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BIM-based model for extracting the elemental graph data model (EGDM)
BIM-BASED MODEL FOR EXTRACTING THE ELEMENTAL GRAPH DATA MODEL (EGDM)

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ABSTRACT

With the rapid increase in complexity in the building industry, professionals in the A/E/C industry were forced to adopt Building Information Modelling (BIM) in order to enhance the communication between the different project stakeholders throughout the project life cycle and create a semantic object-oriented building model that can support geometric-topological analysis of building elements during design and construction.

This paper presents a model that extracts topological relationships and geometrical properties of building elements from an existing fully designed Building Information Model (BIM Model), and maps this information into a directed acyclic Elemental Graph Data Model (EGDM). The model incorporates BIM-based search algorithms for automatic deduction of geometrical data and topological relationships for each building element type. Using graph search algorithms, such as Depth First Search (DFS) and topological sortings, all possible construction sequences can be generated and compared against production and construction rules to generate an optimized construction sequence and its associated schedule. The model is implemented in a C# platform.

Keywords: Building Information Modelling (BIM), Elemental Graph Data Model (EGDM), geometric and topological data models, graph theory, and Three-level Concept.

INTRODUCTION

Construction industry is the largest industry in the world (service) forming more than 10% of a country’s GNP (Gross National Product). Growth in the construction industry is considered as an indicator of the economic conditions of a country. Since, a large segment of the public and private sectors’ expenditure is spent on the construction industry, it is therefore essential to think how to properly direct this huge amount of money spent on such a crucial industry.

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Need for Automated Optimized Construction Planning

Over the past 100 years, the building industry has changed dramatically. Buildings have become much more complex with many interconnected and integrated systems. Project managers are faced with complex decision environments and problems in the construction of the majority of the projects. The elements of such problems are numerous, and the interrelationships among them are extremely complicated and highly nonlinear. Changes in the elements of a problem may not be related by simple proportionality. For project managers to take sound decisions, they just rely on human value and judgment systems which are integral elements of project problems as well. Therefore, the ability to make sound decisions regarding the selection of the optimal construction methodology is very important for the success of a project.

This complexity has forced the designers in the A/E/C industry to consider more inputs in their design analysis. With the added complications, owners, designers and contractors had to adapt to these changes and take into consideration more and more factors in order to keep up with the continuously growing industry. To analyze these factors in a proper manner where all communication requirements are met, professionals in the A/E/C industry began searching for better ways to model facilities/buildings and coordinate all this information together between all the involved parties throughout the project’s life cycle (Krygiel, et al., 2008). These efforts which were backed up with research in the field of computer-supported building design led to the continuous advancement in the modelling of building data models.

Building Data Model

Building data model describes the physical characteristics of building elements by means of their three-dimensional (3D) geometry and topology. Geometric data represents the building element’s dimensions and location, whereas topological information represents spatial relationships among the building elements comprising connection, adjacency, containment, separation, and intersection. (Nguyen, et al., 2005). Project participants/stakeholders consider topological information essential to perform various analyses during design and construction. For example, structural engineers require information about connections between individual structural elements to be able to perform the structural performance analysis or constructability evaluation, whereas architects require the adjacency and intersection between building spaces and their boundaries to plan layout and create functional space. MEP engineers utilize the topological relationships between building elements, as well as spaces and their enclosing structures, to check compliance with building codes, for instance, sunlight analysis, heat-loss calculations, thermal analysis, and building energy optimization. Moreover, construction planners need topological and relationship information to determine the vicinity among construction zones in layout planning, and, hence, establish the interdependencies of construction activities to be performed. (Nguyen, et al., 2005) For such complex tasks to be performed with the aid of building data models, advanced ways of extracting and presenting geometric and topological information should be adopted. (Khalili & Chua, 2014).

While geometric data of building elements can be manipulated and managed by a Computer-Aided Design (CAD) interface, their topological information are conventionally inserted into the model. However, the manual data representation is essentially a complex and challenging task as each constructed facility usually
comprises of hundreds of elements with multiple types of topological and relationship information, such as adjacency, separation, containment, and intersection (Nguyen, et al., 2005).

The current lack of such building models that support geometric-topological analysis resulted in various research attempts in the field of computer-based representation of building elements over the last decade. These efforts have concentrated mainly on the development of a semantic object-oriented building model, also called Building Product Model or Building Information Model (BIM). (Borrmann & Rank, 2009).

