Masonry Product Models for Building Information Modeling

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ABSTRACT: This research focuses on the development of an infrastructure for the data representation and information exchange of masonry units in the life-cycle of a building project. This effort, entitled as Masonry Unit Model Definition (MUMD), is part of the Building Information Modeling for Masonry Initiative in North America. Specifically, this paper discusses the required information for the design, procurement, and construction with masonry products. The primary deliverable is a proposed structure for the Masonry Unit Database (MUD), a data model for the representation of all the geometric and non-geometric information needed to select, specify and purchase masonry units. In this regard, the paper discusses the classification of masonry units at two levels: at the high level in conformity with existing classification systems, and at the low level based on the similarities of materials and other attributes. Finally the paper discusses in detail the workflow of two design and construction sub-processes – structural design, and masonry procurement – with their associated BPMN and ER database models.

Keywords: Building Information Modeling, BIM, Masonry Units, Data Schema

1 INTRODUCTION

Building Information Modeling or BIM is enabling the transition from representations of buildings that contain only geometry to an information-rich environment with embedded semantics that describe the characteristics and functions of building systems. As BIM software has evolved, the need to have attribute data associated with 3D geometric models has become vital to design and construction processes. As a result, building product industries have invested significant resources into developing data models that facilitate design and construction activities through the entire building life cycle. The masonry industry in North America has committed to the development of BIM data for masonry, starting with the development of an infrastructure for the representation and exchange of information regarding masonry units [1].

This paper describes an effort to identify and organize the information needed for design, procurement, and construction with masonry. The project is denoted the Masonry Unit Model Definition (MUMD) and the primary deliverable is the proposed structure for and operation of the Masonry Unit Database or MUD. The goal is to develop a data model to capture all of the geometric and non-geometric information needed to select, specify and purchase masonry units. In the future, we envision that the MUD unit will act as a basis for digital product catalogs, web-based product selection applications, masonry e-commerce, cost-estimating and integrated with the BIM applications to be developed later in overall initiative. It is important to note that the MUD is intended to fulfill two

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distinct but critical roles: first to act as a data repository for the geometric description of the masonry units including its nominal and specific geometry as well as its color and texture and second to capture descriptors needed to facilitate business and engineering processes, such as cost estimating, availability, unit of order, specifications met, etc.

2 BACKGROUND

The masonry unit database to be developed as part of this research is described generically in the literature as a building product model [2] or building object model [3]. The first step in developing a data model of this type is to determine the information needed to support a given design or construction process. Because design and construction processes are complex, with many stakeholders, we have idealized the design and construction process as consisting of 12 sub-processes so as to focus on the information needs at specific stages (Figure 1). The elucidation of data requirements from process models was first described by Eastman et al. in 2002 [4], with further examples taken from the precast concrete industry published by Sacks et al. in 2004 [5].

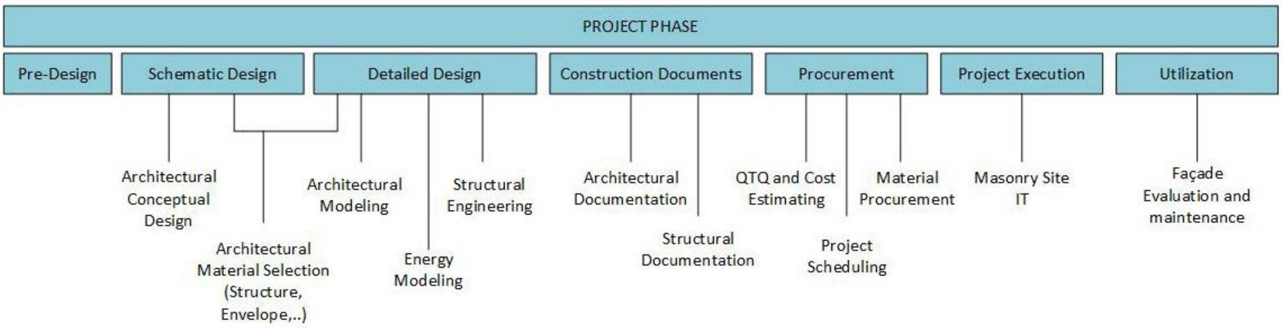

Figure 1. Masonry design and construction project timeline with project phases and proposed masonry material workflows.

