AUTOMATION OF BUILDING CODE ANALYSIS:

Characteristics, Relationships, Generation of Properties and Structure of Various Models

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Abstract. This paper is considered as the second part of what has been presented in ASCAAD 2005, titled "Issues of Integrating Building Codes in CAD", that discussed the conceptual framework of automating the building code analysis process. The proposed framework was composed of three digital interrelated models; Building Code Model (BCM), Building Data Model (BDM) and Computer Aided Building Code Analysis of Design (CABCAD) Program. The International Building Code (IBC) has been selected to understand the characteristics of building codes and to develop the BCM. This paper aimed to discuss the concepts behind the building code requirements, characteristics of building code analysis process, hierarchical relationship between various objects in the BCM and BDM.

1. Introduction

Based on Section 101.3 of International Building Code (IBC), the main purpose of building codes is to protect public health, safety and general welfare using various approaches that focus on providing safety to people's life and property. These approaches are based on two basic concepts; first, identifying the hazard that may affects public health and safety and second, controlling it from spreading. The IBC provisions apply these concepts by specifying several code requirements that cover all levels and aspects of the project. The following examples explain the application in detail. (IBC, 2003)

1.1. IDENTIFY THE HAZARD

The type and source of the hazard should be investigated to determine the expected level of the hazard at all spatial levels. For instance;

1. The activity (or function) occurs in specific area dictates the necessity to provide certain fire-rated building systems. For instance, an area used for storage purposes are more hazardous than another

utility used for educational functions.
2. The increase in number of occupants always required additional safety precautions such as provision of additional or wider exits.
3. The type and characteristics of particular equipments requires additional safety measures where it is located. For example, the provision of automatic fire-extinguisher system in a room equipped with furnace or refrigerant machinery.
4. The level of hazard caused by storing certain hazardous materials. In this case, the building code requirements will be based on the type and quantity of the stored materials.

1.2. CONTROL THE HAZARD FROM SPREADING

If the expected hazard is critical, building codes will require adequate fire control system (e.g. fire-rated wall, fire-rated roof/floor, fire-extinguishing system, fire-rated window/door, etc) that aims to:

1. Contain the spread of smoke and fire to adjacent areas or buildings.
2. Maintain the stability of the structure till occupants can safely evacuate the building or reach a temporary area of refuge.

2. Analysis of Building Code Sections

A detailed analysis has been implemented to the core chapters of the IBC to understand the vital characteristics of building code analysis process and to apply them in the digitizing process of the BCM and in specifying the appropriate structure of the BDM. These chapters are:

- Chapter 3: Use and Occupancy Classification
- Chapter 5: Building Heights and Areas
- Chapter 6: Types of Construction

Three major aspects have been identified through the analysis:

- Spatial characteristics of BDM and BCM.
- Hierarchal relationship requirements of BDM and BCM.
- Generation of object properties (architectural attributes) of BDM.

2.1. SPATIAL CHARACTERISTICS OF BDM AND BCM

Five terms, related to the 3-D spatial characteristics of buildings, have been used several times throughout the IBC. The first two terms are “Room” and “Space”. They have been used in many building code sections without explicitly been defined and sometimes have been overlapped with the term “Area”, which also been used to refer to different spatial entities. In order to align the intent of the building code with the objectives of the research, the study recommends the following definitions:

Room
A volume that is fully, semi, or non-partitioned part of a building and is mostly used for one particular function. For instance, a living room in a house, dining room in a restaurant or merchandize room in retail store.

Space
A volume that is self-sufficient and functionally independent of the rest of the building and is commonly composed of number of rooms. For example, an apartment is a space that composed of several rooms such as bedroom, living room, bathroom, kitchen, corridors, storage room, etc. Another two terms that clearly being defined in IBC – Section 202 are; “Floor” and “Building”.

Floor (or story)
“That portion of a building included between the upper surface of a floor and the upper surface of the floor or roof next above. It is measured as the vertical distance from top to top of two successive tiers of beams or finished floor surfaces and, for the topmost story, from the top of the floor finish to the top of the ceiling joists or, where there is not a ceiling, to the top of the roof rafters.” A floor may contain one space or more.

