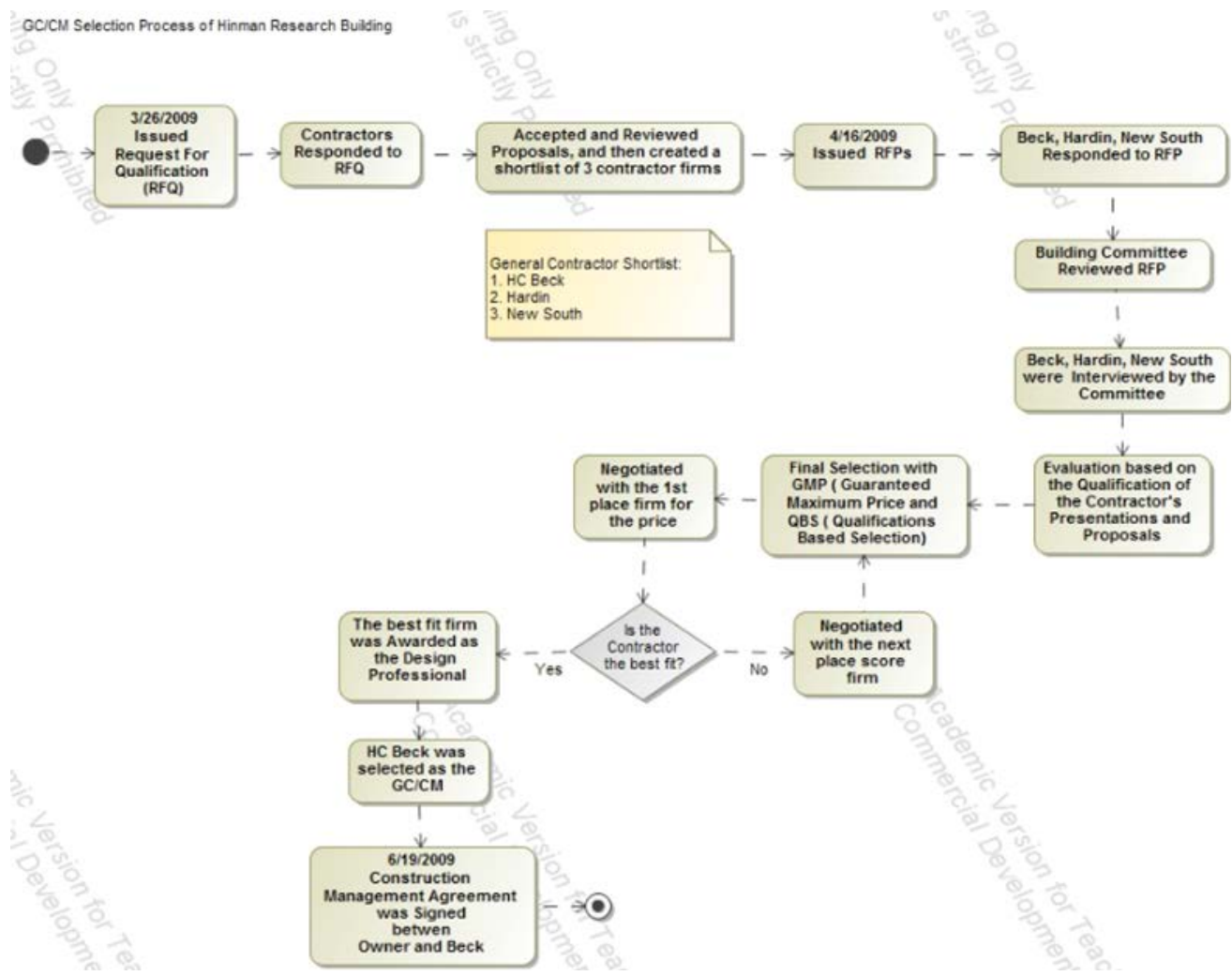


Figure 9-33. GC/CM selection phase.

Schematic Design Phase of Hinman Research Building

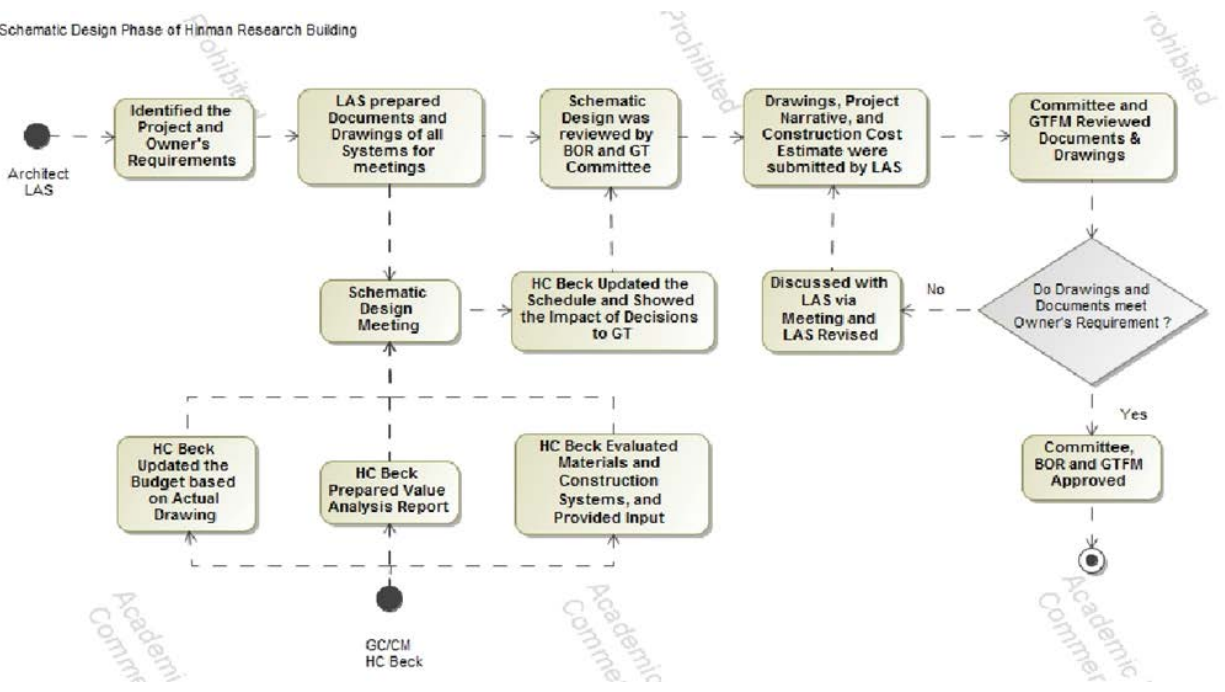


Figure 9-34. Schematic design phase.

