Parametric Form-Based Codes: Incorporation of land-use regulations into Building Information Models

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This project describes investigations into whether parametric modeling using a Building Information Modeling (BIM) platform can represent the provisions and constraints of Form-Based Codes (FBCs). BIM software environments couple 3D modeling with parametric form generation and rich semantics. Further capabilities of an Application Programming Interface that supports Object-Oriented Programming (OOP) results in a very powerful environment for expressing planning and design concepts. While these capabilities were developed under the intention of supporting building design, we hypothesize that they can support planning rules and regulations that are found in FBCs. If our approach is successful, future planning departments will be able to provide architects and urban designers with a FBC that is implemented as a BIM software toolkit, better integrating the planning phase of a project into the building design phase

FBCs and Transect Zoning

FBCs were created as an alternative to conventional zoning and land use regulations by addressing the public realm and urban form (Ben-Joseph 2005). FBCs deal with the typology of block, street, open space, and building façade, whereas conventional land use regulations focus on the building use and the development capacity.

Transect zoning is an urban planning model that defines the hierarchical development scale from sparse suburban to dense urban cores (Forsyth 2003; Hascic 2006; Ligmann-Zielinska 2008; Stephenson 2002). The character of each transect zone is defined by the degree of density, open space, and urban form. Transect zoning provides a map, Transect Codes for each property, and requirements for each Transect Codes, but users need to locate all constraints and requirements from those documents. FBCs are an example of transect zoning ordinance, and follow the same structure. The main components of FBCs are the Regulating Plan with Transect Codes, Public Space standards, and Building standards, and users need to locate all requirements from those components (Parolek 2008). The general steps of using FBCs and Transect Zoning Ordinance are:

1. Define the public space type and the building type from the Regulating Plan
2. Define the allowed building locations and parking locations from the Regulating Plan
3. Obtain requirements for the public space from the Public Space Standards
4. Obtain requirements of materials and building configurations from the Building Standards
5. Overlay collected information to the Regulating Plan

FBCs users should overlay all components to understand what the consequence of FBCs is, but this overlay process is not always obvious (Figure 1). In all components of FBCs, various parameters are used to control urban geometry, and many of them are associated with other parametric values. For example, the principle building and the parking structure area are correlated with each other. If more floor area is planned, then a larger parking area would be required. As the parking area increases in the ground floor, the available first floor area of the building decreases. However, the allowed locations and heights of building and parking buildings are also defined, so these associations among constraints make the overlay process complex.

In addition, when we apply given FBCs standards to properties that have atypical morphology, the property geometry affects many parameters such as front façade locations, floor plan dimensions, and building volumes (Kim and Clayton 2010). Thus, this complex interaction among parameters and constraints can delay changes and analysis not only as users overlay FBCs components, but also as creators make decisions regarding FBCs provisions. The use of "what if" scenarios could lead to decisions that result in better codes.

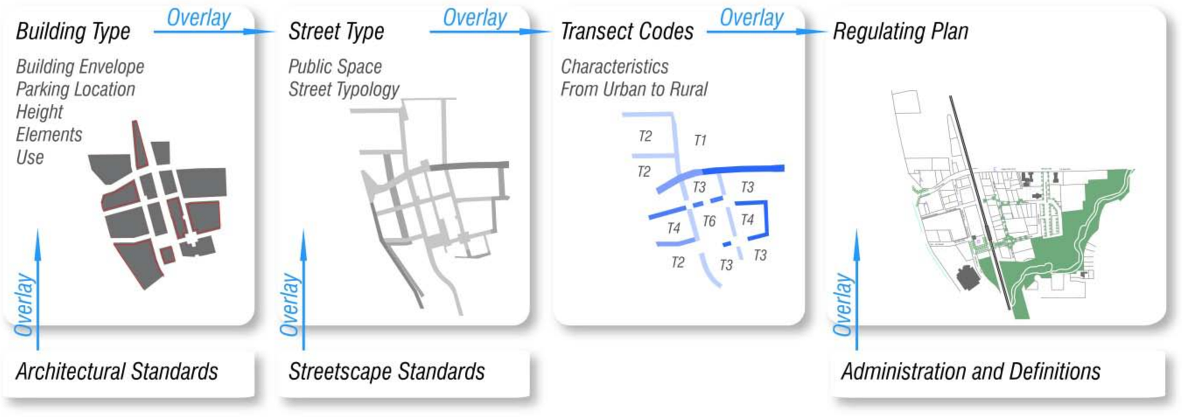


Figure 1: Overlay Process of FBCs. Main components of FBCs are the Regulating Plan, Transect Codes, Standards of building and street. Users of FBCs need to overlay all components of FBCs, which delay a real-time analysis and interpretation of FBCs.

