BIM for Masonry: Development of BIM Plugins for the Masonry Unit Database

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Masonry Unit Database (MUD) is an integral part of Building Information Modeling for Masonry (BIM-M) initiative. MUD provides a data structure framework for storing the required data for digital representation of masonry units. Specific information about masonry units such as price, geometry and physical properties is needed throughout the lifecycle of a building project, including the design, construction, maintenance, and demolition stages. The development of MUD contributes to enhancement of masonry BIM tools for practitioners to incorporate up-to-date masonry product information into their projects. There are five main stages in the development of MUD: development of process map of masonry building project lifecycle, data requirement identification, physical design of database, design of data import structures, and finally design of data export structures. This paper focuses on the development of the SQL based MUD, and a Revit-Dynamo data export plugin for this database. The developed plugin is especially beneficial as it provides a tool for fast and accurate generation of the parametric and data enhanced masonry units as Revit families on the fly from the stored dimensions and attributes in the database. The generated masonry units with this method would be embedded in masonry wall systems in BIM building project.

Keywords: *BIM, Masonry, Relational Database, Building Object Model, SQL, Revit, Dynamo*

INTRODUCTION: MUD AS A BOM PORTAL

Building Information Modeling for Masonry (BIM-M) is an initiative in North America to implement masonry materials and systems in BIM software for AEC industries. This initiative is in nature similar to previous endeavors for the development of Building Information Modeling standards for other architectural and construction systems including steel [1], precast concrete [2], and cast-in-place concrete [3]. The BIM-M initiative involves industry trade associations, all stakeholders in masonry industry, BIM and other software providers to the AEC industry, and subject matter experts (Sharif et al. 2015). The main goal of the project is to develop a BIM data model for masonry with embedded semantics to describe the characteristics and functions of building systems, facilitating collaboration and information exchange across all disciplines involved in a building project.

This paper focuses on the development of Masonry Unit Database (MUD), one of the main subprojects of the BIM-M that is a data structure framework for storing and sharing the required data for digital representation of masonry units, including clay brick, CMU, cast stone, and cut stone. The necessity for the development of MUD derives from the fact that there are thousands of masonry product manufacturers, where each produces many products to fulfill a wide range of architectural requirements (Arnold and Wishart 2008). In general, building products along with other construction materials typically account for 40- 45% of the cost of all construction work (Kong et al. 2005). Specific information such as price, geometry and physical properties is needed throughout the lifecycle of a building, including the design, construction, maintenance, and demolition stages. Consequently, access to the comprehensive and updated masonry products information is crucial for AEC practitioners in any masonry building project (Kong et al. 2005, Kong, Li, and Shen 2001).

While traditionally masonry product information was available in paper-based catalogues, or recently the same type of data on the manufacturers' online websites, the advancement of BIM tools and online systems has provided more efficient means for practitioners to acquire useful products information digitally. For the development of MUD, the masonry units have to be defined as Building Object Models (BOM). There are certain required information for BOMs to be fully embedded into BIM models, and enable material selection and comparison. Eastman outlines these primary required information for BOMs as: 2D or 3D geometric representations of physical products, parametric geometry (if not fixed), material representation, connection locations and requirements with other systems, performance specifications, maintenance cycle, and other specifications used in product selection, and finally Links to product distribution channels (Eastman et al. 2011).

The import of Building Object Models from BOM libraries or portals into BIM design platforms and their integration into building projects supports interoperability and interfacing with other tools for cost estimation, system analysis, and building code and building program assessment applications, among others. BOM portals serve as Web access points for building objects (Eastman et al. 2011). These portals primarily support hierarchical navigation, search, download, and in some cases upload for BOM files. Some examples of product library portals are Autodesk SEEK, ARCAT, SmartBIM, NBS BIM library, McGraw-Hill Construction Sweets Network, ArchiBase. The development of MUD as an instance of a BOM Portal will provide a more efficient tool for practitioners to acquire up-to-date product information about all range of masonry units for their BIM masonry projects.