**Schematic Design Phase**

The CM at Risk project delivery method allowed the General Contractor to act as a CM agent to the Owner during the Design Phase. During this Schematic Design Phase, LAS identified the Owner requirements and developed conceptual documents. The Beck Group updated the budget based on actual drawings, prepared Value Analysis Report, evaluated materials and construction systems to provide input to owner during schematic Design meeting. The BOR and the Georgia Institute of Technology for approval reviewed the Schematic Design documents. The Schematic Design documents comprised drawings, narratives, and construction cost estimates.

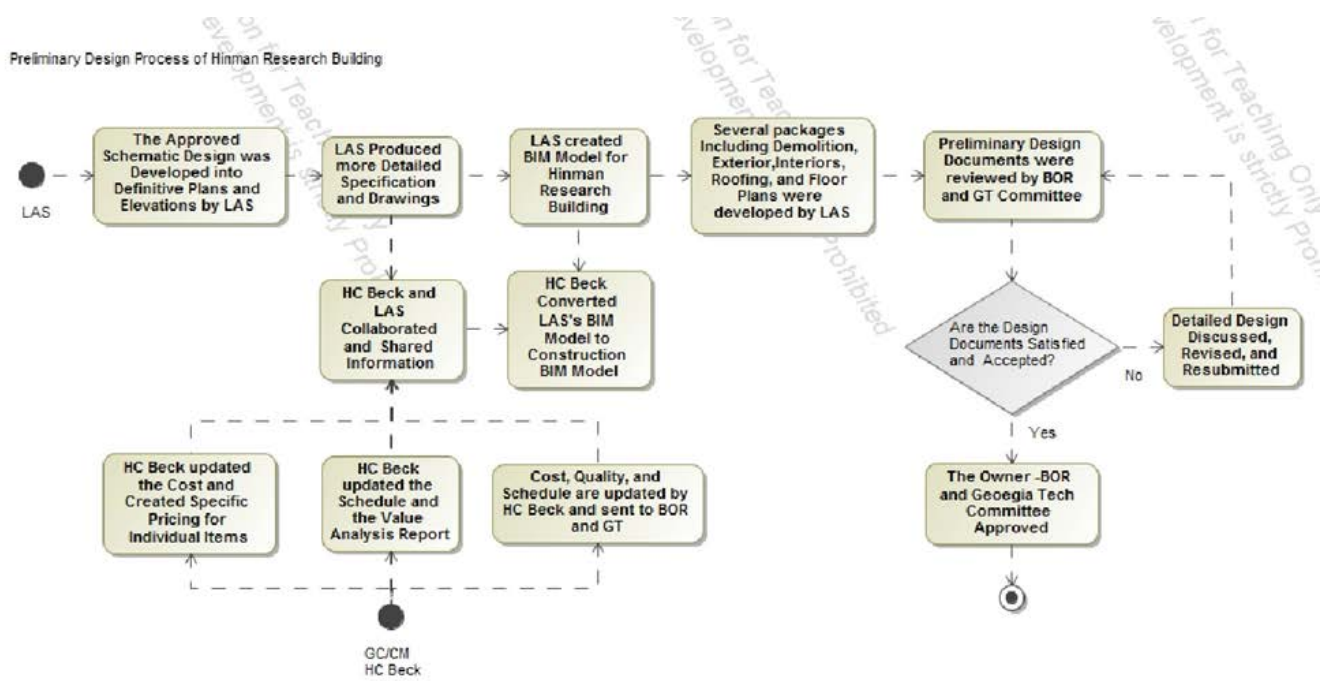


Figure 9-35. Design development phase.

### Design Development Phase

The beginning of Design Development is an extension of Schematic Design. During the Design Development phase, the specifications and drawings were further developed. LAS developed the approved schematic design into definitive plans and elevations, and collaborated with the Structural Engineer who identified conflicts between systems. Four packages of drawings and specifications including demolition, exterior, interior, roofing, and floor plans of Hinman Research Building were divided and developed by LAS. The Beck Group updated the cost and created specific pricing for individual items, updated the schedule and value analysis report. In addition, collaborated with LAS and adopted the design intent BIM model for the construction BIM model. At the end of the Design Development phase, multiple packages were reviewed and approved by the Owner.