The Parametric Approach in Existing Urban Design Tools

Computer-based urban modeling allows designers and planners to describe existing and future cities, in large part replacing the traditional use of physical urban models. These tools have been shown to lead to better decisions in developing urban planning regulations and specific urban designs (Al-Douri 2006).

CityCAD was developed by Holistic City, which can report a variety of design analysis data (Holistic City Software 2011). CityCAD provides a user-friendly interface and built-in object libraries, but the function mainly focuses on the building façades design. The built-in objects are based on parametric techniques, but users can access limited parameters of the site information and urban typologies. In addition, this tool does not offer programming interfaces that allow its extension (Jorge Gil et al. 2010).

CityEngine was initially developed by ETH Zurich, and then commercialized by Procedural Inc. in Switzerland. CityEngine is a 3D modeling application for urban environments, which focuses on visualization aspects of realistic cityscapes for the movie and video game industries (Procedural, Inc. 2011). This tool also provides a limited interface for editing the regulation parameters without any analysis features.

Project Galileo, created by Autodesk, is a planning tool for creating 3D city models with civil, geospatial, and building data. For now only a test version is available (Autodesk, Inc. 2011). This tool has an interface for the energy consumption analysis of urban developments. Project Galileo models can be presented with rendering images and movies also. Various file formats can be imported and exported for ArcGIS, AutoCAD Civil 3D, Revit, Project Vasari, and etc., but further research on the parametric modeling features and the programming interface are required.

In sum, the above programs have a limited feature for the parametric modeling and programming interface. The feature for responding to the planning regulations is also limited in these programs, whereas they provide for robust and quick visualization (Jorge Gil et al. 2010); therefore, there is a significant need for the new urban design platform that would enables policy makers to analyze regulations' consequences and users to interpret regulations more easily.

The Capability of Parametric Modeling in BIM

Parametric modeling is one of the main features of BIM that has been widely used in AEC industry, and has a potential to support implementation of FBCs. With the parametric modeling approach, objects can express geometry through formulas. By storing the object information as parameters, elements of objects may be regenerated according to any parametric values (Eastman et al. 2008; Smith 2009). As such, parametric modeling offers a degree of flexibility that is constantly responsive to change. Whenever users control any parameters of an object, they can test multiple scenarios, check the building geometry and urban morphology, and analyze the results of each scenario. These capabilities of parametric modeling can ease the complexity of the urban design process. We applied parametric modeling to FBCs components and tested its' capability to express aspects of the FBC. To do so, we used Revit Architecture (Autodesk, 2010) and the Application Programming Interface (API) of Revit to incorporate Object-Oriented Programming in C#.

Test Case: FBCs of Farmers Branch

We conducted a test case of the FBCs of Farmers Branch, which is located north of Dallas, Texas. Since the extension plan of the Dallas Area Rapid Transit (DART) included a station in Farmers Branch, the city has created the conceptual master plan, land use, and the FBCs. The FBCs focus on the physical form to produce safe and attractive station areas. Most of the FBCs regulations define the geometry and design style of buildings and open space around the DART station.

The city provides two different Regulating Plans, which allow a wider range of design options. However, the components and standards follow the typical structure of other FBCs. The components in the Farmers Branch FBCs are as follows (The City of Farmers Branch, 2007):

- **The Regulating Plan**: Identify a project boundary and allowed building envelope and streetscape standards
- **Streetscape Standards**: Identify typical configuration for streets for both vehicle lane and pedestrians.
- **Building Envelope Standards**: Govern public and private space through three dimensional building placement and building elements, such as storefronts, balconies, and street walls.
- **Architectural Standards**: Govern coherent architectural character for the locality, such as materials, configurations, and construction types.
- **Administration**: Describe intention of Codes and set forth the provisions.
- **Definitions**: Describe specific meaning of terms in the FBC

Process and Findings

Before proceeding with BIM and parametric modeling, we needed to define the required parameters from FBCs standards, and identify the association among parameters. The Farmers Branch FBCs have two Regulating Plans, five Street types, and six types of Building Envelope Standards. Table 1 is a part of standards. Most of the parameters that deal with three dimensional building geometries are defined in the Building Envelope Standards.