MUD DEVELOPMENT PROCESS

In this research, five main steps in the development of a comprehensive Masonry Unit Database have been identified (Figure 1). First stage is the development of a process map for the representation of a BIM-enhanced masonry building project lifecycle, which involves different stakeholders and the exchange of information among them in different stages of the project (Gentry et al. 2014, Witthuhn et al. 2014). Second, based on the defined exchange requirements, the specific set of masonry data has to be

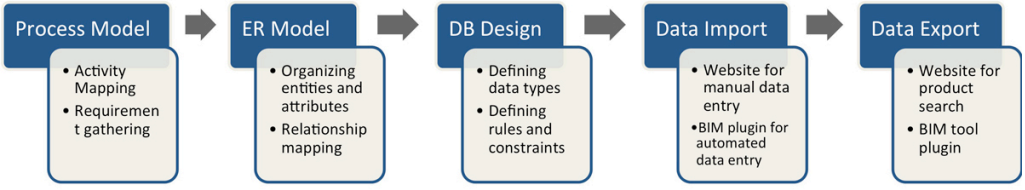


Figure 1
Five stages of MUD development

identified. The data requirement determines how the main attributes of the masonry products have to be classified (Sharif et al. 2015). These attributes include geometry, material, physical properties, color, texture, manufacturer, suppliers, etc. The third stage is the design and implementation of the database where all the masonry unit data is stored in a structured system, which can be accessed by different project actors in different stages of a BIM project. After the development of the MUD back-end structure, at the next two stages, the front-ends of MUD, the access structures for both data import and data export have to be designed and implemented.

PROCESS MODEL AND DATA REQUIREMENTS

The first step in the development of MUD is to assess the required information about masonry units to support a given design or construction process in different use scenarios and workflows in the lifecycle of a BIM building project (Figure 2). In this context, workflows are defined as business processes that involve stakeholders, exchanges of information among them, and their access to the MUD in different stages. The main stakeholders can be categorized into product manufacturers, product suppliers, trade associates, clients, and on the AEC side, architects, engineers (structure, mechanical, and energy), contractors and fabricators. This research has adopted a formal method for documenting these processes using Business Process Modeling Notation or BPMN [4]. Detailed description of the complete proposed workflow for BIM masonry projects has been reported by BIM-M research group (Gentry et al. 2014). A segment of the masonry project workflow in the design development and construction documentation phases for the structural design and modeling is shown in figure 3. In this stage of the process for the structural analysis of the project, structural engineers would need to query MUD for geometric, and mechanical and physical properties data of masonry units that have been specified in the BIM model by the project architects (Figure 3).

SCHEMA DESIGN AND ER MODEL

The main part of MUD is a database that stores all object data in a structured system, which can be accessed with different BIM building project actors via software tools in different stages of a project. Based on the information gathered from the stakeholders and domain experts in the workgroups and modeled in the process map, the masonry unit information requirements was classified in a conceptual schema in order to be use for database design. For the development of MUD, Entity-Relationship model (ER model) has been acquired that is a high-level conceptual schema with the ability to describe in detail the entity types, relationships, and constraints of masonry units (Navathe and Elmasri 2010). Conceptual schema is easier to understand and communicate with nontechnical users, as concepts do not represent implementation and storage details. Readability by nontechnical users is an important aspect that ensures the complete identification of users' data requirements and prevents any possible requirements

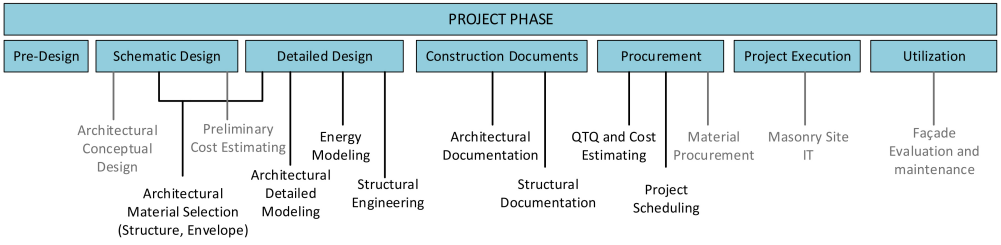


Figure 2
Masonry design and construction project timeline with project phases and proposed masonry material workflows