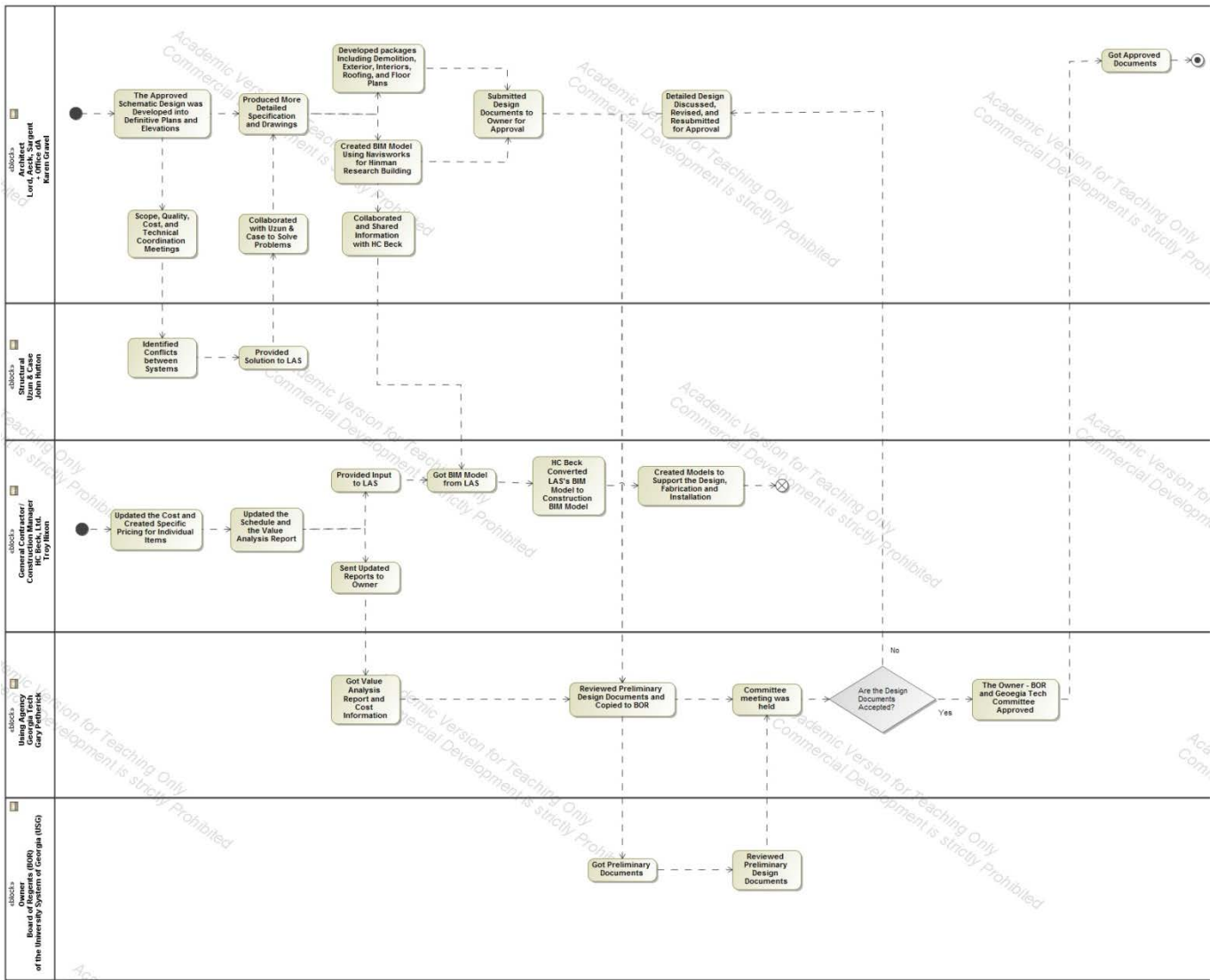


Figure 9-36. Activity diagram of design development phase.

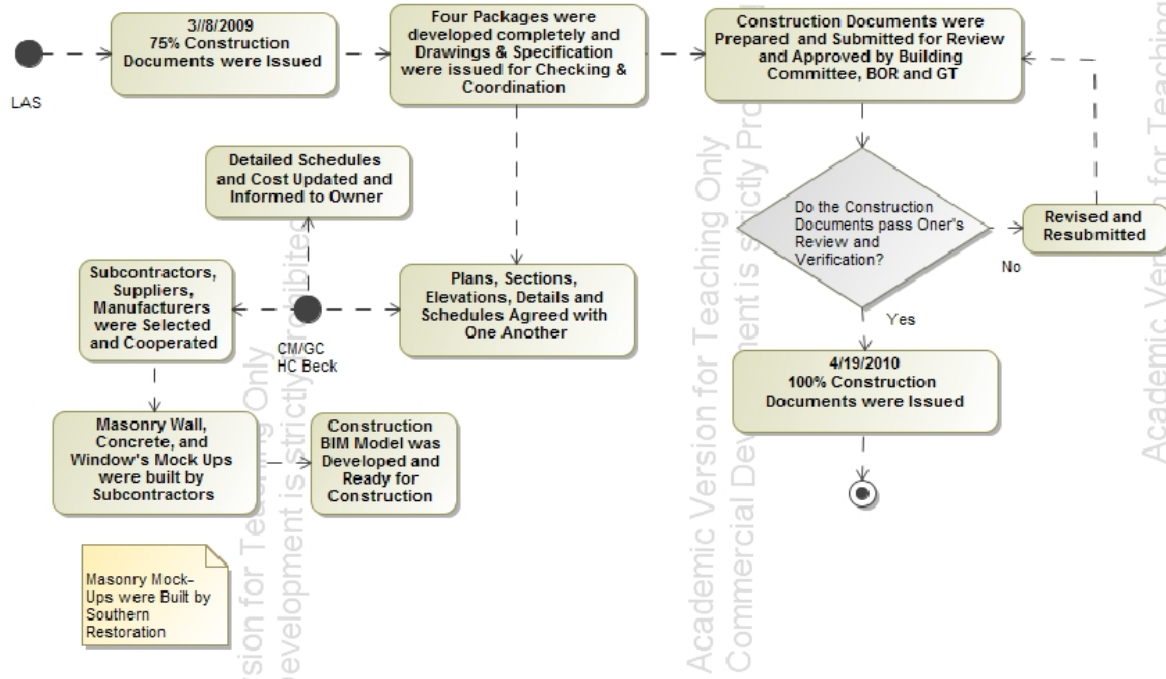


Figure 9-37. Construction documents phase.

**Construction Document Phase**

The Construction Documents (CDs) were prepared at a more focused, detailed scale than the schematic design or preliminary design phase of a project. CDs are legal documents that become part of the contract between the owner and CM at Risk. If there is any conflicting information in the legal CDs, the costly change orders can happen. Therefore, the early involvement of the CM can ensure more cost-effective design decisions.

During the Hinman Construction Documents phase, the Subcontractors, Suppliers, Manufacturers were selected. The Subcontractor’s responsibilities comprised renovating existing masonry walls and concrete, and generating window mock-ups per the drawing and specifications. In addition, schedules and cost estimates were constantly updated and submitted for review.