**Building Information Modelling (BIM)**

Building Information Modeling (BIM) is a revolutionary technology and process that has transformed the way buildings are designed, analyzed, constructed and managed. It was introduced to distinguish the information rich 3D modeling from the traditional 2D drawing, and is becoming a better known established collaboration process in the construction industry. BIM is simply a building design methodology characterized by the creation and use of coordinated, internally consistent computable information about a building project in design and construction.

General Services Administration (GSA) of the United States government defines BIM as: "Building Information Modeling is the development and use of a multi-faceted computer software data model not only to document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users’ needs can be extracted and analyzed to generate feedback and improvement of the facility design". According to the National Institute of Building Sciences (NIBS), it is best to think of BIM as: "A digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" (Suermann, 2009).

To conclude, a Building Information Model is primarily a three-dimensional digital representation of a building and its intrinsic characteristics. It is made of intelligent building components which includes data attributes and parametric rules for each object. For instance, a door of certain material and dimension is parametrically related and hosted by a wall. Furthermore, BIM provides consistent and coordinated views and representations of the digital model including reliable data for each view. This saves a lot of designer’s time since each view is coordinated through the built-in intelligence of the model. Hence, it can be said that BIM is the process and practice of virtual design and construction throughout its lifecycle. It is a platform to share knowledge and communicate between project participants (Parvan, 2012).

**BIM and its implementation in the Construction Industry**

The main benefits of BIM for construction professionals include but not limited to: visualization, 3D coordination, prefabrication, construction planning and monitoring, quantity take offs, and record model. Project savings are considerably high if BIM is used during the early design phase. This is mainly due to coordination efforts that yield to minimization of trade conflicts in the field.
BIM opportunities that are currently being leveraged and explored by construction companies around the globe are staggered. As BIM becomes more widely adopted, information on buildings will increasingly be recorded in models, which can then be utilized for other purposes. (Langenhan, et al., 2013).

**Current Practices/Problems in The Construction Industry**
Most BIM users today utilize it for visualization in design and documentation, as first phase of BIM utilization. Data-driven analysis, as the second phase, is being experimented with and is yet not smoothly integrated. The last phase incorporates simulation models where BIM imitates the characteristics of the physical system i.e. the construction project, for optimization, engineering, testing and gaining insight into the functioning. Hence, BIM not only helps in better visualization, but is also a catalyst of a new and better process in the design and construction industry, which attempts to improvise the functionality within the project team. BIM models usage fused with analytical and simulation tools allow efficiently prototyping a building, check its performance and activities related to its construction before breaking the ground. Such prototyping holds a lot of value. BIM implores designers to avoid fudging practices, hence, improving quality and productivity and bringing out best practices (Montaser, 2015).

To harvest true value, BIM, as a semantic object-oriented building model, should be utilized to develop a reliable model that can support geometric-topological analysis of building elements during design and construction. And, hence, aid professionals in the A/E/C industry to make sound decisions regarding the selection of the optimal construction methodology in order to obtain better cost and time trade-off.

For this purpose, an intelligent framework with advanced computational tools and algorithms was designed and created to achieve a higher degree of design-construction integration and spatial integration of individual building elements. This framework enhances coordination and integration between the designer and the contractor considering physical, functional and spatial properties of building elements. Furthermore, this framework gives maximum flexibility to the designer while considering constructability criteria.

Accordingly, this research aims to develop the necessary concepts, framework and tools to improve design-construction integration while achieving an optimized construction plan. In other words, the objective of this research was to develop a framework to configure the optimal sequencing of construction building elements in order to obtain a better cost and time trade-off, and, accordingly, recommend the Optimized Elemental Construction Method, Schedule & Resources, and, hence, generate 4D and 5D BIM models. The framework was, then, validated with the aid of a set of automatically generated test cases in order to assess the research findings.

**RESEARCH CONCEPT**

The overall framework was designed based on a three-level concept, namely: Elemental Graph, Inter-Elemental, and Entra-Elemental.

1. **Elemental Graph** – In this level, each building element can be mapped into a set of vertices or nodes and their interrelationships can be converted into a set of edges,
thus, forming a directed acyclic Elemental Graph Data Model (EGDM), as shown in Figure 1 (a).

2. Inter-Elemental – In this level, each element type can be built with a set of construction methods, as shown in Figure 1 (b). By selecting an appropriate construction method for each building element, the Elemental Construction Method Graph is formed.