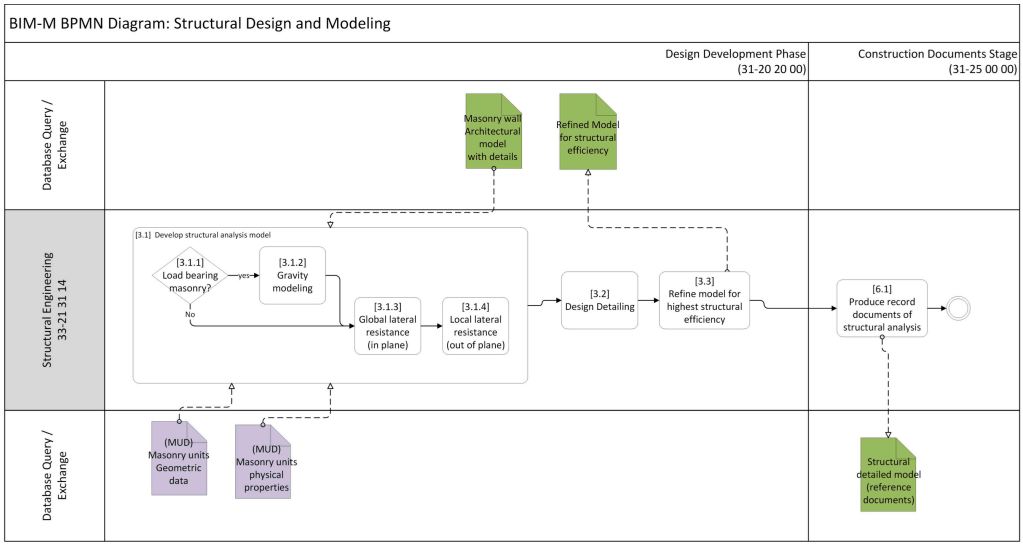


Figure 3
Structural engineering analysis and construction documentation workflow

conflict. The complete developed ER model for MUD is shown in Figure 4.

DATABASE PHYSICAL DESIGN AND DATA INSTANTIATION

At the next stage, the developed ER Model was translated into SQL, a Relational Database language, by using Microsoft SQL Server environment as the RDBMS (Relational Database Management System) (Navathe and Elmasri 2010). The developed database includes the requirements needed for MUD logical and physical design choices and physical storage parameters, as well as detailed specification of data elements, data types, and indexing options. The MUD SQL database is composed of the following tables: Unit, Geometry, Material, Physical Properties, Color, Texture, Manufacturer, and Supplier (Figure 5).

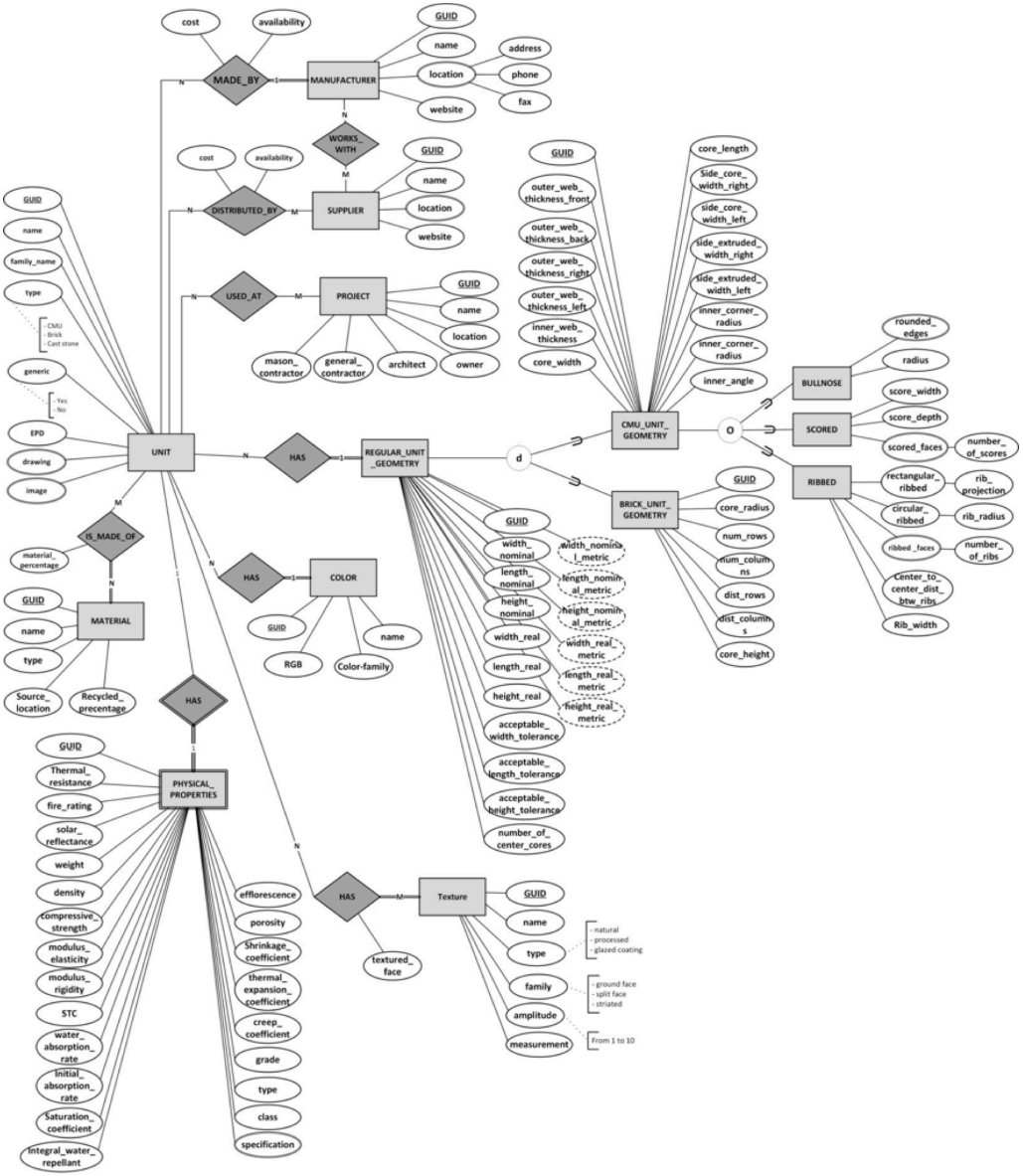
For the fulfillment of the MUD physical design, the database was instantiated with data for about 90 masonry units (Clay Brick, and CMU) from various manufacturers, in order to test the data requirements and relationships. As a result, the database data structure was edited to be able to incorporate all possible masonry unit requirement and data formats.