3 CLASSIFICATION OF MASONRY UNITS

Once the masonry information is identified, it must be organized in ways that are machine readable by BIM systems. Therefore, a major aspect of this research is the grouping of similar data regarding masonry units. The American Society of Testing and Materials (ASTM) describes classification as: "*a systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use*" [6]. At the highest level of classification, the masonry data must fit within existing classification systems for building projects and products. At this level of classification the system helps define how masonry integrates with other building systems. At a somewhat lower level, the masonry units must be ordered and grouped in a way so that units can be compared with and selected from units with similar attributes. These two levels of classification are discussed in more detail in the text that follows.

3.1 Classification of Constructed Facilities and Projects

The classification of construction information began with the development of specification formats such as MasterFormat in the United States, primarily as means to organize project manuals [7]. As these formats promote document management strategies, they do little to facilitate the organization of information in BIM systems. Construction classification systems that evolved more recently, such as OmniClass in North America [8, 9] and Uniclass in the United Kingdom provide organizational structures for projects, products, and assemblies, which can be more closely linked to BIM tools.

Much of the BIM product data available today is organized according to OmniClass Table 23 (Building Products) or Uniclass Table L (Products). The extent of the masonry classification in these systems is at a fairly high level, as can in that portion of OmniClass Table 23 that pertains to masonry (Figure 2). As can be seen in Figure 2, the OmniClass Table gives a high-level view of how the masonry information might be organized, but it does not provide detailed information on the geometric or functional aspects of the masonry systems, nor a way to link masonry units to other elements and materials within masonry wall systems.

The European Standard EN 81346 for the modeling of industrial products provides elements of a classification strategy along with some relational semantics of the objects represented in the data structure [10]. According to Ekholm and Haggstrom, the Danish Building Classification system or DBK, is based on the EN 81346 and provides the most well-developed structure for organizing building product data for use in BIM [11]. The relational semantics in the DBK are limited to the following:

1. Parts with functional relations, for example: cast stone sill supports window frame;
2. Parts with compositional relations, for example, exterior wall is composed of stretcher and header units in a set pattern such as Flemish bond;
3. Parts with spatial relations, for example, sun screens are adjacent to masonry wall.

Despite the apparent robustness of the DBK system, it is not clear whether a linked classification and compositional description is desired. It may be that a pure classification system for masonry units and their accessories, along with separate compositional description within an Open BIM environment that supports IFCs [12] will provide the best way of hosting and maintaining masonry product data. The remainder of the paper will focus on classifying masonry units and associated materials and products, without focusing on the larger issues of the composing of masonry units into assemblies.

3.2 Classification of Masonry Materials at the Detailed Level

OmniClass Table 23 (Figure 2) provides a high-level approach for grouping masonry units. The primary division is by material type. For each unit type, there is a tremendous amount of geometric and non-geometric data associated with the unit. This information is discussed in detail in the sections below, organized by material types.

Concrete Masonry Units

Concrete masonry units (CMUs) are typically manufactured blocks formed out of zero-slump (very low amounts of water) concrete mix. These units are typically nominally 16 inches long and 8 inches high with widths that vary typically between 4 inches and 14 inches. In addition to material type, these nominal dimensions provide the primary means by which units are classified and referred to, but units are typically manufactured at 3/8ths of an inch less than those given. This allows for a typical mortar joint of 3/8ths of an inch to form a 16 by 8 inch section of wall.

Units can be formed as solid units or have hollow cores where rebar, grout, insulation, or plumbing and electrical chases may be placed. Typical units have 2 cores, but manufacturers produce units with up to 4 cores as well. Outside faces and ends can be manufactured with multiple different textures for a specific feel or use of the unit, and the entire concrete mix can be colored with pigments to deliver a range of colors.

Though the nomenclature for concrete masonry unit types and sizes has not been standardized – there are generally recognized names for units. In the late 1990’s, the National Concrete Masonry Association (NCMA) proposed a standard nomenclature and dimensional guidance for masonry units for use across the country – but this draft standard has not been adopted [13]. A current technical note from the NCMA does provide dimensions for the most common units [14]. The NCMA also promotes a standard nomenclature for the surface finish and texture of CMUs, but it is not clear to what extent this nomenclature is used in industry [15].

