# A NEW MODULAR PARADIGM IN BUILDING INFORMATION MODELING

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***Abstract —*** *As powerful as Building Information Modeling (BIM) tools are in modeling the built environment, current BIM strategies limit the size of facilities that can be modeled while increasing the time needed for modeling and the quality of BIM models produced. In the same way that prefabricated modular construction techniques are improving the speed and quality of construction delivery, a modular approach to BIM modeling substantially increases the scale of facilities that can be modeled while decreasing modeling time and increasing model quality. As a case study of this new approach we will look at Bechtel Civil's Project Planning and Development (PPD) design for a new community in Angondje, Libreville, Gabon where 6,000 dwelling units using 21 different building types for a population of 30,000 people were produced.*

***Keywords —*** *BIM, modular BIM, SmartCode, master Planning, community development, Revit*

## INTRODUCTION

Great strides are being made in prefabricated modular construction technology such as Bechtel's use of ModSpace's workforce housing in remote Labrador City, Canada and the erection of the 30 story T30 hotel in China in only 15 days. These impressive improvements in speed and quality of construction have not been matched on the design side.

As Building Information Modeling (BIM) technology has matured and organizations have brought ever larger buildings and facilities into the BIM workflow, the traditional BIM approach of capturing almost all of a facility in a few linked models has caused increasing difficulties. These very large model files cause serious issues:

- for collaborating with others in file transfer times,
- for quality of the model where tens of thousands of modeling errors are not uncommon,
- for easily reusing updated components across a portfolio of projects,
- and for working efficiently on the model where ever more powerful workstations are unable to keep up with the strains of growing model size.

**Figure 1. Rendering of Angondje, Libreville, Gabon**

As a case study for this paper, we will look at Bechtel Civil's Project Planning and Development (PPD) design for a new community in Angondje, Libreville, Gabon. This project is being delivered by the Agence Nationale des Grandes Travaux (ANGT), a government entity that Bechtel has helped establish. The development comprises a range of housing options for all income levels as part of neighborhood development that will include hospitals, green areas, roads and schools together with infrastructure to support it for a total population of over 200,000 people.

### ABBREVIATIONS, ACRONYMS, AND TERMS

| | |
|---|---|
| **BIM** | **Building Information Modeling** |
| **CAD** | **Computer Aided Drafting** |
| **Revit** | **Autodesk's BIM Software** |
| **PPD** | **Bechtel Civil's project Planning and Development Group** |
| **ANGT** | **Agence National des Grandes Travaux – A Government Agency Bechtel helped to establish to deliver projects in Gabon** |
| **SmartCode** | **A model form-based unified land development ordinance designed to create walkable neighborhoods across the full spectrum of human settlement** |

**Frederick Gibson**

**Fcgibso1@bechtel.com**

In phase 1 of Angondje, where the PPD team was faced with designing 6,000 dwelling units using 21 different building types for a population of 30,000 people, a traditional BIM approach with a few massive files would simply not have worked. Instead, a modular BIM approach was developed and deployed.

**Figure 2. Rendering of Phase 1 of Angondje**

**Figure 3. Rendering of Parcel 1, Phase 1 of Angondje**

## WHAT IS BIM?

Building Information Modeling (BIM), according to the National Institute of Building Sciences, is "horizontally integrated building information that is gathered and applied throughout the entire facility lifecycle, preserved and interchanged efficiently using open and interoperable technology for business, functional and physical modeling, and process support and operations."[1]

Traditional Computer Aided Design (CAD) systems deal with two dimensional representations composed of lines and arcs and other entities that have no "awareness" of their role with respect to adjacent lines and arcs or in the system of the facility as a whole. BIM, on the other hand, allows the creation of models using "intelligent" three dimensional objects that are "aware" of other objects they connect to and how they need to interact. For example, a door "knows" that it cuts a hole in the wall, and the wall "knows" that if it moves, the door must move with it, and the dimension linked to the wall "knows" it must change accordingly as must all the data tags associated with the wall. Additionally, these objects can be instances of classes of objects that can be defined with complex relationship logic and interference requirements with embedded parameters allowing use in a wide variety of specific cases.