MUD ACCESS: DATA IMPORT AND EXPORT STRUCTURES

After the initiation of the central RDBMS for MUD, data import and export structures for automated access to the database have be to be developed. MUD can work with two different types of access gates: web based front-ends, and plugins for BIM platforms, both with direct access to the database for data read-/write (Figure 6).

The data input structure would be accessed by the masonry product manufacturers, material suppliers, trade associates, in addition to database managers. Producers and suppliers of the masonry products can import and update their products information into the database, which later can be access by the other stakeholders involved in the masonry projects. Although at the current stage, the data write is performed by database managers, in the fu-

Figure 4
MUD Complete ER Model



ture development of MUD two automated system of data import is envisioned. First a web-based front-end with direct connection to the database, and second a plugin for BIM platforms with access to the database for extraction of masonry unit information from masonry unit 2D or 3D models and import to MUD SQL database.

After the compilation of new or the update of the existing data of masonry units by product manufacturers and suppliers, BIM-M users need to access this information for the project development and embed in the BIM models. The same as the data import tools the data export can be performed through web-based application or plugins for BIM software tools.

Development of MUD Hosting and Search Website

At the current stage, two main export access gates for MUD are under development. First, a web-based access platform that would provide search, view and compare of masonry units for the users. As the developer of product hosting and search website, CODIFYD company has been collaborate on this stage of the project. CODIFYD has incorporated the developed SQL MUD database by Georgia Tech team, into their XML based search tool, Bridge. They populated the new web-based version of MUD with more than 1000 modules from two main masonry manufacturers with 3D, and color and texture images. This MUD web-based front-end can be accessed online [5].