Table 23	Products					
OmniClass Number	**Level 1 Title**	**Level 2 Title**	**Level 3 Title**	**Level 4 Title**	**Level 5 Title**	**Level 6 Title**
23-13 21 00		**Blocks and Bricks**				
23-13 21 11			**Concrete Masonry Units**			
23-13 21 11 11				Concrete Blocks		
23-13 21 11 13				Exposed Aggregate Concrete Masonry Units		
23-13 21 11 15				Fluted Concrete Masonry Units		
23-13 21 11 17				Interlocking Concrete Masonry Units		
23-13 21 11 19				Molded Face Concrete Masonry Units		
23-13 21 11 21				Prefaced Concrete Masonry Units		
23-13 21 11 23				Preinsulated Concrete Masonry Units		
23-13 21 11 25				Sound Absorbing Concrete Masonry Units		
23-13 21 11 27				Split Face Concrete Masonry Units		
23-13 21 13			**Calcium Silicate Masonry Units**			
23-13 21 15			**Glass Masonry Units**			
23-13 21 17			**Adobe Masonry Units**			
23-13 21 19			**Clay Masonry Units**			
23-13 21 19 11				Common Bricks		
23-13 21 19 13				Face Bricks		
23-13 21 19 15				Fire Bricks		
23-13 21 19 17				Glazed Bricks		
23-13 21 19 19				Ceramic Glazed Clay Masonry Units		
23-13 21 19 21				Clay Tile		
23-13 21 19 23				Structural Clay Tiles		
23-13 21 19 25				Clay Flue Linings		
23-13 21 19 27				Terra Cotta Units		
23-13 21 21			**Masonry Anchorage and Reinforcement**			
23-13 21 21 11				Masonry Reinforcing		
23-13 21 21 11 11					Continuous Joint Reinforcing	
23-13 21 21 11 13					Reinforcing Bars	
23-13 21 21 13				Masonry Ties		
23-13 21 21 13 11					Flexible Masonry Ties	
23-13 21 21 13 13					Masonry Veneer Ties	
23-13 21 21 13 15					Rigid Masonry Ties	
23-13 21 21 15				Masonry Anchors		
23-13 21 21 15 11					Masonry Veneer Anchors	
23-13 21 21 15 13					Stone Masonry Anchors	
23-13 21 23			**Special Profiles for Masonry**			
23-13 21 23 11				Special Masonry Shapes		
23-13 21 23 13				Masonry Sills and Thresholds		
23-13 21 23 15				Masonry Moldings		
23-13 21 23 17				Masonry Copings		
23-13 21 23 19				Masonry Quoins		
23-13 21 23 21				Masonry Cornices		
23-13 21 25			**Structural Support for Masonry**			
23-13 21 25 11				Lintels		
23-13 21 25 11 11					Lintel Former Units	
23-13 21 25 13				Wall Connectors and Starters		
23-13 21 25 15				Supports for Masonry		
23-13 21 25 15 11					Masonry Angles	
23-13 21 25 15 11 11						Masonry Shelf Angles
23-13 21 25 15 13					Gussets	
23-13 21 27			**Ancillary Products for Masonry**			
23-13 21 27 11				Embedded Flashing		
23-13 21 27 13				Cavity Closers		
23-13 21 27 15				Cavity Weep and Ventilation Units		
23-13 21 27 15 11					Cavity Weeps	
23-13 21 27 15 13					Cavity Vents	
23-13 21 27 15 15					Cavity Drainage Material	
23-13 21 27 17				Masonry Joint Materials		
23-13 21 27 17 11					Masonry Control Joints	
23-13 21 27 17 13					Masonry Expansion Joints	
23-13 21 27 19				Airbricks		

Figure 2. OmniClass classification for masonry.

Architectural Brick

Architectural or facing brick is used in veneer applications or structurally in multi-wythe walls. In common North American practice these bricks are not used in load-bearing applications, though they do carry their own weight or may help stiffen the backup wall section. Typically the bricks are attached by ties to a backup system of CMUs, steel stud, concrete, or in some residential applications wood studs. These ties bring any out of plane forces, such as wind, into the structural element of the wall system.

Brick is classified by size, method of manufacture, color and texture. The Brick Industry Association (BIA) provides information on the most common brick sizes produced in North America, but the major brick suppliers provide many thousands of special brick types [16].

Structural Brick

Structural or hollow brick is made with clay, like architectural brick, but are generally larger so as to have structural capacity in single-wythe applications. Structural bricks often have cores for reinforcing and grout. In the United States, the Western States Clay Products Association is specifically manufactured for seismic resistance. The association does not publish standard sizes of structural brick.