In the case of Revit, the model is captured in the form of a database where all information is stored within three distinct environments, the underlying model itself, the views looking at the model, and the sheets containing the views. View objects are used to gain a real-time view of the model and define whether, for example, the desired view should be a two-dimensional slice through the model at a particular place, a three-dimensional view using particular camera settings, or a schedule listing out data about the model. All annotations in the view and graphic settings are stored within the View object and are not a part of the model environment itself. These view objects can be placed on sheets and then additional annotations and parameters added in the sheet environment. Similar to a wall, a sheet "knows" the views that are on it and automatically coordinates all annotation references within the views with the proper parametric sheet information.

Standard industry practice and the current trend is to have as few BIM models as possible in a project, usually split between disciplines. Large projects, such as SOM's Freedom Tower, are produced with as few as 5 linked models. Strategies for breaking up BIM models revolve around staffing issues rather than the underlying facility structure.[2]

The problems with massive BIM models are numerous, including serious difficulty in collaborating with remote locations given large file sizes. Even with a BIM solution like Revit, where element level permissions within a model are used allowing a team of people to work on the same model at the same time, whenever a team member saves their changes to the central model, all others are prevented from saving or loading the latest changes until the save is complete. In a very large file with many people working on it, this intermittent locking can truly bring progress to a halt, especially during intense deadline periods when productivity is needed most.

As these BIM models increase in size, ever more powerful workstations are needed to process them leading to a strategy of breaking up models based on what a workstation can process.[2] Additionally, because of the massive amount of data in one model, it becomes increasingly difficult to maintain and correct the errors that conflict-detection systems find between various elements.

The most serious problems with large models, however, are the inability to easily reuse and maintain a library of well engineered components captured from earlier completed work and updated through time, and the inability to scale projects successfully to ever larger facilities and ever greater numbers of buildings with increasing levels of productivity.

## THE MODULAR BIM PARADIGM

In starting design work for six thousand buildings, we quickly realized that a new BIM approach was needed – massive files would simply not work. Our design program called for buildings that could be easily prefabricated, and this modular approach to the design naturally led to a modular approach to BIM modeling.

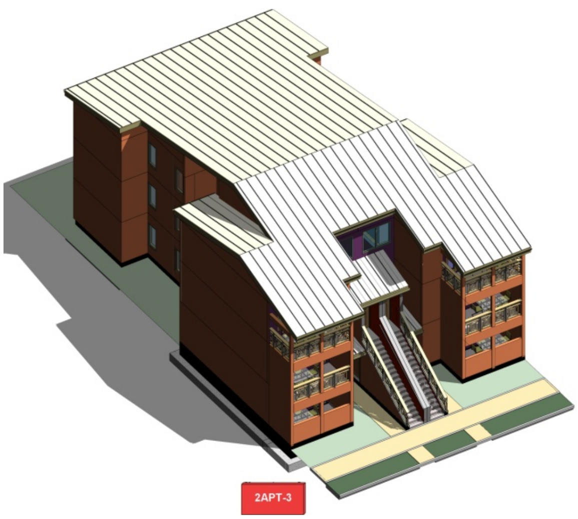


**Figure 4. 2APT-3 Building Type**

As we continued to design different building types, it quickly became evident when parts of buildings could be shared that separate models could then be linked to both types. This process led to the principle that modules should always be created if the building sub assembly is used more than once within any building or across different buildings. This modularity allowed a very high level of quality in the models and drawings as all information only needed to be drawn once and revised and corrected in one place with automated updating of all affected sheets in the various building models and drawing sets.

An example of the modularity is the level 2 quality three bedroom six unit apartment building (2APT-3) shown in Figure 4 and expanded in Figure 5.