3. Entra-Elemental – In this level, customized user-defined relationships are introduced to mimic any practical constraints, as shown in Figure 1 (c).

Figure 1: Three-level Concept: (a) Elemental Graph, (b) Inter-Elemental, and (c) Entra-Elemental
PROPOSED MODEL

This paper focuses on the first level of the three-level concept, i.e. the Elemental Graph.

It presents a model that extracts topological relationships and geometrical properties of building elements from an existing fully designed Building Information Model (BIM Model) (semantic object-oriented data model), and maps this information into a directed acyclic Elemental Graph Data Model (EGDM) (semantically rich representation able to handle constructability related queries). The model incorporates BIM-based search algorithms for automatic deduction of geometrical data and topological relationships for each building element type. The model is implemented in a C# platform.

The Elemental Graph Data Model (EGDM), representing topological relationships and semantic information of building elements in micro-spatial environments, is considered a base for the next two (2) levels, where it is utilized using graph search algorithms, such as Depth First Search (DFS) and topological sortings, to obtain all possible construction sequences and, hence, recommend the Optimized Elemental Construction Method.

Topological Data Model
Literature review has indicated that there are several existing models to represent geometric data and topological relationships among building elements through topological primitives. However, these models are inadequate to handle various queries and complex network analysis. Most of these models store limited semantic information about rooms, openings and walls. Furthermore, such models only deal with connectivity and adjacency neglecting any other type of topological relationship. However, BIM demands the availability of all the types of relationships (e.g. connectivity, containment) and their effective storage, in order to enhance the performance of spatial analysis such as energy simulation, emergency response and prefabrication optimization. (Khalili, 2013).

Since graphs are highly versatile models for analyzing a wide range of practical problems in which points and connections between them have some physical or conceptual interpretation, a novel Elemental Graph Data Model (EGDM) is proposed in this research to abstract and represent building elements and their relationships in a graph in which vertices denote building elements; while edges represent the topological relations. The EGDM is enhanced by adding semantic information to the vertices to be able to handle wide ranges of queries. Furthermore, a novel BIM-based algorithm is proposed to deduce the topological relationships among building elements.

Elements of the Proposed Elemental Graph Data Model (EGDM)
The Elemental Graph Data Model (EGDM) abstracts and represents building elements and their relationships in a simple directed (all the edges are directed) acyclic (graph has no cycles or loops) graph.

The EGDM is composed of three main elements, namely: vertices, edges, and semantic data table (SDT). In the EGDM’s graph structure, vertices represent building
elements, and directed edges represent topological relations, whose direction identifies the interrelationships between the respective building elements and allow for assigning customized relationships that would mimic any practical constraints in a later stage: Level 3. This simple directed acyclic graph is a logical network data model that can be utilized to handle graph search algorithms, such as Breadth First Search (BFS), Depth First Search (DFS) and topological sortings, to obtain all possible construction sequences. The building elements’ semantic information required for such algorithms and a wide range of queries, are attached to their respective vertices by a data table, the semantic data table (SDT), which is the third element of the EGDM.

1. Graph Data Structure
The graph data structure is a definition for 3D objects from a specific group that are topologically related. In order to build the EGDM, a vertex is assigned for each building element, and paired vertices are joined with an edge on the condition that the corresponding building elements are interrelated. As shown in Figure 2, building elements in the actual model are mapped as vertices in the Elemental Graph, and, then, topological relationships between different building elements are mapped as edges. A beam and two (2) columns, as shown in Figure 2, are mapped into vertices B1, C1, and C2 in the Elemental Graph. Since the beam B1 is supported on the two (2) columns C1 and C2, two (2) directed edges are mapped from the columns C1 & C2 (tails) to the beam B1 (head) respectively to denote the elemental dependencies between the elements.

Figure 2: Mapping building elements to a directed acyclic Elemental Graph

For an entire building, the Elemental Graph defines the spatial relationships of its building elements. The types of topological relationships are represented through the direction of the edges, whereas the building elements’ properties are included in the semantic data table (SDT), which are labels assigned to the associated vertices. Upon retrieval of all the building elements’ properties, additional computed ones are added to the semantic data table (SDT) of each building element respectively, as shown in Figure 2.