Cast Stone

Almost all cast stone is custom designed in a collaboration between the architect and cast stone producers for building accent pieces such as lintels, sills, and trim parts. Because the range of parts is quite variable, all pieces are generally made to order and require more complicated design drawings than a standard masonry wall. Almost all cast stone exists in a “custom” masonry workflow. This provides particular challenges for BIM systems, because generic cast stone does not exist, and the instantiation of cast stone in BIM will require a database that is flexible enough to handle complex geometries as well as variations between parts. Some aspects of these custom masonry workflows for cast stone have been developed and documented by Richard Carey, and are described in his U.S. patents (see for example: [17]).

4 MATERIAL AND PRODUCT SPECIFICATIONS AND REQUIREMENTS

The building industry is driven by requirements. In North America, a vast majority of verifiable data comes from ASTM (American Society for Testing and Materials) standards. There are two distinct types of ASTM standards for masonry units, specifications and test methods. Specifications provide the requirements for a material, unit, or assembly that is to be specified in a given situation, and test methods provide the method for determining those requirements. There are many different ASTM methods that are applicable to the masonry industry. Figure 3 depicts the complex relationship of requirements for concrete masonry units, depicted as specifications and test methods related to ASTM C90: Standard Specification for Loadbearing Concrete Masonry Units [18] and ASTM C140: Test Methods for Sampling and Testing of Concrete Masonry Units and Related Units [19].

There are 14 different ASTM methods that are referenced by ASTM C90 (with many and another 13 referenced by ASTM C140. These methods create a matrix of testing procedures to determine physical and geometric properties of a CMU which are used for design in the Architectural and Structural workflows. The largest take away from this discussion is to see that a simple building material contains a vast amount of fairly complicated data to represent it, all of which must be contained in a data structure in order to effectively contribute to the design process.