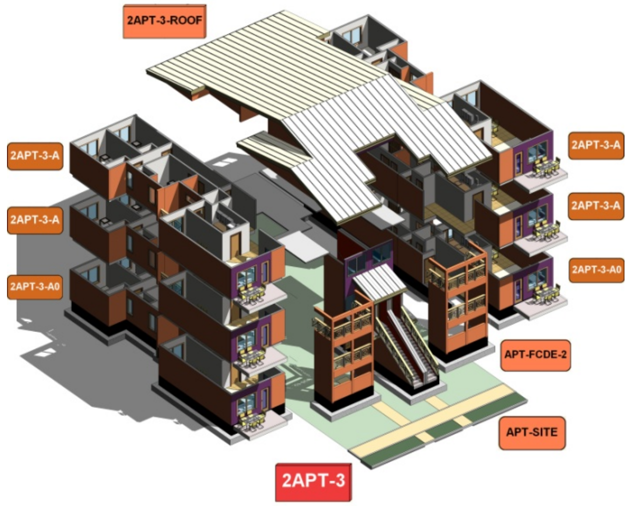


**Figure 5.**
**Expanded View of 2APT-3 Building Type**

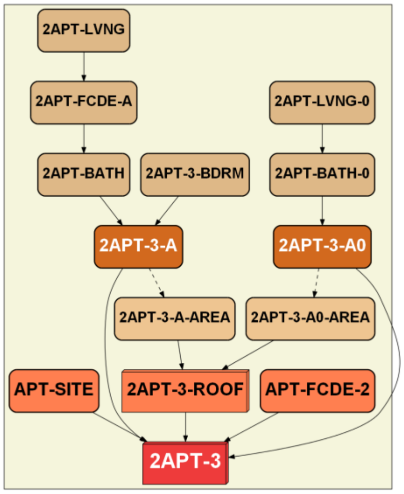


**Figure 6.**
**2APT-3 Module Hierarchy**

This building is assembled using a total of 14 separate modules with 5 separate Revit model links at the top level in the main building model as shown in Figure 6. Only one model link is used for the typical three bedroom apartment (2APT-3-A) and copied and mirrored in addition to the ground level apartment (2APT-3-A0) to give the building six units. The roof link is used in a 2 story version of this building. The apartment unit links are used in both a 2 story version of this building and a mixed use building which has commercial at the ground floor.

**The most serious problems with large models are the inability to easily reuse and maintain a library of well engineered components**

These 5 module links of the main building are further broken down into modules as shown in the typical 3 bedroom unit model (2APT-3-A) in Figure 7 made up of a total of four modules. The rear module (2APT-3-BDRM) varies based on the bedroom count of the unit, and the façade (2APT-FCDE-A) varies among buildings.

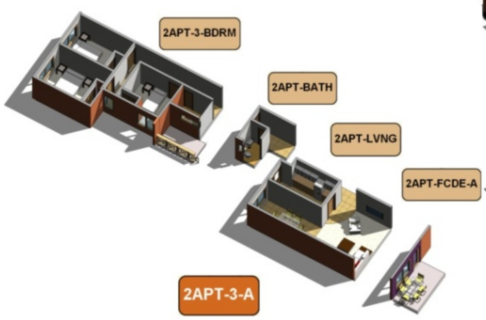


**Figure 7. Modular Components of 2APT-3-A Unit Type**

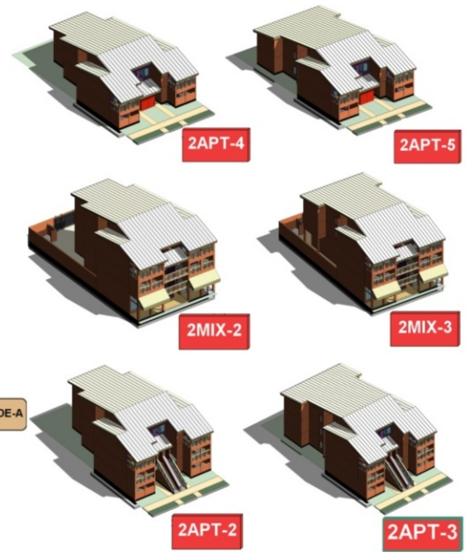


**Figure 8.**
**2APT and 2MIX building Types**

The 2APT and 2MIX building types shown in Figure 8 are made from a total of 49 modules. Similar building types, such as 2APT-4 and 2APT-2, share 78% of their modules. The graph in Figure 9 shows the model link structure for the seven total 2APT and 2MIX building types.