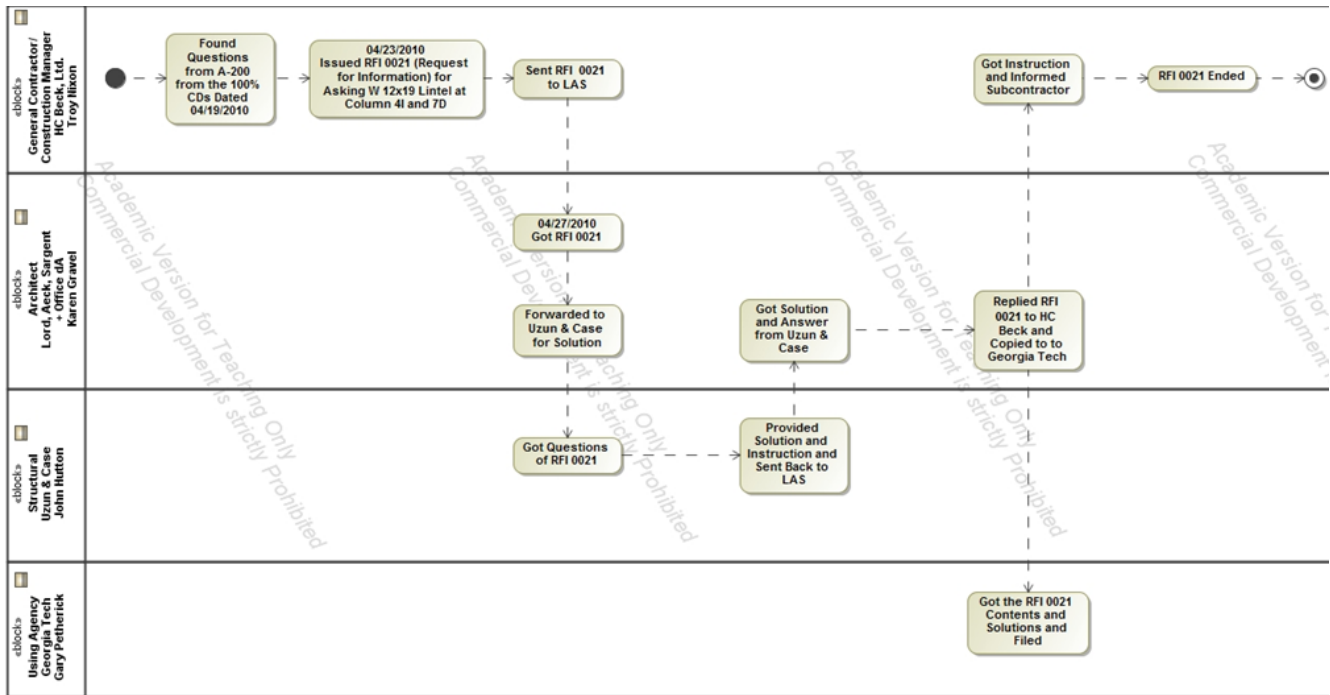


Figure 9-38. Activity diagram of RFI 0021 on brick masonry lintel detail.

### Brick Masonry Lintel Details

The RFI 0021 is an example that happened during Construction phase. The General Contractor, Mr. Troy Nixon from the HC Beck asked Ms. Karen Gravel, the Architect (LAS) to clarify the Brick Masonry Lintel Detail from the drawing A-200 of the 100% CDs dated 04/19/2010. The RFI 0021 is shown in Figure 9-39.

RFI # 0021

Is this a short W 12x 19 lintel (to match others)?  
Here is the opening at the 3<sup>rd</sup> floor level near Column 4I.

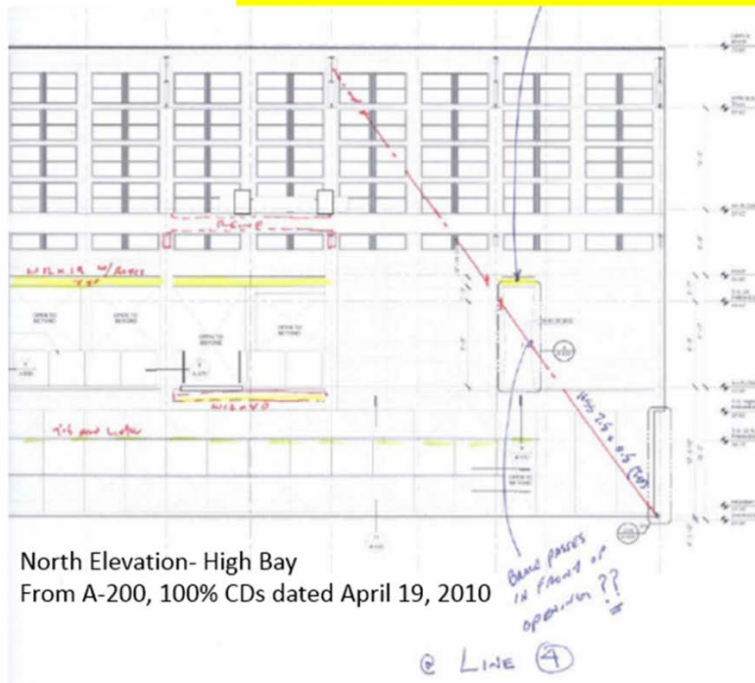


Figure 9-39. RFI 0021 on lintel detail.

When Ms. Gravel got the RFI 0021 from Mr. Nixon, she forwarded the information to the structural Engineer, Mr. John Hutton from UZUN&CASE for the solution. The solution was using the attached sketch (SSK-2) for revised detail 2/S002 for short masonry wall lintels. After the structural engineer provided the solution and instruction, Mr. Hutton sent back the solution with attached sketch to Ms. Gravel, and then Ms. Gravel (LAS) replied the RFI 0021 to Mr. Nixon (GC) regarding the instruction.

## 10. Young Harris College, Enotah Hall



Figure 10-1. Enotah Hall

Young Harris College in Young Harris, Towns County, Georgia had a new student housing facility constructed in 2008. The total campus area of Young Harris College is 30 acres, with a jobsite area for this particular project of 3.38 acres. The building was constructed in response to an increased need for student housing due to increased enrollment at the college. The College also used this project to assist with marketing and branding as Young Harris College aspired to become more recognized as a traditional 4-year university. This facility was an opportunity to explore some new architectural styles while refreshing some of the student housing and bridging some design gaps between older and newer construction on campus.

The final design was 62,645 total square feet of new student housing (see Figure 10-1). The building was a three-story building with 200 new residential units and a basement of 4,219 square feet for mechanical systems. Each unit consisted of two bedrooms, two bathrooms and a common living room. The university also sought to create a design that was capable of growing and changing with the university as it grew and changed. This desire would later become an important component of the decision-making for the final design.

What eventually became known as Enotah Hall at Young Harris College consisted of two separate wings of the facility, which met in the middle via a common, atrium area. The total construction cost of the building was approximately \$16M. Aside from the unique architectural and masonry features of the building, one of the most unique characteristics was that the project team sought and attained LEED Silver Certification upon building commissioning. This goal was an important consideration in the overall project design and when coupled with some of the unique masonry features, makes this building truly unique for Young Harris College. The final design was two separate wings that comprised the actual living space, joined at the center by a structural steel atrium. These structural interfaces presented some unique challenges to this building and required some additional engineering in the final building design.

### *Masonry Scope*

The major masonry systems for this building consisted of:

- Load-bearing CMU construction with structural steel tie-ins for the atrium in between the two wings of the building
- Brick skin over CMU walls with brick tie-ins
- Architectural cast stone
- Architectural masonry designs for brick, including herring bones, arched windows and window lintils. This included metal framed arched windows with masonry arched details.

There were several other masonry materials listed in the specifications, in addition to these major masonry design components.