A demonstration for the building-to-graph generation is shown in Figure 3 (a) and (b). Figure 3 (a) shows an example of a simple concrete structure composed of four (4) columns and four (4) beams, which is represented as a directed acyclic graph (DAG) composed of eight (8) vertices and eight (8) edges. Figure 3 (b) shows an example of a simple concrete structure composed of four (4) foundations, eight (8) columns, eight
(8) beams, two (2) slabs, four (4) walls, a door and a window, which is represented as a directed acyclic graph (DAG) composed of twenty-eight (28) vertices and thirty-eight (38) edges.

Example No. 1 (4 columns and 4 beams)

(b) Example No. 2 (4 foundations, 8 columns, 8 beams, 2 slabs, 4 walls, door, and window)

Figure 3: Simple building examples and their respective Elemental Graphs

The graph data structure in its presentation preserves the physical and topological characteristics of building elements, as well as the topological consistency through mapping all the building elements along with their topological relationships into a set of vertices and edges.

2. Semantic Data Table (SDT)

Upon the retrieval of the logical Elemental Graph based on the spatial relationships among building elements of a structure, building elements’ properties, such as: category, center-point, faces, ID, length, level, materials, max point, min point, surface area, volume, etc…, are included in the semantic data table (SDT), which are assigned
to the associated vertices. Upon retrieval of all the building elements’ properties, additional computed ones are added to the semantic data table (SDT) of each building element respectively, as shown in Figure 2. These properties include: bounding box, dependencies, number of elemental construction methods, resources required, construction duration, start and finish times, etc.

With the aid of the building elements’ semantic data table (SDT), the EGDM can handle a wide variety of queries and search algorithms, such as Breadth First Search (BFS), Depth First Search (DFS) and topological sortings, to obtain all possible construction sequences.

**Extraction of Topological and Geometric Data**

As mentioned earlier, the EGDM covers all types of building elements supported by Building Information Modeling. Building elements are retrieved and represented in the Elemental Graph. For each building element, the topological relationships of that element with respect to the others is, then, derived by creating a bounding box surrounding the selected element and obtain all building elements that intersect or overlap with it. Hence, the extraction of topological relationships requires the creation of a bounding box for each building element, which will be elaborated in the subsequent sections. Then building elements’ semantic data are extracted and derived to form the Semantic Data Table (SDT).

The BIM data structure is a semantically rich environment explicitly representing both topological and geometric information, along with non-geometric properties (e.g., material properties). To extract topological and geometric information, various research attempts in the field of Information Technology is and was undertaken to ensure a continuous flow of the required information from Building Information Models. AutoDesk Revit, being a design and documentation platform that supports the design, drawings, and schedules required for Building Information Modeling (BIM) (AutoDesk Revit, 2017), facilitated the smooth extraction and exchange of data between Building Information Models and applications, hence, avoiding the time-consuming and error-prone process of obtaining and sharing such data. Data extraction is carried out using the AutoDesk Revit SDK and AutoDesk Revit APIs to communicate with AutoDesk Revit. AutoDesk Revit customization capabilities have been significantly extended over the past few years. AutoDesk Revit Application Programming Interface (API) allows users to program with any .NET compliant language such as VB .NET and C# .NET. With the AutoDesk Revit APIs, it is now possible to extract topological, geometric, and semantic information of building elements to complete the proposed EGDM.

**Topological/Geometric Representation of Building Elements in BIM Model**

AutoDesk Revit API is used to facilitate the implementation of the EGDM’s topology-driven approach in deducing topological relationships by providing the required topological features, as well as predefined topological relationships in its hierarchical structure.

**1. Representation**

Families are the basic building blocks of the Autodesk Revit software platform. Families are grouped and sorted by category in the content libraries, for example: doors, curtain walls, furniture, lighting fixtures, etc... Almost every object within
Revit is based on a family definition. The family contains the geometric definition of the element and the parameters used by the element. There are numerous types of families, which all serve certain functions, and have certain uses. Families, such as walls, windows, stairs, doors, etc…, are used to build the Building Information Model. Each family can have multiple types, such as different size, materials, parameter variables, etc. Any change to a type is updated in every instance throughout the project. An example is illustrated in Figure 4.

Parametric modeling refers to the relationships among all elements in a project that enable the coordination and change management that AutoDesk Revit provides. This capability delivers the fundamental coordination and productivity benefits of AutoDesk Revit: AutoDesk Revit coordinates any alteration in any part of a project to directly impact the entire project affect. (Autodesk Revit, 2017) AutoDesk Revit uses 2 key concepts that make it especially powerful and easy to use. The first is the capturing of relationships while the designer works. The second is its approach to propagating building changes.