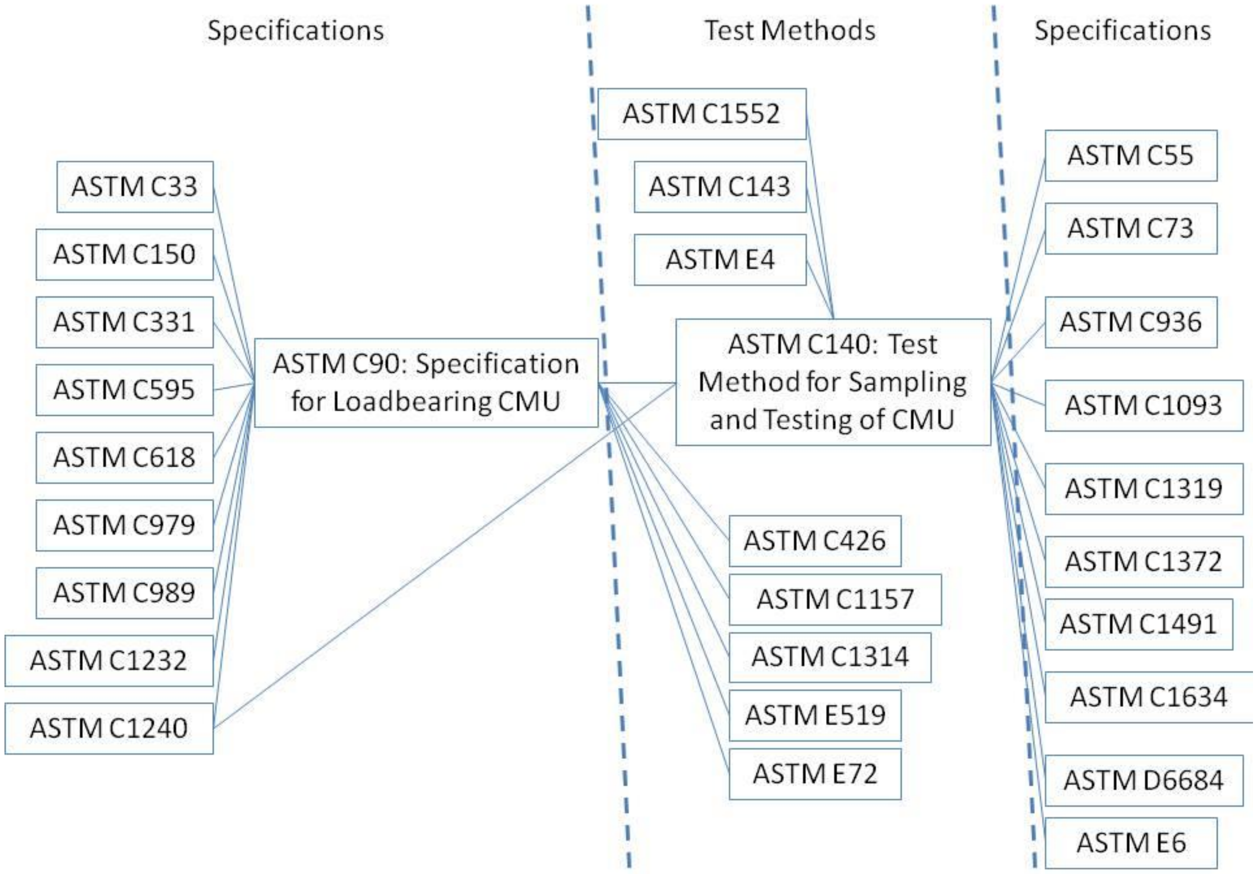

Figure 3. ASTM Specifications and Test Methods in relation to Concrete Masonry Units

5 WORKFLOW DEFINITIONS

In the context of this paper, workflows are defined as high-level business processes that involve stakeholders and exchanges of information. This research has adopted a formal method for documenting these processes using Business Process Modeling Notation or BPMN. These process models have been used successfully to document information requirements in the precast concrete and curtain wall industries [20, 21]. A typical BPMN workflow involves multiple actors set into different “swim lanes” oriented horizontally across the page with the follow of information moving from left to right. The interaction between actors is denoted an “exchange” and the information that is passed back and forth between these exchanges defines that data needed for the masonry unit database. A total of 12 process models, as defined in Figure 1, have been identified, but in the text below, we focus on three key exchanges that demonstrate the method.

In addition to the process model, it is necessary to model the structure of the data itself as the data appears as a “block” in BPMN – with no implied data schema. To that end a separate entity-relationship model is used. This ER model has the capacity to incorporate some of the essential semantic information about the masonry units in the real world, based on the data requirements of the users and functional requirements of the applications [22, 23]. The main data requirement for masonry unit database (MUD) are the geometric description of the masonry unit (nominal and specific geometry), color, and texture, as well the descriptors needed to facilitate business and engineering processes, such as cost estimating, availability, unit of order, and specifications. In addition, the proposed ER model for MUD provides the structure needed for storing, accessing and updating the data during the course of product development to utilization cycle. The proposed ER model for MUD is represented by an ER diagram, the special diagrammatic notation associated with the ER models.

Figures 4 depicts the first workflow associated with architectural design of masonry units, and the ER model of the data associated with this workflow. As the workflow is initiated, the architect starts by browsing the web (manufacturer's web sites) and also by reviewing units and mortar samples on-hand in the firm's materials library [1.1]. The MUD is used to maintain the information on the website and could also be used to order and track the samples that are housed in the architect's materials library. Based on these initial review, the architect requests a sample with one or more masonry units with one or more mortar colors [1.2]. The product representative receives the request for the sample board [1.3] and checks with the manufacturer to determine if the masonry unit meets the architect's requirements, which could include availability, lead time for production, availability of complementary units, location of production, and price [1.4]. The manufacturer accesses internal information stored within the ERP system to retrieve product information and verify that the product meets the specification [1.5]. The manufacturer forwards this information back to the product representative who communicates back to the architect [1.6]. The architect compares this updated information with project requirements and determines if the selected masonry product(s) are acceptable [1.7]. In many cases, the process may iterate as one or more of the attributes of the masonry are not acceptable to the architect [1.8 and 1.9]. When a product selection has been made, the product representative requests a sample board from the manufacturer [1.10], who creates the sample board [1.11]. When the architect receives the sample board [1.12], it is hoped that a masonry sale has been made.

6 ADDITIONAL MASONRY WORKFLOWS

In the sections below, two additional workflows are described. These workflows are associated with structural modeling and design (by the structural engineer) and with materials procurement (by the mason contractor). The remaining workflows are still under development, and will be reported on in future work by the authors.