### *Stakeholders*

The stakeholders on this project are as follows:

- Young Harris College: The building is owned, financed and operated by Young Harris College
- Brailsford & Dunlavey: This company was responsible for program management for this project
- Lord, Aeck & Sargent: This is the architectural firm that delivered architectural and design services
- Eberly & Associates: This firm had the responsibility for the civil engineering and landscape architecture services
- KSi: This is a structural engineering firm that was responsible for all associated structural engineering services

- Andrews, Hammock & Powell, Inc.: This company was responsible for all mechanical, electrical and plumbing work as well as the delivery of the fire protection systems
- Hardin Construction Company, LLC: Hardin was the construction manager for the delivery of this project
- Zebra Construction: Zebra was the major masonry subcontractor for this project
- Cherokee Brick and Tile Company: This was one of the major masonry suppliers for brick and cast stone
- Hanson Brick: Masonry supplier for brick
- North Georgia Brick Company: Masonry supplier for brick
- Holcim Masonry Cement: Masonry mortar supplier
- Bradley Block Company: Structural CMU supplier

### **Project Schedule**

The construction progress schedule was managed by the construction manager per the contract requirements. As to the masonry component, the mason materialmen and supplier subcontractors coordinated their buyout and construction progress with the construction manager. The third party project manager was responsible for managing the overall project schedule on behalf of the owner. The overall construction schedule was bolstered with early masonry construction. They used high-early concrete at the cast-in-place foundation walls. The completion of the majority of the load-bearing masonry walls prior to cold weather also allowed for an early start and avoidance of probable weather delays in the structural component.

### **Structural Analysis**

A structural analysis of several different designs was a major component of this project. Pursuant to this effort, the engineer submitted three system options: light gauge metal framing, block and plank, and concrete frame. The owner wanted the flexibility of re-purposing in the future if need be. They did not want a facility that would have to be torn down should its use need to be changed from housing to an academic or administrative purpose. Given the desire for flexibility, the use of light gauge steel frame was ruled out. The construction manager's familiarity with the block and plank system, and the design professional and owner's preference for a masonry backup for a brick veneer wall, made the block and plank system the most viable option. It was also within the project budget allowance.

### **Cost Estimation**

The construction manager engaged in a few cost estimates during the preconstruction activities, as per contract requirements. Pursuant to the masonry component the structural engineer presented cost estimates for lateral forces in reviewing an additional level of plank which would have required roof framing members be erected. The result of estimate was reversal to the engineer's initial proposal for a bearing plank on the two exterior walls and one corridor wall. The cost effectiveness of all alternatives and system options were reviewed in like manners. Another example of estimates being used to decide between alternatives, was where the two wings integrated. The estimating effort by the construction manager and design professional resulted in a structural steel and composite deck so they could give the owner the span and height they wanted in this space.

## Modeling by Specification

One exercise this project team conducted for the case study was modeling a wall section based on specifications. This would allow stakeholders to identify correlated work tasks and better coordinate the workflow on a job site. For this exercise, group dissected a specific wall section of the construction drawings. Each component was identified and cross-referenced according to the construction specs. Based on the specifications the group decided which areas would require coordination beyond just the general contractor and the masonry contractor. Each component was tied to the trade contractor that would be responsible for the installation. These coordination items were prepared in a spreadsheet that dissected a standard masonry wall from this project by trade and contract specification (see Figure 10-2).

No.	Activity	Installer	Material Requirements	Labor Requirements	Equipment Requirements	Info. Required from Model	Coordination with Mason
09260.GW	Gypsum Wallboard	Drywaller	Gypsum board	Drywall crew	Small hand tools	Dimensions	Yes
04810.CM	Concrete Masonry Units	Mason	CMU, mortar	Masonry crew	Lifts, mortar mixer	Dimensions, block type, mortar specs	Yes
04810.FB	Facing Brick	Mason	Facing brick, tie-in, mortar	Masonry crew	Lifts, mortar mixer	Dimensions, block type, mortar specs	Yes
07280.I	Insulation	Insulation contractor	Insulation material	Insulation crew	Small hand tools	R-values, insulation specs	No
07280.WR B	Weather-Resistant Barrier	WRB Contractor	WRB material	Installation crew	Small hand tools	WRB material specs	No
07280.M	Mastic	Mason	Mastic	Masonry crew	Small hand tools	Mastic specs	Yes
03300.PTS	Precast Topping Slab	Structural	Precast slab	Structural crew	Crane, lifts, other HE	Slab dimensions	Yes
03420.PCU	Precast Concrete Units	Structural	Precast concrete units	Structural crew	Crane, lifts, other HE	Precast concrete specs	Yes
04810.VA	Veneer Anchors	Mason	Anchors	Masonry crew	Small hand tools	Anchor specs	Yes
07650.SF	Sheet Flashing	Mason	Flashing	Masonry crew	Small hand tools, metal brake	Flashing spec	Yes
07650.ME	Metal Edge	Mason	Sheet metal	Masonry crew	Small hand tools, metal brake	Measurements, dimensions, steel specs	Yes
07900.JS	Joint Sealant	Mason	Sealant	Masonry crew	Small hand tools	Sealant specs	Yes
02780.SSPi	Sand-set Pavers	Mason	Pavers	Masonry crew	Lift	Paver specs and dimensions	No
05300.RD	Steel Roofing Deck	Roofer	Steel roofing deck materials	Roofing crews	Lift	Dimensions, steel specifications	No
09260.FS	Metal Stud	Framing contractor	Metal studs	Framing crew	Lift, small hand tools	Dimensions	No
07466.SP2	Soffit Paneling 2	Roofer	Soffit paneling material	Roofing crews	Small hand tools	Dimensions	No
07466.LSV	Liner Soffit Vents	Roofer	Soffit vents	Roofing crews	Small hand tools	Dimensions	No
07466.T	Trim	General Contractor	Trim materials	Installation crew	Small hand tools	Material type, dimensions	No

Figure 10-2. Table of model specifications.

## Masonry Wall Mockups

Similar to the EBB, this project also required mockups to be constructed to test the masonry walls and their systems, including flashings and openings. The mockups were also part of the final deliverable from the construction manager and, ultimately, the masonry subcontractor to the owner (see Figure 10-3).



Figure 10-3. Mockup of masonry wall system.

### **Schematic Design Phase**

The masonry system used for the design of the building is load-bearing CMU with a brick veneer. The brick is little more than a façade to facilitate the architectural design that both the owner and the architect were seeking in the final product. It is the load-bearing CMU that is the most interesting from a design perspective. The decision to pursue load-bearing masonry was a combined architectural, engineering and owner-drive decision. The initial design sought three different options for the structural design. These designs included load-bearing CMU as a block and plank system, load-bearing CMU with steel framing and cast in place walls. These three options were fed into a design decision. The steel framing was eliminated because the owner desired to have the ability to adapt the building for future purposes. Steel framing would be expensive to reconfigure and was therefore eliminated. The cast in place design was eliminated because of cost and project timeline. Curing the cast in place design would be impossible during the winter months and would therefore cause an undesired level of project acceleration. This left the design team with a block and plank design. Still, the specific design drawings were yet to be completed.