Building
“Any structure used or intended for supporting or sheltering any use or occupancy.” A building consists of at least one floor or more. Another term is “Project” which is used a lot in both the IBC and IZC without apparent definition to its scope limitation. (IBC, 2003; IZC, 2002) The study defines it as follows;

Project
The highest-scale spatial building component that encompasses all 2-D and 3-D building and non-building (e.g. landscape and landuse) elements, involved in the development of the building facility. In addition, the examination of the IZC requirements indicates the need to define more spatial entities that is crucial to the application of any building code analysis. These entities are:

Lot
A 2-D spatial element with boundaries defining its shape, which represents the outline of the project.

Landscape
A 3-D object used inside or outside the building for various purposes (e.g. trees, light post, fence, etc).

Landuse
Any 2-D spatial element with boundaries that defines its shape, located outside the building envelope and used for particular function (e.g. parking lot, passageway, driveway, landing zone, etc). Figure 1 explains the structural relationship between the above listed spatial elements.

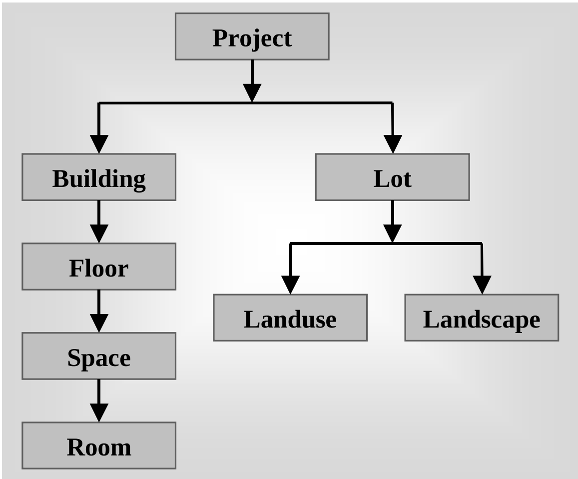

Figure 1. Spatial objects of BDM

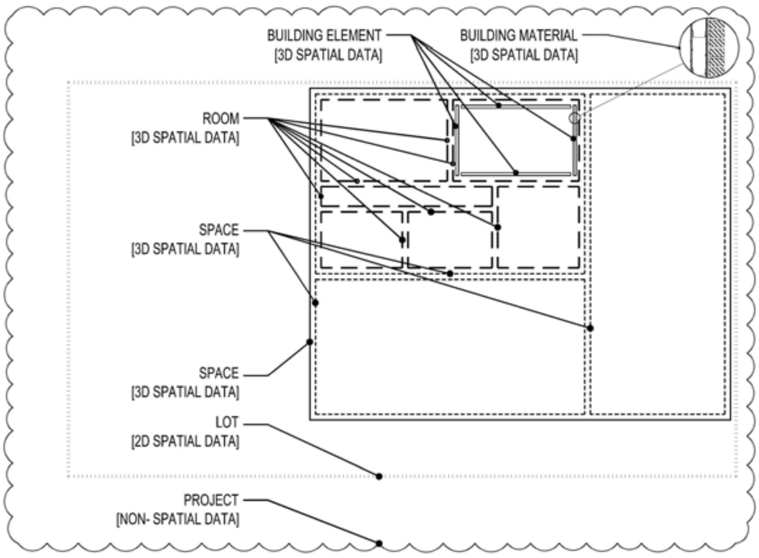

Figure 2. Graphical representation of the spatial relationships – A project is composed of Buildings. A building composed of floors and spaces. A space is composed of rooms.

2.2. HIERARCHAL RELATIONSHIP OF BDM AND BCM

Three conceptual (spatial and non-spatial) hierarchal relationship types between different building areas and components have been identified through the analysis of building code sections and the purpose behind their formation.

2.2.1. Containment

Refers to a spatial dimensional relationship between various spatial objects [Project [Building [Floor [Space [Room]]]]]. Refer to Figure 2.

2.2.2. Property

Refers to the attributes associated with building objects. The value of these attributes can be created and also used to create particularly new object groups. This production process is either based on one attribute or a combination of many ones. For instance, it can be generated based on typological information (e.g. adjacency, intersections, proximity, connectivity, etc), building material type and characteristic, building component type, functional role, etc.

2.2.3. Membership

Refers to the constructional relationship between various building components. For instance, a metal joist is part of a roof assembly system that may include a ceiling, roof deck, system insulation, etc.

The following examples symbolize the complexity of these hierarchal relationships required by the building code requirements and reflect the required features in the BDM structure.