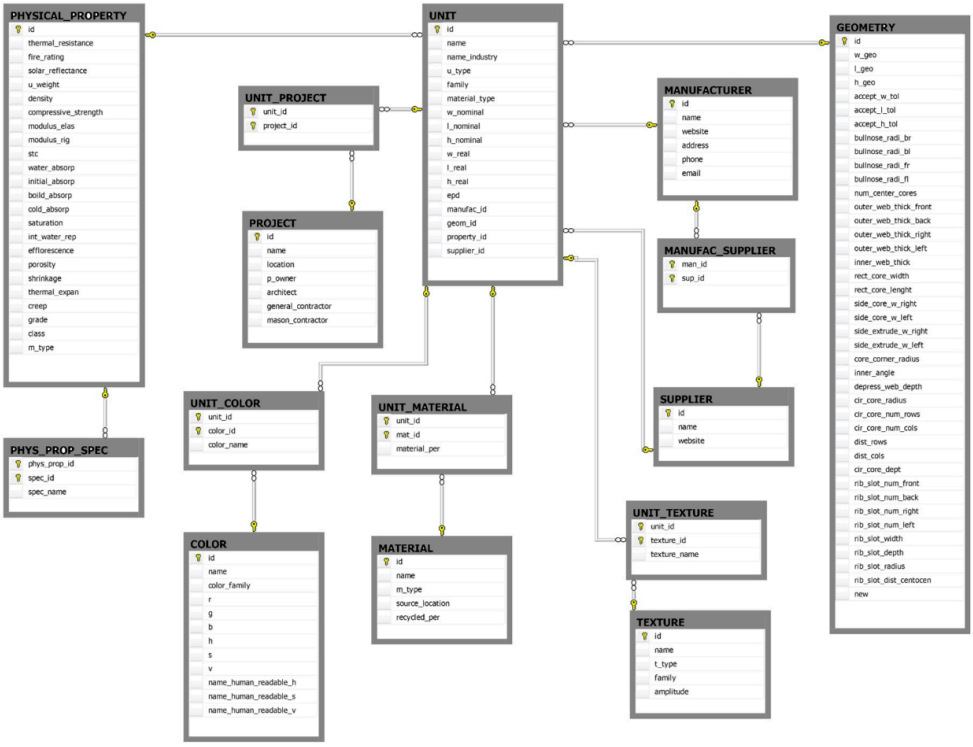
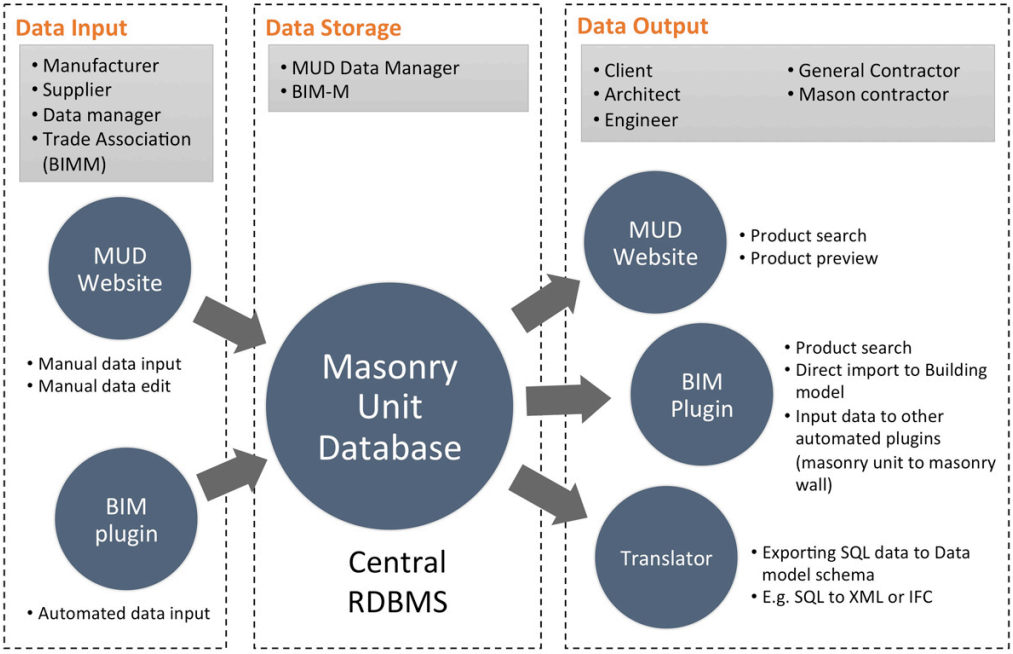


Figure 5
MUD Microsoft SQL Server interface, showing the generated diagrams of MUD entities and their relationships