![Figure 4: AutoDesk Revit Family – Type – Instance Concept](https://example.com/figure4.png)

Basically, each building element in the AutoDesk Revit Building Information Model has a geometric/topologic representation. And each element category is modeled and represented in a distinct manner. For instance, structural columns, structural foundations, doors and windows are typically characterized by their “Location Point”, while structural framing and walls are typically characterized by their “Location Curve”. Figure 5 illustrates the structural column and structural framing representations along with the retrieved minimum and maximum points which will be utilized in the following section.
2. Obtaining Minimum and Maximum Points

N.B. In order to create the bounding box, two (2) points, minimum and maximum points, should be identified with the aid of building element’s geometry and the LocationPoint/LocationCurve. These two (2) points are simply computed and added to the building element’s semantic data table (SDT) respectively.

3. Predefined Topological Relations

Besides the topological/geometry representation of building elements, AutoDesk Revit Building Information Model contains predefined relationships between certain types of elements. For instance, in the door and window type properties, the property: wall closure identifies the hosting element whether it is a wall or a skylight in a roof. Hence, the instance’s properties define its hosting predecessor element (the element’s topological relations).

Proposed Framework for Deriving the Elemental Graph Data Model (EGDM)

Figure 6 shows how the EGDM proposed architecture that derives the Elemental Graph with the aid of EGDM basic elements and the building elements’ topological/geometric representations. The EGDM comprises two main modules, namely: Project Analysis, and Elemental Graph Retrieval.

In the first module: Project Analysis, building elements that are represented as nodes in the Elemental Graph, are extracted from the Building Information Model.

In the second module: Elemental Graph Retrieval, building elements’ topological relationships that are represented as directed edges in the Elemental Graph, are deduced from the Building Information Model. The topological deduction algorithm first checks for predefined relationships then checks for the conditions of relationships discussed in the previous section: containment, connectivity, separation, and intersection. Then the adjacency matrix is formed for further network analysis.
1. Project Analysis Module
Essentially, the Project Analysis Module, as shown in Figure 6, is the first unit in EGDM that, with the aid of the Analyzer, parses the input data acquired from the Information Feeder (General Information and Project’s BIM Model), and, then, builds an internal data structure to release Element(s) Data that would provide easy data access for its receptor, the Elemental Graph Retrieval Module.

The process starts with the Information Feeder in which the user feeds in the Project’s fully designed BIM Model.

Next, the Analyzer imports building elements data, including topology/geometry properties, dimensions, materials, and functionality, from the BIM Model into the framework. It, then, builds an internal data structure to map the data obtained into the memory. The data structure is a linked list, comprising a list for each building element which gets linked together. Each building element’s list carries the retrieved semantic data for that element including: category, center-point, faces, ID, length, level, materials, max point, min point, etc… It is worth mentioning that this list gets further extended and lengthened throughout the following modules to include additional imported and calculated data. This process finally categorizes and segregates all the building elements based on their element category to release the Element(s) Data that would serve as an input for the following module.

2. Elemental Graph Retrieval Module
The Elemental Graph Retrieval Module, as shown in Figure 6, is a functional unit in the EGDM that transposes the geometry and topological relationships of building elements, Element(s) Data, obtained from the Project Analysis Module to a graph model. This module, with the aid of the Dependency Retrieval, utilizes the internal data structure together with the embedded data in order to automatically deduce the topological relationships among building elements. Building elements along with their relationships and semantic data are mapped into a novel data representation model: Elemental Graph Data Model (EGDM). The output of this module is the EGDM which is presented in the
form of a directed acyclic Elemental Graph that could be used to generate an optimized construction sequence and its associated schedule.

In this module, the Dependency Retrieval employs a “topology–driven” approach that further examines the project’s building elements and utilizes the internal data structure together to create bounding boxes around building elements to deduce the topological relationships among them, as described earlier. Hence, locating the building elements and their respective dependencies to form the Building Elements’ Dependency Matrix (Adjacency Matrix), which are, then, represented as vertices and directed edges in the directed acyclic Elemental Graph.

By the end of this process, the outcome of the Dependency Retrieval is the Elements’ Dependency Matrix along with an Elemental Graph of the project under study, Elemental Graph, which could be used to generate an optimized construction sequence and its associated schedule.