6.1. Structural Modeling and Design

The structural capacity of masonry walls is determined from calculations on masonry assemblies – not on units themselves. The combination of unit, grout, mortar, and rebar allows for specific axial, shear and flexural strengths to be calculated depending on the sort of design being considered. This adds a level of complexity to the MUD, as the critical values required for design do not directly translate into overall assembly strengths. Rather, the unit data must be extracted from the database and then placed into the structural analysis model along with other information regarding loads and geometric properties.

Because this document focuses on the flows of information regarding masonry units, three categories of masonry units are considered:

1. Generic masonry units are those that are described in the design documents by nominal geometry and key attributes (e.g., strength) but for which there are few or no limitations to product substitution. The standard gray CMU is a generic masonry unit.

2. Specified masonry units are those units that are specified in the design documents by brand, color and type. If the contractor wishes to substitute for a specified masonry unit, a formal change order and acceptance from the design team would typically be required. Specified masonry includes most face brick and architectural block.

3. Custom masonry units are those units that are produced specifically for the job and which typically require a shop drawing or other submittal that is approved by the design team. Custom masonry units include most cast and cut stone.

There are two basic classes of data needed from masonry units to effectively create these structural wall systems. The first is geometrical data, such as unit width, density, and moment of inertia. These values are typically taken as minimums or averages because it must be aggregated over an entire assembly, and can either be determined from testing (ASTM C140 provides unit measurements and density), or from industry averages (NCMA TEK 14-1 gives values for moment of inertia). The MUD could conceivably calculate more accurate values due strictly to the fact that more information is at the fingertips of designers, which would create much more accurate structural calculations for masonry assemblies.

The second class of unit data required can be described as physical properties. While many different types of units can share geometric properties, physical classification is what truly separates them. The initial data would need to contain items like unit strength, modulus of rigidity, and tensile strength of masonry. Once again there are two ways currently that these values are determined, testing and reference materials. Under most circumstances, ASTM testing such as test method C140 is required to gain most physical properties, but the Building Code Requirements for Masonry Structures does provide a fair amount of reference information that is conservatively estimated from large testing projects. It is important for this data structure to allow for either reference data or values achieved by testing to be used.

In many structural design firms it is common for historical data on masonry properties to be used. Not only does this create a large disconnect between what the producer is supplying and what is being designed, but it does not utilize the masonry system fully. The most common problem is that designers choose low-strength units when higher-strength units are available at the same price. The structural information in the MUD should promote the designers use of accurate information on data strengths and geometry to effectively use the masonry capacity, which requires the producer to provide testing data early on in the design process. In order to be used as a structural masonry component, all units must be sampled and run through ASTM C90 testing. Currently it is common for that testing to not be completed until 28 days after production, when many units are already installed on the jobsite. Masonry assemblies could be much more efficient if this data was provided during the initial design phase.