## PRODUCTION DRAWINGS

For the Angondje housing, our task was to document 30% complete preliminary engineering drawings which resulted in a set of roughly 200 A1 size drawing sheets for the 21 building types. Revit allows hierarchical inheritance of view settings and all their associated annotations from linked Revit models. The views for any module reside in that module's model file, thus linking together modules to create various building types automatically results in complete detailed and annotated drawings. As an example, Figure 10 shows the complete Level 2 Floor Plan for the 2APT-3 building type.

Figures 12 through 16 show the views from the various modules which are linked together to form the Sheet shown in Figure 10.

Separate model files were created for plotting each building type and then linked to sub and master index files for plotting the sub and master index sheets.

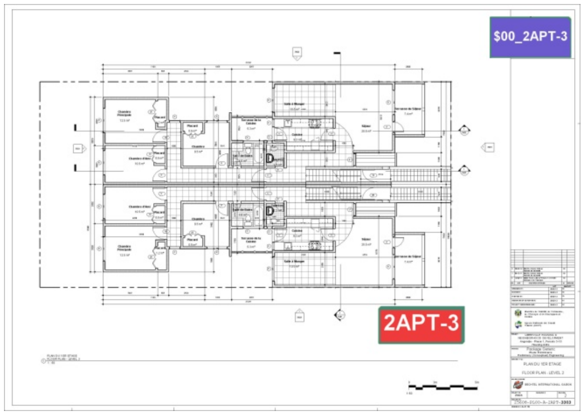


**Figure 10.Sheet 25608-PL00-A-2APT-3303 – Floor Plan Level 2 for the 2APT-3 Building Type**

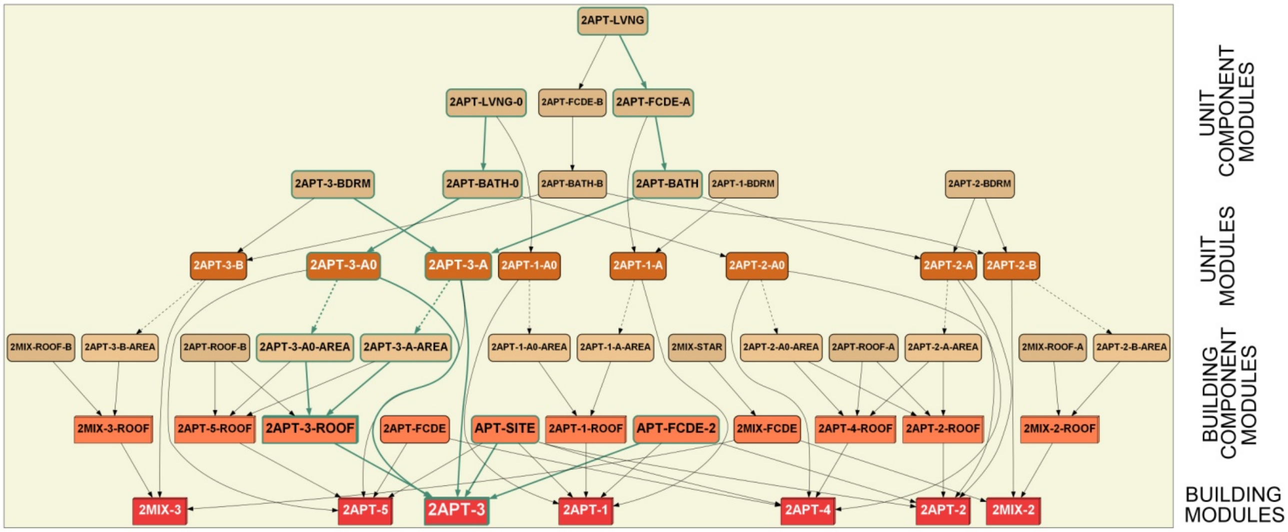


**Figure 9. 2APT & 2MIX Module Link Structure**

| Material | Count | Material: Area |
|---|---|---|
| Floor: Floor Slab - 100mm @ grade | 3 | 88.7 m² |
| Floor: Conc - 150mm | 1 | 31.8 m² |
| Floor: Floor Slab - 100mm @ grade | 3 | 88.7 m² |
| Basic Roof: Wood Framed Roof | 2 | 105.9 m² |
| Basic Wall: Maçonnerie d'agglomérés creux 150mm | 2 | 21.7 m² |
| Béton - Coulé sur Place Linteau / Concrete - Cast-in-place Lintel: 184 x 200mm | 2 | 1.5 m² |