We analyzed all FBCs components to locate the association among parameters. As shown in Table 1, the parking structure height is related with the principal building height. The Open Area ratio is defined by the Total Buildable Area. Our concern was how to access all associated parameters within differing FBCs components, and how to control dispersed parameters together.

To do so, we tested the parametric modeling capability in BIM. We created Revit family models for Building Envelope Standards and Streetscape Standards , and then made a Revit project for the Regulating Plan. Figure 2 and 3 show the test case that shows two different Building Standards. In family models, type parameters for number, length, area, and ratio are added. As we discussed, the associated parameters are linked by using formulas.

Also we investigated methods to overlay all components to the Regulating Plan. We selected a block near the DART station that has two properties. The topological information was obtained after we simplified unnecessary segments to reduce the number of lines and nodes. Based on GIS parcel data and the Regulating Map, we built a base plan that shows property lines, setback lines, the Required Building Line (RBL), and the First Ground Required Building Line (FGRBL).

The selected two properties have two Building Envelop Standards, so two families were imported after we changed parametric values in the family edit interface. Once family models are inserted in the project file, we could add floors that show total floor area and ground floor area (Figure 3). In addition, we could insert building components including walls, windows, doors, and roofs, which have a potential for supporting the Architectural Standards.

Our major finding is that parametric modeling in BIM can be used to support some aspects of FBCs. Our BIM model and applications enable users to access regulation database, modify parametric values in FBCs standards, overlay these standards to each property, and analyze developable capacity immediately. These features of parametric modeling can assist decision making processes for both planners and designers.

This project demonstrates a part of FBCs that deals with geometrical requirements. However, Architectural and Urban Design standards of Farmers Branch include many other requirements that deal with the local tradition, design style, and place making. With only urban geometries and building typologies, the quality of the public realm cannot be accomplished, so further research is required for the new parametric regulating modeling that holds both geometrical and non-geometrical information.

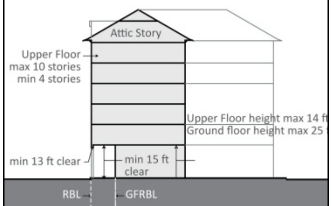
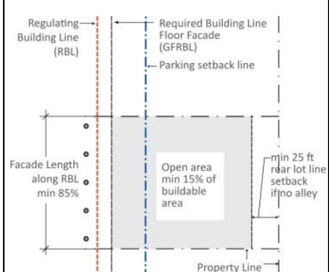
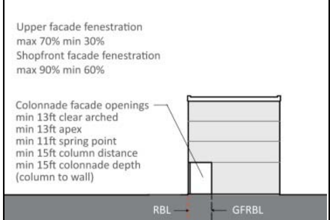
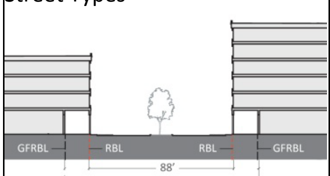
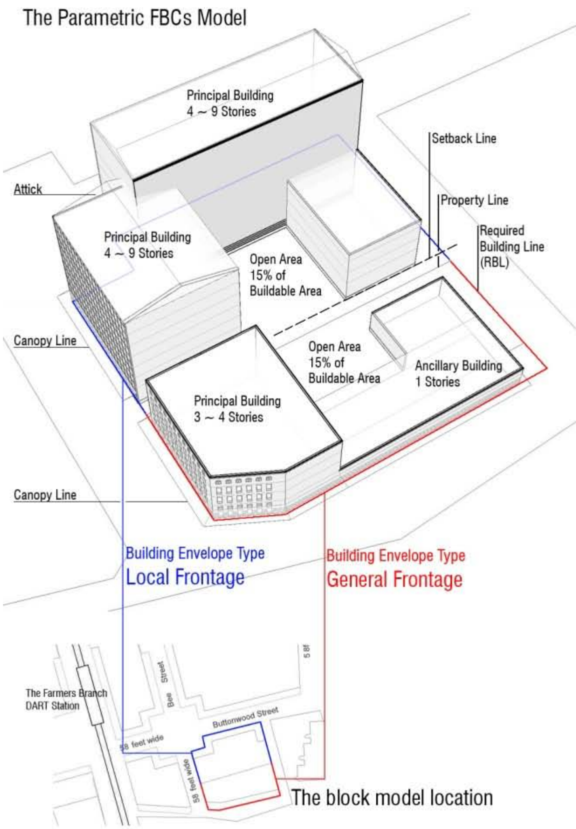
Categories	Parameters	Values
Building Height	Principal Building	4 stories (min) 10 stories (max)
	Parking Structure	Lower than principal building’s eave or parapet height
	Ground Story	25 ft. (max)
	Ground Story Interior	15 ft. (min)
	Upper Story	14 ft. (max)
	Mezzanines	13 ft. (min)
	Street Wall	Locate GFRBL if wall height is between 6 and 18 ft.
Siting	Regulating Building Line (RBL)	
	Required Building Line Ground Floor Façade (GFRBL)	
	Building Front Façade on RBL / or	85% (min)
	Ground Story Unit Frontage Widths	120 ft. (max)
	Rear Lot Line Setback	
	Side Lot Setback	
	Parking Setback	
	Buildable Area	Within RBL, GFRBL, and setbacks.
	Open Area	15% of the total Buildable Area (min)
	Garage Entries / Driveways	75 ft. from corner or other garage entry (min)
	Garage Entries Height	Height 16 ft. (max), width 24 ft. (max)
	Vehicle Parking Areas	Behind the Parking Setback Line
	Vehicle Parking Areas	Behind the Parking Setback Line
Elements	Fenestration Area (Ground Floor)	60% (min) 90% (max)
	Fenestration Area (Upper Story)	30% (min) 70% (max)
	Building Projections	Beyond RBL (except overhanging eaves, balconies, bay windows, and awnings)
	Entry Door Intervals along Ground Story Facades	60 ft. (max)
	Colonnades Clear Height	15 ft. (min) from interior floor to ceiling
	Colonnades Opening Height	13 ft. (min) from ground to beam
Street Types	Street space (width)	88 ft. (min) 120 ft. (max)
	Sidewalks	6 ft. (min)
	Median & Tree Planting Strip	14 ft.
	Travel Lanes	4 x 11 ft.
	Dedicated Parking Lanes	11 ft.
	Pedestrian Crossing Distance	63 ft.