Spatial object/Property

Several code sections require particular value of specific spatial object's property. For example;

1. Building/OccupancyType = “Group A”
   Refers to the occupancy type of a building as required in IBC–Section 302.
2. Room/Function = “Equipment Room”
   Refers to a purpose of using certain room (e.g. as Equipment room, merchandize room, etc). For details refer to IBC-Section 302.1.1 and Table 302.1.1.
3. Space/TotalArea = 14,000 ft. sq.
   Refers to the total allowable area of a space as dictated by IBC-

Section 503.

4. Lot/OpenSpace/Width >= 20 ft.
   Refers to the width of an open space surrounding a building as required by IBC–Section 506.2.
5. Project/PurposeOfConstruction = “New Construction”
   Refers to the purpose of constructing a project as required by IBC-Section 602.1.

Spatialobject/Equipment/Property
Room/Equipment/BtuPerHr = 40,000

IBC–Table 302.1.1 requires if a room with equipment that produces over 40,000 BTU per hour input should be provided with 1-hour separation or an automatic extinguishing system.

Spatialobject/BuildingComponent/Property
Room/CeilingAssembly/FireRate >= 1 hr

IBC–Section 302.1.1 requires if a room used for storage purpose and its area exceeds 100 ft. sq., the roof assembly should have at least been 1-hour fire rated.

Spatialobject/GroupofSimilarTypeofBuildingComponents/Property
Space/SurroundingWalls/FireRate >= 2 hrs

IBC-Section 302.1.1 requires if a space used as Paint Shop with no fire extinguisher system, the surrounding walls should be at least 2-hour fire rated.

Spatial object/GroupofNon-BuildingObjects/Property
Room/SeatsGroup/Count <= 49

IBC–Section 303 requires if a room is used for assembly purposes and needs to be classified, as part of a main occupancy type, the room occupancy load as well as the number of seats should not exceed 49.

Spatialobject/ArchitecturalElement/GroupofBuildingMaterials/Property:
Building/Tower/GroupofConstructionMaterials/FireClassification = “Combustible”

IBC-Section 1509.5 requires if a building contains a tower built of combustible building materials and not used for habitation or storage, the total height of the tower should not exceed 20 feet above the allowable total height of the building.

Spatial object/Spatial object/ArchitecturalCriteria/Property
Space/Mezzanine/MeanofEgress/Count >= 2.

IBC-Section 505.3 requires that a mezzanine should have a least 2 means of egress when its travel distance exceeds the limitations of section 1004.2.5.

Spatialobject/Spatialobject/ BuildingComponent/ BuildingMaterial/ Property
Building/Mezzanine/FloorAssembly/Ceiling/Height - Building/Mezzanine /FloorAssembly/FloorFinish/Height >= 7 feet.

IBC–Section 505.1 requires a minimum 7 feet clear height above and below the mezzanine floor construction.

2.3. GENERATION OF OBJECT PROPERTIES OF BDM

The properties of various objects of the BDM that are used in the building code checking process evolved through two paths:

2.3.1. Through the architectural design development process

Architects develop the architectural properties of building objects as they proceed into producing the final BDM. The process start with describing the design intent and it evolves to describe the proposed building itself. (Refer to Figure 3, which explain the development process of architectural information)

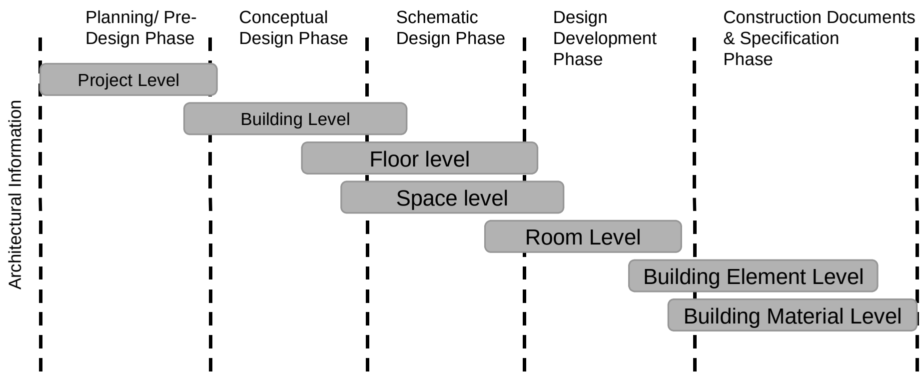

Figure 3. BIM and classification of architectural information during the architectural design process

2.3.2. Through generation process of building code related properties

The examination of properties associated with the BDM and related to building code analysis process indicates that they can be categorized into groups based on the way they have been generated. Table 1 explains how the values of these properties are identified.