| Béton de Colonne / Concrete Column: 180 x 180mm | 2 | 2.5 m² |
| Basic Wall: Maçonnerie d'agglomérés creux 150mm | 1 | 30.8 m² |
| Béton - Coulé sur Place Linteau / Concrete - Cast-in-place Lintel: 184 x 200mm | 8 | 4.6 m² |
| Béton de Colonne / Concrete Column: 180 x 180mm | 16 | 22.9 m² |
| Basic Roof: Wood Framed Roof | 2 | 105.9 m² |
| Floor: Conc - 150mm | 1 | 31.8 m² |
| Basic Wall: Maçonnerie d'agglomérés creux 100mm | 18 | 211.4 m² |
| Basic Wall: Maçonnerie d'agglomérés creux 150mm | 17 | 364.3 m² |
| System Panel: Roof | 37 | 105.7 m² |
| Basic Wall: CMU 200mm | 8 | 34.5 m² |
| | | 1252.6 m² |

**Figure 11. Example Material Schedule**

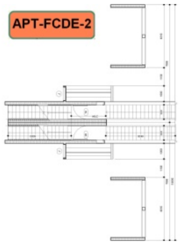


**Figure 12. APT-FCDE-2**

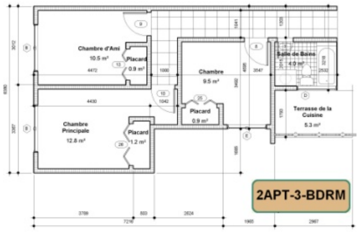


**Figure 13. 2APT-3-BDRM**


**Figure 14. 2APT-BATH**

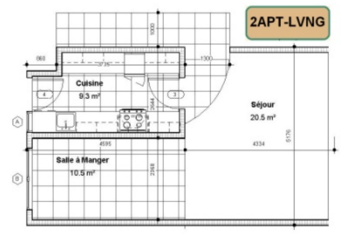


**Figure 15. 2APT-LVNG**

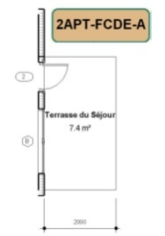


**Figure 16. 2APT-FCDE-A**

## SMARTCODE

The SmartCode, a model form-based unified land development ordinance designed to create walkable neighborhoods across the full spectrum of human settlement, was used as the key master planning design guide for Angondje.

The SmartCode uses complex formulas and relationships which were captured with parameters in the zoning areas. These parameters automatically controlled color and were reported in schedules capturing the various zoning algorithms allowing real-time design and analysis as shown in Figure 18 with an example of metrics shown in Figure 19.