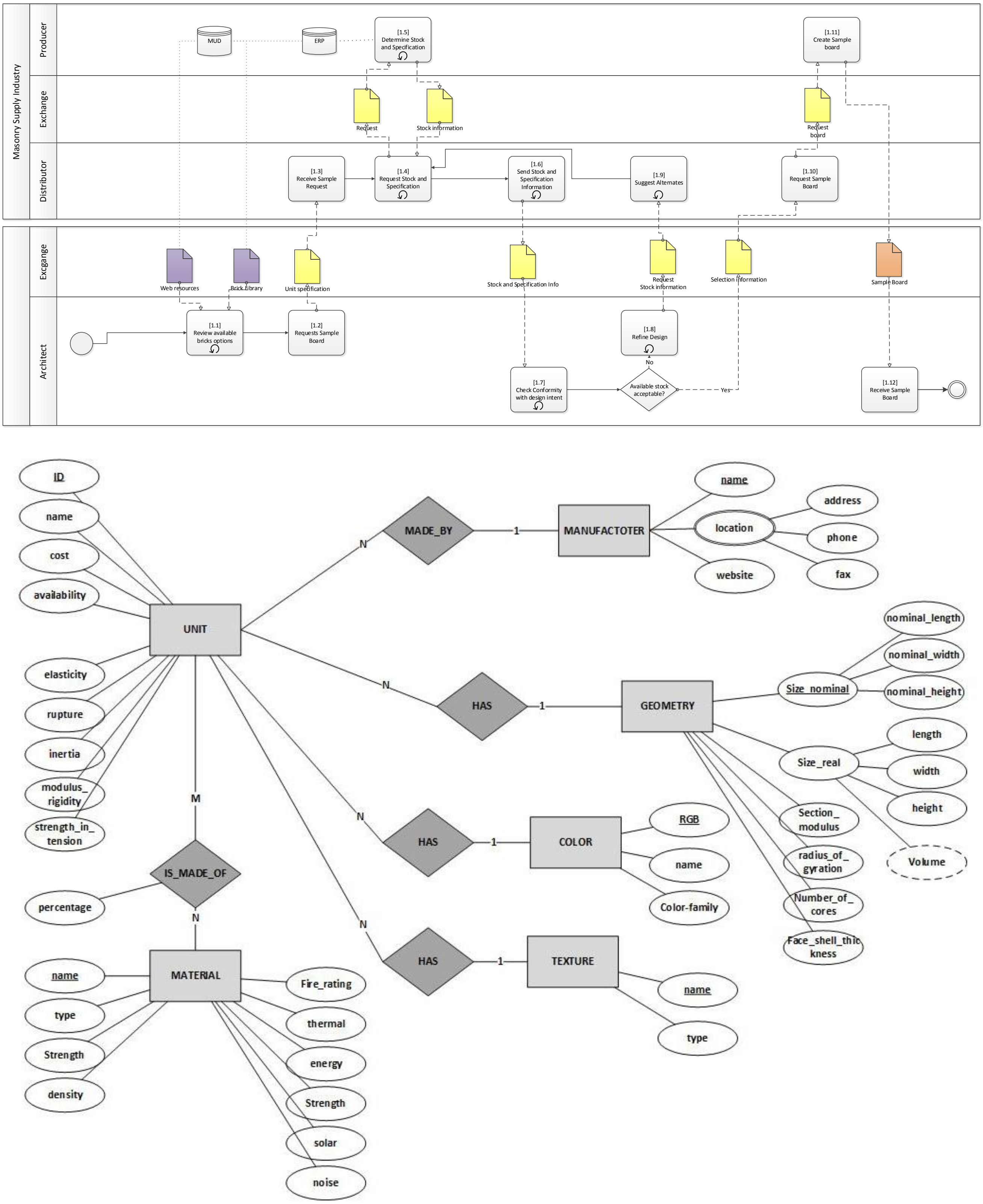

Figure 4. Architectural materials selection workflow in BPMN and associated entity relationship model for the data exchanged as part of this workflow provided by producer.

6.2. Masonry Procurement

BIM offers the ability to order and track materials electronically, from the production plant to being put in place. This is especially helpful in the masonry industry as the piece-count of products delivered to a job site generally numbers in the thousands if not higher on a typical job. In order to facilitate lean construction techniques or just on time delivery, having a robust model to support procurement and order fulfilment is important.

In the current practice, the mason contractor deals with local distributors of masonry units or in some cases directly through the masonry producer. In addition, the masonry construction industry equally uses two different methods for procurement and quantity take-offs. About half of the masonry contractors use an in-house proprietary process based on analyzing the printed drawings and specifications (2D) and subsequently enter this information into a spreadsheet for quantity and cost estimation. The other half of the industry uses specialized software tools, such as Tradesmans software, which is a dedicated cost estimation tool for masonry that maintains an internal historical pricing structure for the contractor, and also builds a graphical 3D model of the masonry walls as the walls on the project are identified. In general, the use of these tools is based on a manual analysis of the 2D contract drawings and specifications. In a future sate BIM -enabled environment, a quantity take-off and cost estimation workflow is proposed and described here which presents a view of how the mason contractor will interact with BIM models and the masonry unit database. The workflow illustrated here is applicable to both “generic” and “specified” masonry units. For “custom” masonry units, a more detailed workflow with additional exchanges between the mason contractor, architect, and mason supplier is required (Figure 5).

At the start of a BIM-enabled process for quantity take-off and cost-estimating, the mason contractor initiates a task [3.1] received from the architect. In the next step, the mason contractor queries the BIM model with the specialized BIM software for quantity take-offs to extract the data for masonry units (in terms of areas and or number of units, depending on the nature and quality of the building model). This task also inquires into the masonry unit database to identify the “generic” and “specified” units that are contained within the BIM model and determine a “match” with units found in the MUD. Finally, this initial task can be configured to return the accessories associated with the units, so that these can be captured as part of this initial data transfer.