Through manual input

In very few cases, architects have to manually enter some property values in order to proceed on the automated building code checking process such as the function, name and desired load of spatial objects.

Table 1. Process of generating properties

Symbol/Leve l	Process of generating properties
(1)	Through manual input
(11)	Through a CAD program and use of manually entered data in level (1)
(111)	Activated and generated through a CAD program
(2)	Through CAD program that extracts directly from the BDM.
(22)	Through CAD program and use of data extracted from BDM in level (2)
(222)	Through CAD program and use of data extracted from BDM in level (22)

Through a CAD program and use of manually entered data in level (1)
The values of some object properties are based on the manual input of specific properties. For example, entering the function of a space determines its occupancy type; the use type of a room is based on some factors such as its function, its area, the existence of sprinkler extinguishing system, etc.

Activated and generated through a CAD program
Based on the architect manual input or automatically extracted data, a custom CAD program will activate and generate specific list of properties and prompt the architect to accept the default values, select another value or add new one. For example, if certain space used as ‘a shop”, a CAD program will prompt the architect to select the “shop type” (e.g. Paint shop). Also when a function of a building is entered, a sub-function list will be activated, from which the architect can select (or add) the appropriate function of any room located inside the building. Also, the “sub-occupancy type” property will be activated based on the value of the “Main-occupancy type” property value. Each of these programs addresses a specific code issue. Each of these programs addresses a specific code issue.

Through a CAD program that extracts directly from the BDM
Many properties can be extracted directly from the BDM without manual input from the architect through a custom CAD program. For instance, the gross and net area of a space can easily be extracted from the database with a custom developed procedure.

Through a CAD program and use of data extracted from BDM in level (2)
Many properties can be created based on basic data extracted from the BDM. For example, to decide if a room is fully enclosed or not, a custom CAD

program can extract all data regarding the location, height and length of each wall in the building. The CAD program will then identify those surrounding the room and verify if they fully surround the room and if they have any openings.

Through a CAD program and use of data extracted from BDM in level (22)
A CAD program can be used to generate many new similar property object groups by extracting the value of those particular properties. After identifying the object, using the same procedure previously mentioned, a group of similar object can be created through a custom CAD program; i.e. Surrounding-Walls-Group, Interior-Walls-Group, Non-Load-Bearing-Walls-Group, Full-Height-To-Ceiling-Walls-Group.

3. Building Data Model (BDM)

This research proposes a structure for the BDM (See Figure 4) that complies with requirements and procedures used in checking architectural design for building code compliance as well as the architectural design development process. This structure is based on the capabilities of the following;

1. Spatial characteristics of BDM and BCM
2. Hierarchal relationship requirements of BDM and BCM
3. Generation of object properties of BDM

3.1. DEFINITIONS

- Access: The operation of seeking, reading, or writing stored information. (Vertaasis)
- Access method: A technique used to transfer a physical record from or to a storage device. (Vertaasis).
- Data Structure: A logical relationship among data elements that is designed to support specific data manipulation functions. (Vertaasis).
- Access to BDM objects: The hierarchical structure of BDM shows which object provides access to the next level of objects, as indicated in Figure 4. Understanding the data structure is a key in developing the software used in accessing objects database similar to using a road map to go from one place to another. Table 2 explains how to access various object.

Table 2. Access to various objects

Object Type	Access via

Project object	Application
Lot object	Project or LotsGroup
Landuse object	Project/Lot or LanduseGroup
Landscape	Project/Lot or LandscapeGroup
Material object	Project/Lot/Landscape or MaterialsGroup
Building object	Project or BuildingsGroup
Floor Object	Project/Building or FloorsGroup
Space object	Project/Building/Floor or SpacesGroup
Room object	Project/Building/Floor/Space or RoomsGroup
Building Element object	Project/Building/Floor/Space/Room or BuildingElementsGroup
Building Material object	Project/Building/Floor/Space/Room/BuilingElement or BuildingMaterialsGroup
Furniture object	Project/Building/Floor/Space/Room or FurnitureGroup
Equipment object	Project/Building/Floor/Space/Room or EquipmentsGroup
Material object	Project/Building/Floor/Space/Room/Equipment or MaterialsGroup
Material object	Project/Building/Floor/Space/Room/Furniture or MaterialsGroup

4. Building Code Model (BCM)

This research uses the proposed BDM structure and property definitions as guidelines in digitizing the building code requirements. The following are examples of how the building code sections can be structured.