**Figure 17.**
**1MFA, 2APT, 2MIX & 3MIX Plotting Hierarchy**

| RCD-A Community Transect Distribution | | | |
|---|---|---|---|
| Name | Area | Percentage | Dwelling Units |
| Community | 14.3 hectare | 6% | 0 |
| Green | 34.7 hectare | 15% | 0 |
| Park | 19.1 hectare | 8% | 0 |
| School | 3.3 hectare | 1% | 0 |
| Square | 1.2 hectare | 1% | 0 |
| T4 | 22.0 hectare | 9% | 256 |
| T4-TDR | 10.2 hectare | 4% | 289 |
| T5-TDR | 25.9 hectare | 11% | 1550 |
| T6 | 95.8 hectare | 40% | 2899 |
| T6-TDR | 11.1 hectare | 5% | 1116 |
| Grand total: 272 | 237.4 hectare | 100% | 6110 |

| RCD-A - T5 - TDR (60 Density max) | | | | | |
|---|---|---|---|---|---|
| Transect Zone | Area | Percentage | Dwelling Units | Averaged Density | Parcel |
| T5 | 3.3 hectare | 13% | 220 | 8.5 | 1 |
| T5 | 3.2 hectare | 12% | 232 | 9.0 | 3 |
| T5 | 2.7 hectare | 10% | 194 | 7.5 | 4 |
| T5 | 3.7 hectare | 14% | 144 | 5.6 | 5 |
| T5 | 4.2 hectare | 16% | 160 | 6.2 | 6 |
| T5 | 2.4 hectare | 9% | 148 | 5.7 | 7 |
| T5 | 1.7 hectare | 7% | 128 | 5.0 | 8 |
| T5 | 3.1 hectare | 12% | 204 | 7.9 | 9 |
| T5 | 1.6 hectare | 6% | 120 | 4.6 | 10 |
| Grand total: 21 | 25.9 hectare | 100% | 1550 | 60.0 | |