Table 1. Parameters of the Building Envelope and the Street Type Standards. A summary of Shopfront Colonnade Site and Colonnade Street adapted from the Farmers Branch FBCs



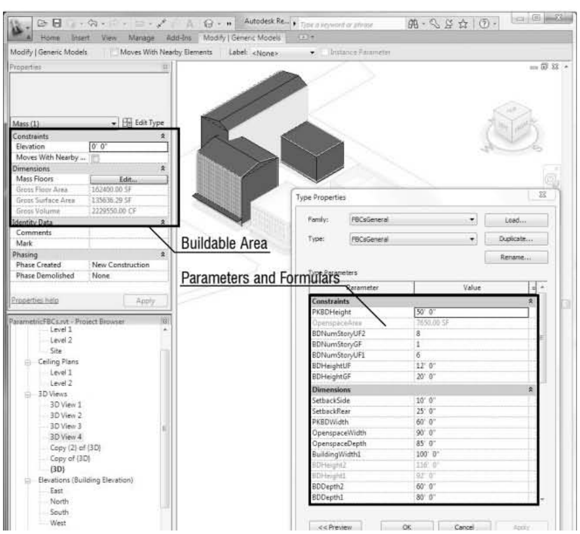


Figure 1. (above) The Parametric FBCs model includes two family models for representing two Building Envelope Standards.

Figure 3. (below) In the BIM environment, parameters can be added and the associated parameters can be linked with formulas. In addition, total floor area or buildable area can be obtained.

Conclusion

This project shows the potential to facilitate the integration of parametric techniques and FBCs. We project that in the future people can use parametric modeling to condense complex FBCs information into the solutions, conduct real-time data analysis, and represent highly differentiated urban patterns in accordance with regulation alternatives. As a decision-support tool, the parametric FBCs enable stakeholders to overlay each component, interpret regulations, as well as analyze and determine the consequences of alternatives. As a data exchange model, the parametric FBCs enable the invention of an urban design platform. The optimized data exchange platform can allow stakeholders to communicate each other in the BIM environment, which can change the traditional and chronological work flow in urban design domain. By using the same platform as the architects and engineers will use in later stages of the design process, an FBC expressed through BIM may be better integrated into the life cycle of the building.

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