EXAMPLE (1)

IBC - Section 302.1.1 Incidental use areas reads the following: “Spaces which are incidental to the main occupancy shall be separated or protected, or both, in accordance with Table 302.1.1 or the building shall be classified as a mixed occupancy and comply with Section 302.3. Areas that are incidental to the main occupancy shall be classified in accordance with the main occupancy of the portion of the building in which the incidental use area is located.

Exception: Incidental use areas within and serving a dwelling unit are not required to comply with this section.

IBC – Section 302.1.1.1 Separation: Where Table 302.1.1 requires a fire-resistance-rated separation; the incidental use area shall be separated from the remainder of the building with a fire barrier. Where Table 302.1.1 permits an automatic fire-extinguishing system without a fire barrier, the incidental use area shall be separated by construction capable of resisting the passage of smoke. The partitions shall extend from the floor to the underside of the fire-resistance-rated floor/ceiling assembly or fire-resistance- rated roof/ceiling assembly or to the underside of the floor or roof deck above.

Doors shall be self-closing or automatic-closing upon detection of smoke. Doors shall not have air transfer openings and shall not be undercut in excess of the clearance permitted in accordance with NFPA 80."

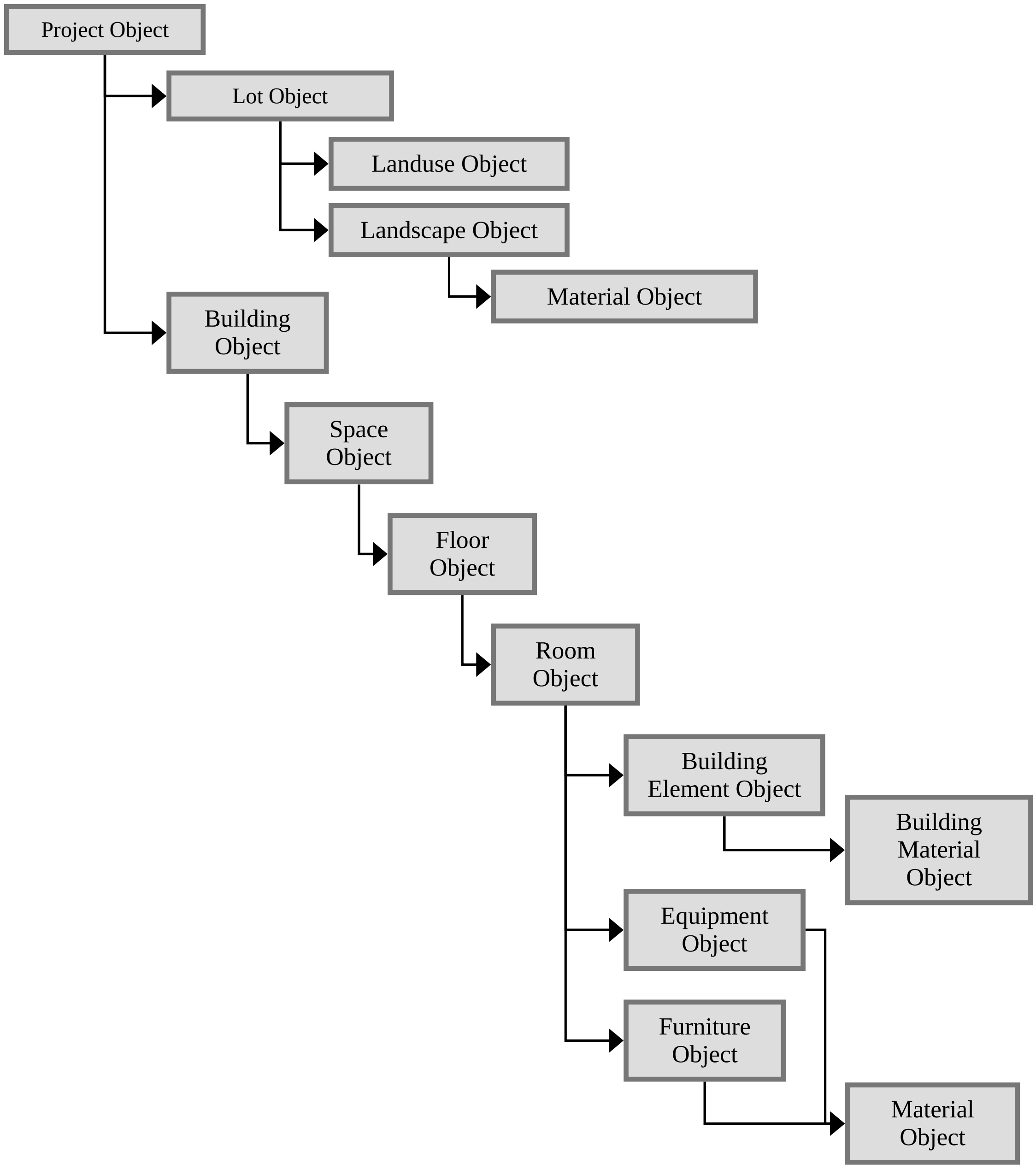

Figure 4. Proposed Structure of BDM

IBC - Table 302.1.1: Incidental use areas (part of the table) (IBC, 2003)

Room or Area	Separation
Furnace room where any piece of equipment is over 400,000 Btu per hour input	1 hour or provide automatic fire-extinguishing system

Structure of the program: Case study of a room equipped with a furnace

If Room.Function = "Equipment Room" and
If Room.EquipmentsGroup.Count= 1 and
If Room.Equipment.Type = "Furnace" and
If Room.Equipment.BtuPerHr > 40,000 and
(Option-1) If Room.FireExtinguishingSystem.Type = Automatic and
If Room.FireExtinguishingSystem.Status = On
Or
(Option-2) If Room.SurroundingWallsGroup.Enclosed = Yes and