Figure 6
MUD structure and the data import and export structures



Development of MUD BIM Plugin

The second option for exporting data from MUD is the direct transport of inquiry result from the database into a BIM tool such as Autodesk Revit in form of 3D geometric models. We acquired Dynamo, as a special plugin developer for BIM and specifically Revit. The developed Dynamo plugin is based on a Python script with the capability to connect to SQL Management systems and run SQL queries to import stored dimensions and attributes from the database into the Dynamo environment, generate 3D models based on the imported data, and export the geometry as a Family object in Revit Architecture (Figure 8). In this plugin, the main entity used for the 3D parametric generation of masonry units is the Geometry entity in MUD. This entity contains attributes for the parametric representation of both CMU and clay brick masonry units (Figure 7). Different data entries for attributes in each query for a specific masonry unit, along with the defined conditional rules defined in both SQL and Python, results in the on the fly generation of each single unit in the Revit environment (Figure 8). For the development of MUD, we classified the units' geometry in three general categories: regular masonry unit geometry, special masonry unit geometry, and custom masonry unit geometry (Sharif et al. 2015).

"Regular" masonry units can be fully identified and categorized based on their parametric attributes. These units are produced by most masonry manufacturers with almost identical size and shape, although with different tolerances. Based on the assigned values to these attributes, each masonry unit can be identically 3D generated with the stored data in the MUD. CMU general units have parent families including stretcher, pier, corner, return corner, sash, corner

sash, bond beam, conduit, lintel, open end, header, starter, and subtype groups such as bullnose, scored, ribbed (circular, rectangular). The clay bricks have two major categories of molded bricks and extruded bricks, and with parent families including thin brick, face brick, structural brick, pavers, etc. The 3D models of three regular units generated with Dynamo plugin and based on queries from the MUD are shown in Figure 8. "Special" masonry units inherit most of the attributes from the regular unit geometry. However these units have some special geometric features unique to these units. They are usually produced by one specific manufacturer based on their system of fabrication or particular preferences. Although these units can be partially represented by the parametric attributes that are defined for regular units, defining a set of parametric attributes to cover all their geometric aspects for a complete representation would be impractical, adding extensively to the complexity of the database data model. Consequently, in MUD they will be matched with their closest regular unit geometry counterparts. " Custom" masonry units are custom designed by the request of the project architect or they are specific to a manufacturer or have such complex geometry that they cannot be represented parametrically. Most of cast stone and cut stone units will be categorized in this group. Geometry of these units is one of a kind, usually complex and includes almost none of the geometric attributes of the regular masonry units. Parameterizing their geometric features for MUD would not be practical. Consequently, these units have to be represented with B-rep (Boundary representation) or CSG (Constructive Solid Geometry) models and to be stored as string data format or 3D files in the database.