The next task [3.3] uses the object data produced in the previous step. At this point the masonry estimator will validate the masonry materials generated from the BIM model query and complete missing information by contacting product representatives [3.4]. In some cases the product representative may have to refer to the MUD that is frequently updated by the producer to validate the selected products. In task [3.5] the estimator finishes the take-off by completing information that did not come forward from the query of the building model.

It is assumed that through a combination of automated processes, along with manual validation, the mason contractor is ready to price the masonry [3.6], for “specified” masonry it is likely that contact with the suppliers and/or producers is required [3.7 and 3.8]. It is expected that with development of necessary tools, these pricing inquiries would be automated or partially automated. For “generic” masonry, the estimator may use historical pricing – without the need for manufacturers’ quotes.

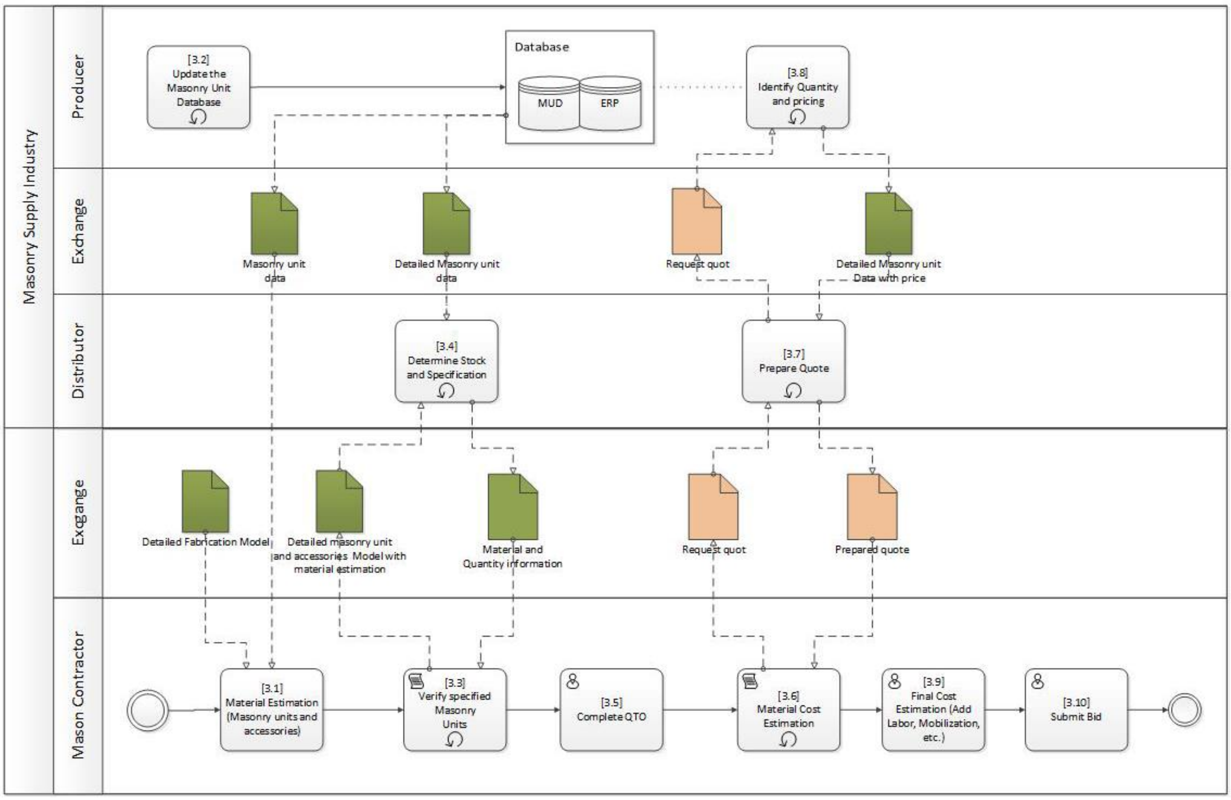

Figure 5. BPMN model for masonry unit take-offs and quoting.

SUMMARY AND CONCLUSIONS

While a database for the masonry industry would be very complex and have a host of actors, when each unit is broken down into a particular workflow with a particular ER diagram the model becomes much simpler. With accurate workflows and models developed by working with masonry industry professionals this MUD will be robust and tailored to the industry it represents.

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