If Room.SurroundingWallsGroup.FireRate = 1 and
Then
(If [Option-1] or [Option-2] = True)
Space.Room.Usetype = "Incidental Use" and
Building.Usetype = "Separated Occupancy"
Else
Space.Room.Usetype = "Part of Main Occupancy"
Building.Usetype = "Mixed Occupancy"

EXAMPLE (2)

Based on IBC-Table 503: Allowable height and building areas–Occupancy Group-B.

TABLE 503
ALLOWABLE HEIGHT AND BUILDING AREAS
Height limitations shown as stories and feet above grade plane.
Area limitations as determined by the definition of "Area, building," per floor.

		TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
GROUP	Hgt(feet) / Hgt(S)	UL	160	65	55	65	55	65	50	40
A-1	S	UL	5	3	2	3	2	3	2	1
	A	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
A-2	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-3	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-4	S	UL	11	3	2	3	2	3	2	1
	A	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
A-5	S	UL	UL	UL	UL	UL	UL	UL	UL	UL
	A	UL	UL	UL	UL	UL	UL	UL	UL	UL
B	S	UL	11	5	4	5	4	5	3	2
	A	UL	UL	37,500	23,000	28,500	19,000	36,000	18,000	9,000

Figure 5. IBC-Table 503 [46]

Program structure: Case study of a building classified as "Group-B"

If Building.MainOccupancyType = B <u>and</u>
If Building.FireExtinguishingSystem.Type = Automatic <u>and</u>
If Building.FireExtinguishingSystem.Status = Off <u>and</u>
<u>And</u>
If Building.ConstructionType = I-A <u>Then</u>
Building.TotalHeight = UL <u>and</u>
Building.FloorsGroup.Count = UL <u>and</u>
Building.TotalArea = UL
<u>Else</u>
If Building.ConstructionType >= I-B <u>Then</u>
Building.TotalHeight <= 160 ft. <u>and</u>
Building.FloorsGroup.Count <= 11 <u>and</u>
Building.TotalArea = UL sq. ft.
<u>Else</u>
If Building.ConstructionType >= II-A <u>Then</u>
Building.TotalHeight <= 65 ft. <u>and</u>
Building.FloorsGroup.Count <= 5 <u>and</u>
Building.TotalArea <= 37,500 sq. ft
<u>Else</u>
If Building.ConstructionType >= II-B <u>Then</u>
Building.TotalHeight <= 55 ft. <u>and</u>
Building.FloorsGroup.Count <= 4 <u>and</u>
Building.TotalArea <= 23,000 sq. ft.
<u>Else</u>
If Building.ConstructionType >= III-A <u>Then</u>
Building.TotalHeight <= 65 ft. and