### **Design Development Phase**

During the next phase of the design, the team examined how to create the load-bearing design. Two options were explored. The first, proposed by the structural engineer was spanning the planks over the two exterior walls and one dividing wall on the interior of the building. The construction manager proposed the use of demising walls to bear the load. The structural engineer examined both options from a cost and feasibility perspective.

With the structural design in place, there were some additional design decisions that related to the final design. The design called for two specific wings of the building that would need to be joined in the center. The owner desired an open collaborative space that met the social needs of the students, while enhancing the LEED goals of the building. Because of this, an open atrium was designed to conjoin the two separate wings. In order to achieve the open concept and the height that they wanted to achieve with the ceilings, the design incorporated a structural steel frame for this specific portion of the design. Because the major skin design was masonry, as requested by the owner, a decision was made to incorporate large arched windows with masonry detail to tie the two buildings together. These masonry features became a unique part of the design. The owner's goal was to incorporate design elements of new and old architectural styles on campus. The large



arched windows were an important part of this design and were a special coordination piece between the masons and the contractors who were installing the glazing.

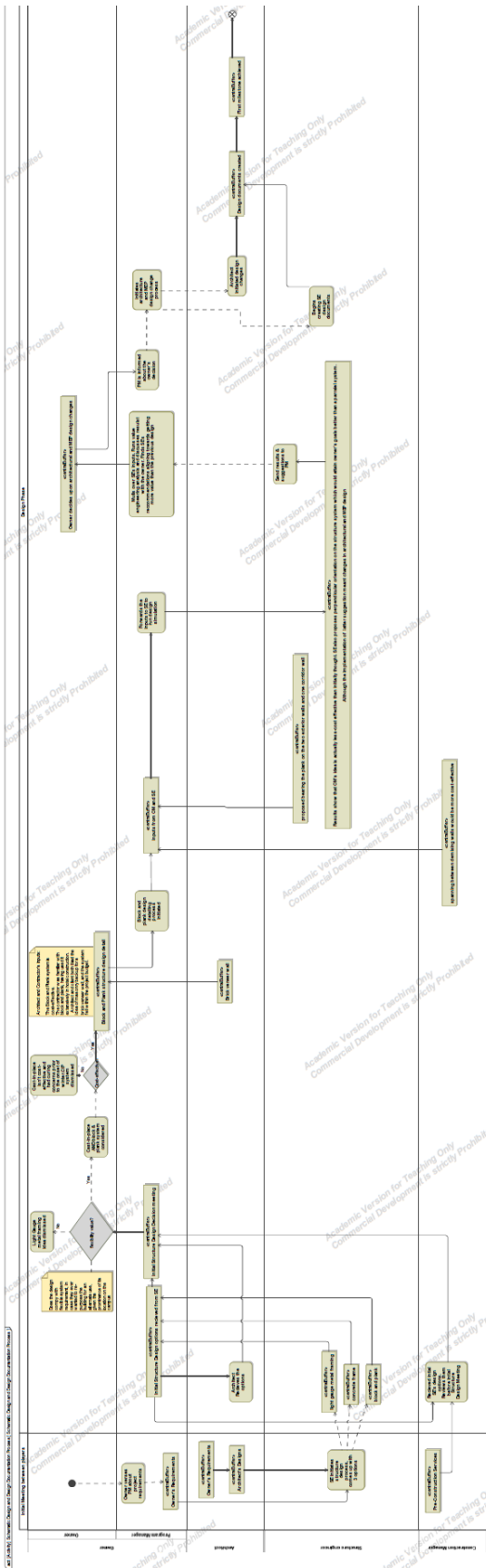


Figure 10-4. Schematic design & design development phases.

## **Construction Documents Phase**

This project did not coordinate the use of BIM or any other 3-d modeling and design application. Lord, Aeck and Sargent developed the design documents along with the KSi and the owner. These design documents were procured in a traditional design-bid-build method. Once the design was developed and reviewed and approved by the owner, they were issued as part of an RFI for general contractors to bid. Once the bids were complete, the construction documents were issued in .pdf format for coordination with subcontractors. The subcontractors developed shop drawings based on the design specifications. The shop drawings were routed through the general contractor to the architect for approval as part of the submittal process. Once approved, the subcontractors were free to execute the work according to the specifications, design documents and shop drawings. One thing that differed for this project specifically was that revisions were captured in drawings and not necessarily in a re-issue of the plans. This allowed for efficiency for field use but created the need to capture all design changes in the final drawings at the completion of the project. The contractor had to pay careful attention to track changes.

## **Contractor Coordination Phase**

An analysis of the RFIs that were issued during the construction of this building indicates a more traditional RFI process for design-bid-build projects. The typical RFI process would start with a recognized ambiguity or need for additional clarification in the design documents. This is typically done by a subcontractor prior to or while performing work. Work lags while the RFI process is completed because subcontractors do not want to complete their portion of the work with inadequate information. A formal RFI is drafted by the subcontractor and routed through the general contractor. The general contractor reviews the RFI and forwards it to the architectural and engineering team.

In the case of this project, clarification was necessary for the lintels. The mason recognized the need for a design change based on the size of the opening. Instead of a lintel with 2 #4 top and 2 #6 bottom lintels, the mason proposed using 2 #5's for the top and bottom. This seemingly insignificant change required routing through the architect. In this instance, it was three days from when the RFI was made to when the approval was issued. The RFI was routed through the GC to the architect. The architect reviewed, provided approval to the general contractor, who then provided approval to the subs. During this time no lintels could be completed.