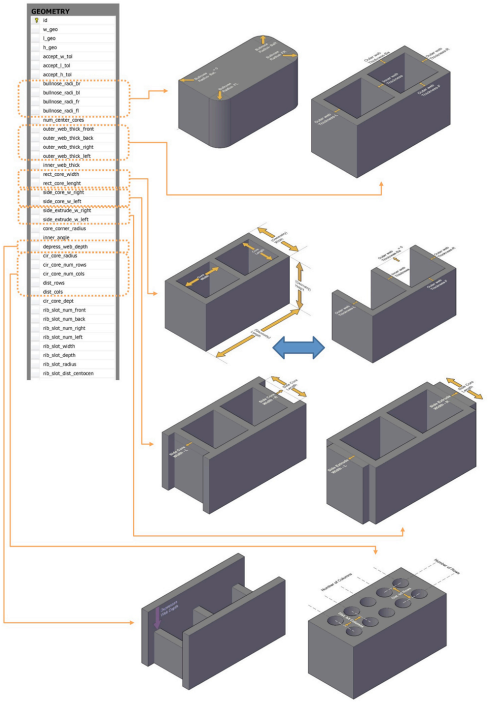


Figure 7
Parametric representation of masonry unit geometry in MUD

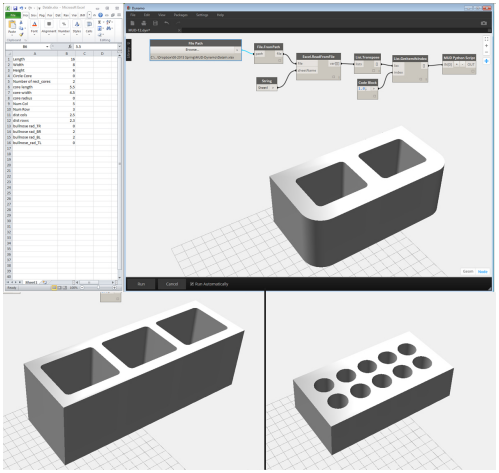


Figure 8
MUD BIM Dynamo Plugin

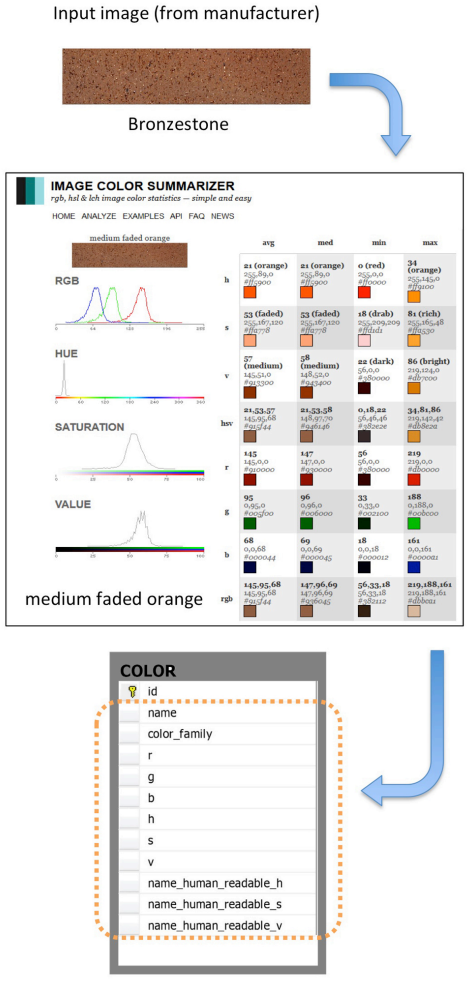
Figure 9
Parametric representation of masonry unit color in MUD

FUTURE STEPS

The next step in the development of the Revit Dynamo plugin for MUD is the representation of other masonry unit attributes that are defined in the MUD schema, information regarding color, texture and physical (mechanical and thermal) properties. In MUD, the color and texture of each unit is parameterized in Color and Texture entities for digital representation of these characteristics.

Based on the images of each masonry unit color provided by the manufacturers, the color of the unit is analyzed into RGB and HSV format. Based on this data, a human readable name is assigned to each color for classification and comparison purposes (Figure 9) [6]. In the same manner, the surface texture of masonry units can be classified based on its amplitude, and categorized into more generalized texture groups, glazed, smooth, textured and rough (Figure 10). However, it should be taken into account that all the detailed attributes for representation of masonry units in MUD may not be required in all LODs (Level Of Development) in BIM masonry projects. Consequently, the final MUD BIM plugin should have the capabilities for the representation of masonry units with different detail levels for LOD 100 to 400, conceptual design to fabrication details.

In addition, at the current stage, MUD just represents masonry units with regular geometry, including clay brick and CMU. However, MUD should have the capability to incorporate all range of masonry units with custom and one of a kind geometric shapes which would include cut stone, and cast stone. The infrastructure for representing these units in the database has to be designed and implemented.



Texture common name/family	Texture range	Texture amplitude
glazed	**Glazed**	0
Polished Ground face	**Smooth**	1
Sand cast Sandstone smooth		2
Velour Wirecut Die skin	**Textured**	3
Matte Face		4
Weathered Handmade Hand Molded		5
Combed Grooved Embossed		6
Tumbled Embossed	**Rough**	7
Bark		8
Split Face		9
Chiseled Face Slumped		10

Figure 10
Parametric representation of masonry unit texture in MUD

CONCLUSIONS

This paper outlined the required steps in the development of a database for masonry units for BIM-M and discussed the development of a Revit Dynamo plugin for parametric representation of masonry units in BIM software tools. The main outcome of the MUD in BIM environment would be the incorporation of masonry unit geometry models in different LOD levels into BIM masonry wall assemblies, including different masonry units and arrangements. This is an important aspect of the future research for BIM-M masonry wall project and BIM-M specification project. For this purpose, the database should be extended to masonry accessories, mortar, grout, ties, and joint reinforcement. The current data model focuses on the attributes of masonry units, and so the schema will need to be extended to include the attributes of accessories, as well as the dependencies between units and accessories.

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