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            Building.FloorsGroup.Count <= 5 and
            Building.TotalArea <= 28,500 sq. ft.
                    Else
 If Building.ConstructionType >= III-B Then
            Building.TotalHeight <= 55 ft. and
            Building.FloorsGroup.Count <= 4 and
            Building.TotalArea <= 19,000 sq. ft.
                    Else
 If Building.ConstructionType >= I-V Then
            Building.TotalHeight <= 65 ft. and
            Building.FloorsGroup.Count <= 5 and
            Building.TotalArea <= 36,000 sq. ft.
                    Else
 If Building.ConstructionType >= V-A Then
            Building.TotalHeight <= 50 ft. and
            Building.FloorsGroup.Count <= 3 and
            Building.TotalArea <= 18,000 sq. ft.
                    Else
 If Building.ConstructionType >= V-B Then
            Building.TotalHeight <= 40 ft. and
            Building.FloorsGroup.Count <= 2 and
            Building.TotalArea <= 9,000 sq. ft.
```

EXAMPLE (3)

Based on IBC-Table 601: Fire-Resistance rating requirements for building elements (hours).

TABLE 601
FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (hours)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[d]	B	A[d]	B	HT	A[d]	B
Structural frame[a] Including columns, girders, trusses	3[b]	2[b]	1	0	1	0	HT	1	0
Bearing walls Exterior[f]	3	2	1	0	2	2	2	1	0
Bearing walls Interior	3[b]	2[b]	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction Including supporting beams and joists	2	2	1	0	1	0	HT	1	0
Roof construction Including supporting beams and joists	$1\frac{1}{2}$[c]	1[c]	1[c]	0	1[c]	0	HT	1[c]	0

Figure 6. IBC-Table 601 (IBC, 2003)

Program structure: Case study of construction type "III-A" without sprinkler:

If Building.MainOccupancyType = A, B or E and
If Building.FireExinguishingSystem.Status = Off and
If Building.ColumnsSupportFloorAssemblyGroup.FireRate >= 1 and
If Building.MembersConnectedToColumnsSupportFloorAssemblyGroup.Fire-Rate >= 1 and
If Building.BracingforGravityLoadsMembersSupportFloorAssemblyGroup.FireRate >= 1 and
If Building.ColumnsSupportRoofGroup.FireRate >= 1 and
If Building.StructuralMembersConnectedToColumnsSupportRoofGroup.Fire-Rate >= 1 and
If Building.BracingforGravityLoadsMembersSupportRoofGroup.FireRate >= 1 and
If Building.ExteriorLoadBearingNonPartyWallsGroup.FireRate >= 2 and
If Building.InteriorLoadBearingWalls.FireRate >= 1 and
If Building.InteriorLoadBearingWallsSupportRoofGroup.FireRate >= 0 and
If Building.ExteriorNonLoadBearingNonPartyWallsGroup.FireSeparation-Distance < 30' and
If Building.ExteriorNonLoadBearingNonPartyWallsGroup.FireRate >= 1 and
If Building.InteriorNonLoadBearingWalls.FireRate >= 0 and
If Building.InteriorNonLoadBearingPartitions.FireRate >= 0 and
If Building.FloorAssemblyGroup.BeamsNotConnectedToColumnsGroup.Fire-Rate >= 1 and
If Building.FloorAssemblyGroup.JoistsNotConnectedToColumnsGroup.Fire-Rate >= 1 and
If Building.RoofAssemblyGroup.BeamsNotConnectedToColumnsGroup.Fire-Rate >= 1 and
If Building.RoofAssemblyGroup.JoistsNotConnectedToColumnsGroup.Fire-Rate >= 1 and
If Building.InteriorWallsGroup.MaterialsGroup.Type = AnyPermittedByCode
Then
Building.ConstructionType = III-A

The previous examples represent three different chapters and give an idea on how to structure the CAD programs that support the automated building code checking process.

5. Conclusion

The next sequential step, addressed as part of my PhD research, titled "Integrating Building Code Analysis within the Architectural Design Process into the Building Information Model" (Satti, 2006) and will be discussed and elaborated on in a separate paper is the graphical explanation of the CABCAD program and the use ADT 2005 and Visual Basic for Applications (VBA) in understanding the nature of CABCAD program and the complexity of creating appropriate data from BDM.

The proposed CABCAD program has been divided into interdependent sub-tasks. Each task has been illustrated graphically by defining the goal of the smaller tasks and what actions should the program execute. The illustration is based on the core building code analysis procedures regardless of the type of users.

References

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