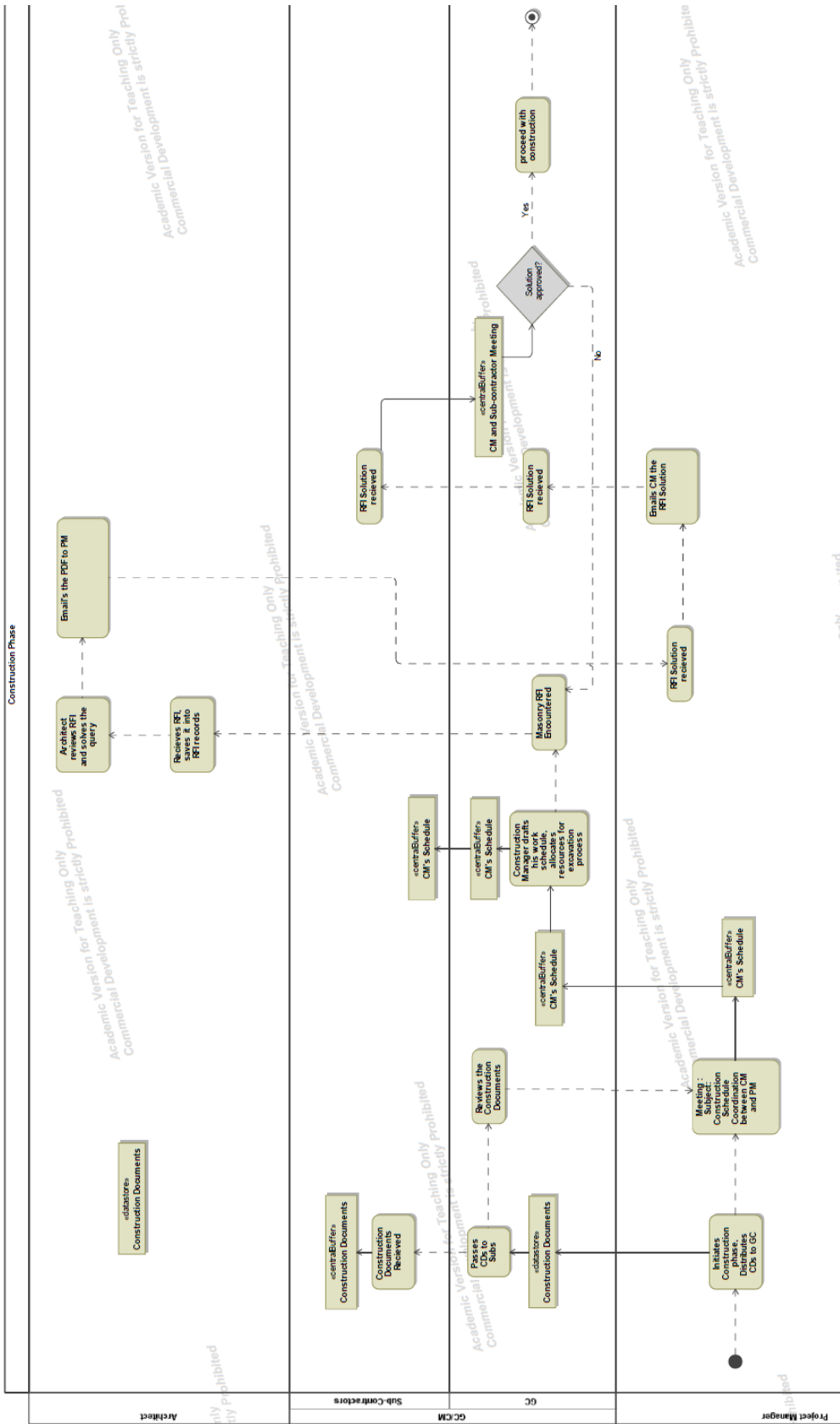


Figure 10-5. Contractor coordination - RFI.

### Subcontractor Installation Phase

The arches in this project are all non-structural in nature. Non-structural arches require support by other elements. Many arches used today are non-structural, built purely for aesthetics. Structural support of the arch may be required because of insufficient arch or abutment strength or the lack of a structural analysis of the arch. Support is provided by a lintel which spans the opening or by a shelf angle which is attached to noncombustible materials.



Figure 10-6. Segmental arch with herringbone pattern.

This particular design element of the façade was not part of the initial plans. Due to change in plans of the interiors, openings had to be closed. Architect proposed use of Herringbone to fill up the openings to add to the aesthetics.



Figure 10-7. Flat gauge arch.

This arch is located at the windows of the rooms. A flat horizontal soldier course is done across the lintel level and an inclined rowlock course is done at the sill level.



Figure 10-8. Masonry arch window.

Semi circular Arch: The arch is non-structural in nature, part of the brick façade and made of twin rowlock brick course. The joints between the brickwork form a distinct semi-circular line to provide definition to the façade.

Construction Process of Segmental and Flat Gauge Arch:

- The masons set the profiles of the face plane and then ensure they are plumb. The gauge is marked on both sides.
- The mason then follows the line level and face plane to begin laying abutment bricks. A constant check on level and plumb is kept.
- One the springer brick (form where the arch begins) is laid, install the wooden framing with jambs on each side
- The formwork for arch is leveled and plumbed. The center is marked. The formwork is then taken off and laid flat on ground
- The bricks are placed vertically with rowlock face and then mason marks their positions on the formwork.
- The marked formwork is then placed on the jambs, leveled and plumbed. With the help of brick position marking, bricks are laid on the arch formwork keeping to gauge marks. The bricks are leveled across to prevent crabbing. This process is repeated on from both sides until the key brick is reached at the crown. Also since it's a nonstructural arch, the flashing would be placed above the steel. A semi-circular arch is more difficult to flash properly. This is because flashing materials such as metal flashings are very rigid and may be hard to work around a curved arch
- Flashing an arch can be difficult, depending on the type of arch and the type of flashing material. Flat gauge arches are the easiest to flash because they are flat.
- Flashing may be placed below the arch on the window framing for structural arches or above the steel lintel for non-structural arches.
- Alternately, flashing may be placed in the mortar joint above the arch or keystone. Attachment of the flashing to the backing and end dams should follow standard procedures

- According to Brick Industry Association Technical note 31, the Centering formwork is kept in place for 7 days in warm weather. Post that, the wedges, props, supports and arch formwork can be removed. The arch joints are pointed and grouted for good finish.

Construction process of Semi-Circular Arch with steel supports:

- The construction of the Semi-Circular Arch differs from the other two types of arches due to its location. This particular section of the building is construction with steel framing.
- Thus the steel window frame came in first with the rest of the steel structural components. The arch section of the steel window frame acted as the centering support during the brick arch installation.
- Typical arch construction procedure is followed with twin rowlock course. Flashing is done along with masonry. A segmental or semi-circular arch is more difficult to flash properly. This is because flashing materials such as metal flashings are very rigid and may be hard to work around a curved arch. That is probably the most intricate part of the arch construction.
- The glazing components are installed post-arch completion.

### **Future State**

The future state of masonry will be dependent on data integration. Most other industries have already achieved some version of information modeling in order to achieve efficiency and save costs. This goal of this case study has been to analyze the construction processes used for Young Harris Enotah Hall and predict future states. This team elected to take this research a step further by projecting what immediate technologies were available to the masonry industry to make data integration more achievable. By using relatively simple software applications that may be BIM-capable in the future, the masonry industry can hope to become a leader in data integration. Perhaps, through modeling complex construction processes, such as the installation of masonry, the industry can contribute to better integration across multiple disciplines in the future (see Figure 9-9).