**Automatic Deduction of Topological Relationships**

![Figure 7: Structural Column and Structural Framing Bounding Boxes](bb Min bb Max bb Min bb Max bb Min bb Max)

In order to automatically generate the EGDM, BIM-based algorithm is proposed to deduce the topological relationships among building elements by means of the creation of a bounding box (generated from element’s retrieved min and max points) surrounding the elements, and, hence, deducing the predecessor/dependent elements, as demonstrated in Figure 7. The algorithm extracts the four major types of topological information: adjacency, containment, separation, and intersection as defined by (Nguyen, et al., 2005). (Nguyen, et al., 2005) proposed algorithm extracts the topological relationships from 3D geometric data indicated in the CAD model, which is not efficient in terms of computation and data storage. Furthermore, unlike topology-driven models, geometry-driven models need geometric modifications for further analysis (Khalili & Chua, 2014).

Using geometric/topological representations in AutoDesk Revit Building Information Model, the proposed BIM-based algorithm enhances deduction in three ways. First, AutoDesk Revit Building Information Model may be used to directly extract the topological primitives and their geometric information instead of obtaining them from...
lines and points in a CAD environment. Second, the AutoDesk Revit Building Information Model building elements representations cover a wider range of elements when compared to conventional CAD modeling. Third, AutoDesk Revit Building Information Model comprises predefined relationships between certain types of elements, eliminating the need for pairwise comparison to deduce their relationships. Hence, reducing computation time and complexity.

Examples to demonstrate the deduction of the topological relationships are presented in Figure 8.

![Figure 8: Structural Framing Dependency – Single Frame](image_url)

**Computer Implementation**

AutoDesk Revit Application Programming Interface (API) allows users to program with any .NET compliant language such as VB .NET and C# .NET. The application main development language is C# (simple, modern, general-purpose, object-oriented programming language), based on .Net framework 4.0 platform and has been written using Microsoft Visual Studio Integrated Development Environment (MS VS IDE). It uses AutoDesk Revit SDK and AutoDesk Revit APIs to communicate with AutoDesk Revit Software. The AutoDesk Revit Software Development Kit (SDK) is a programming package that enables a programmer to develop applications for a specific platform. Typically, an SDK includes one or more APIs, programming tools, and documentation.

**CONCLUDING REMARKS**

This study develops a semantically enhanced, 3D topological data model, which is called the Elemental Graph Data Model (EGDM), to represent the topological relationships among building elements. The EGDM exploits BIM capabilities for geometric/topological representation, thus simplifying the abstraction of the topological relationships among building elements using the vertex-edge structure of the graph. The semantic information is added as weights to vertices and edges and is termed SDT.
The elements of the proposed EGDM make it an elaborated intelligent model to represent topological relationships that will be able to handle wide ranges of queries efficiently. Having a graph data structure, complex topological queries can be implemented through advanced graph algorithms. Moreover, SDT makes the GDM a knowledge-embedded model, which would be able to run rule-based queries and constraints.

The EGDM presented in this paper contributes to the advancement of research in the area of 3D topological models for A/E/C applications and also overcomes several limitations of the existing models in the following ways: first, it explicitly represents the building elements (structural and nonstructural) of buildings using a graph data structure; second, because the proposed model is not limited to any specific geometric representation of building elements, a wide range of building elements can be modeled. However, the present proposed model does not cover curved-shape building elements. The model may be extended to cover circle and curved-shape elements in future work. Third, using AutoDesk Revit APIs as a data-exchange platform enables the EGDM to exploit the predefined topological relationships in a building information model to significantly reduce the deduction time. Fourth, previous graph data models, such as those developed by (Borrmann & Rank, 2009), (van Treeck & Rank, 2007) and (Lee & Kwan, 2005), are limited to adjacency and connectivity for the sake of specific purpose of finding shortest path among spaces in a building, whereas the EGDM covers all four major spatial relationships for all A/E/C applications. Fifth, the proposed EGDM is enriched with the semantic information obtained from the building information model which enables the handling of complex semantic-based queries for different project stakeholders. Sixth, and finally, network-based analyses can be performed to maintain computational efficiency while avoiding storage of massive geometric data of complex buildings.

The EGDM, serving as the first part of the research, is, then, utilized and graph search algorithms, such as Depth First Search (DFS) and topological sortings, are performed to generate all possible construction sequences. The sequences are, then, compared against production and construction rules to generate an optimized construction sequence and a better cost and time trade-off. And, finally, recommend the Optimized Elemental Construction Method, Schedule & Resources, and, hence, generate 4D and 5D BIM models.

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