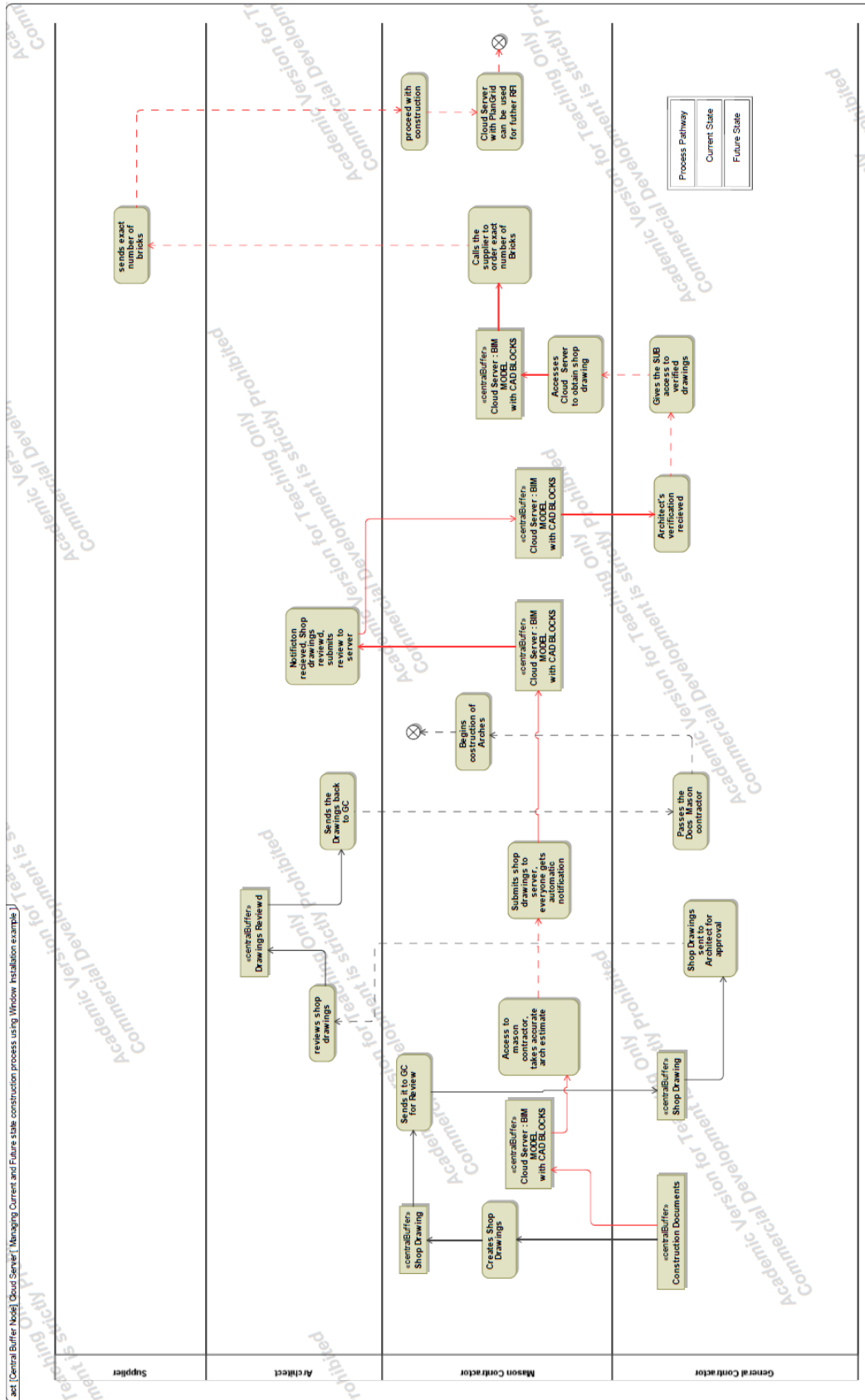


Figure 10-9. Proposed future-state mobile collaboration.



## 11. Conclusions

Current masonry construction processes are manual. Handling masonry units and laying brick and block are still done by hand and require great effort and labor by mason crews. Although advanced tools, such as robotic automation and pre-fabrication, are being researched and developed, they have not been fully realized or adopted in masonry construction practices.

Construction documents are primarily created and maintained as paper copies, and any models created with software tools rarely contain useful masonry details. Site coordination involves face-to-face communication and relies heavily on paper drawings. Due to these weaknesses, the masonry construction industry may fall behind as the rest of the AEC industry continues to progress. Throughout the case studies, these problems are evident and could be attributed to a few key issues: a disconnected industry and system, inadequate preparation, and the absence of sufficient management and organization. These issues could be addressed through early integration, early planning, and better onsite coordination.

For better integration, more information on masonry systems and components being used or considered is necessary, including geometric and functional coordination. A more cohesive design and analysis process between architects and engineers, including structural and MEP, would greatly improve the effort towards better and earlier project integration.

In order to have a well-planned project, we need to know what goes where, when, why, how, and by whom. Better planning leads to better scheduling and better quantity takeoffs. By knowing these details, considerations of labor and supply chain management could be made well in advance. This will also improve the understanding of sequence dependencies among different assemblies throughout the project lifecycle. Overall, early planning will result in better cost estimation.

Better onsite coordination is crucial to having a construction project finish on time or early, with the least number of errors and high quality. Project stakeholders need access to the right information at the right time while on the construction site. Furthermore, crews, equipment, and supplies should be readily available and well-coordinated.

A systems modeling workflow can be used to help document and analyze the observations made in case studies. This model-based systems engineering tool can describe, in detail, the various processes and elements, including activities, stakeholders, tools, materials, and information, involved in masonry construction. SysML models allow us to view and access all the relevant data of specific masonry construction processes that cannot be achieved as easily through a paper-based workflow and current masonry industry processes.

The case studies and SysML documentation inform the necessities of BIM models and BIM-based processes in masonry construction. Today, BIM has minimal benefit for masonry construction, since BIM models only show 3D solids with nominal details of masonry buildings. This research begins to identify the who, what, when, where, why, and how of masonry constructions processes that are required for BIM implementation.

The initial findings from this research reinforce the fact that BIM for masonry will only be implemented successfully if we understand the various transactions, queries, and analyses that occur in the masonry industry and develop the software-enabled workflows that facilitate these activities. This benchmark project will be critical as the BIM-M research transitions to Phase III with BIM-M software specification. These case studies are substantially important on their own. However, further case studies of similar and other masonry construction projects are needed. Ideally, each case study criterion for the masonry industry should be

represented (i.e. one cell in the 3D visualization guide), so that the analyses and documentation are as comprehensive as possible. Furthermore, industry validation of these masonry construction processes and workflows are needed. This research provides the foundation for creating the requirements and tools to implement BIM for masonry.