**Figure 19. Example SmartCode Metrics**

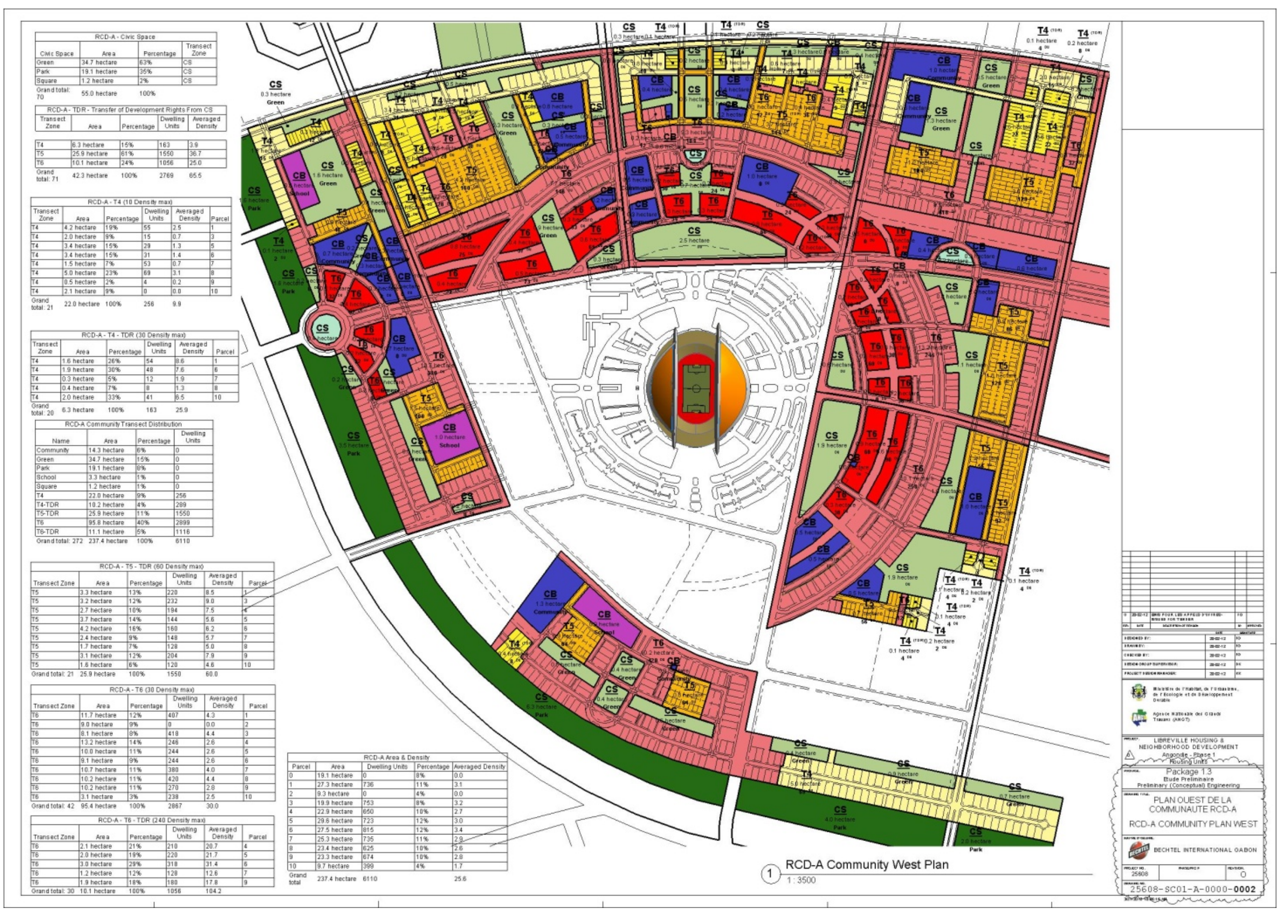


**Figure 18. SmartCode Community Zoning Plan – West**

The SmartCode includes strict parking requirements that potentially limit the area of development. Parking compliance was confirmed using lot and unit based parameters as well as parking element parameters. Each lot object has parameters that describe the zoning and other parking factors , and each unit has parameters describing the building type and quality level of the unit. This information is then used in Revit schedules to compute parking requirements based on the lot characteristics. For example, in the case of a Mixed-used building, Revit will automatically compute parking requirements for each of the dwelling units as well as separate parking requirements for the commercial space. However, in the case of a single family house, Revit will only compute a residential parking requirement.

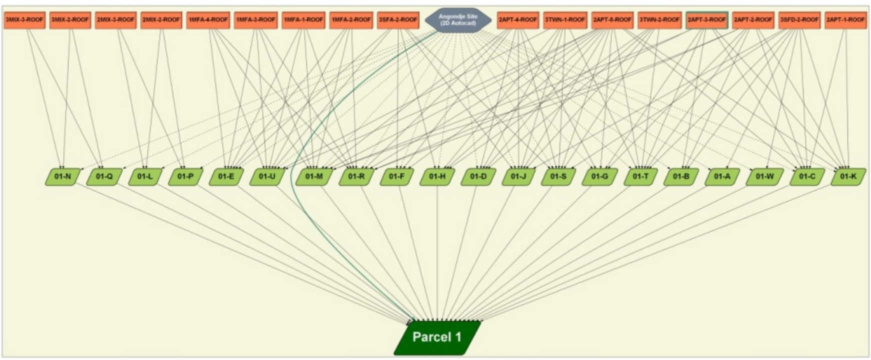


**Figure 20. Parcel 1 Module Hierarchy**

## SCALING TO THOUSANDS OF BUILDINGS

As buildings were added to the parcels, the performance degraded to the extent that an alternative solution had to be found even after turning off the visibility of all non-needed elements. A separate model was created for each of the 10 parcels in phase 1 and further broken down into separate street blocks with buildings linked as needed into the blocks as shown in Figure 20.

Because access was needed in the parcel model to many parameters about the various buildings such as quality level and bedroom count as well as building areas, we embedded all the parameters in the unit area objects and referenced those into the roof modules.

The roof modules were then linked directly into the parcel blocks bypassing the rest of the modules that make up the buildings dramatically improving performance. Figure 21 shows a typical Parcel plan with shadowed roof objects.

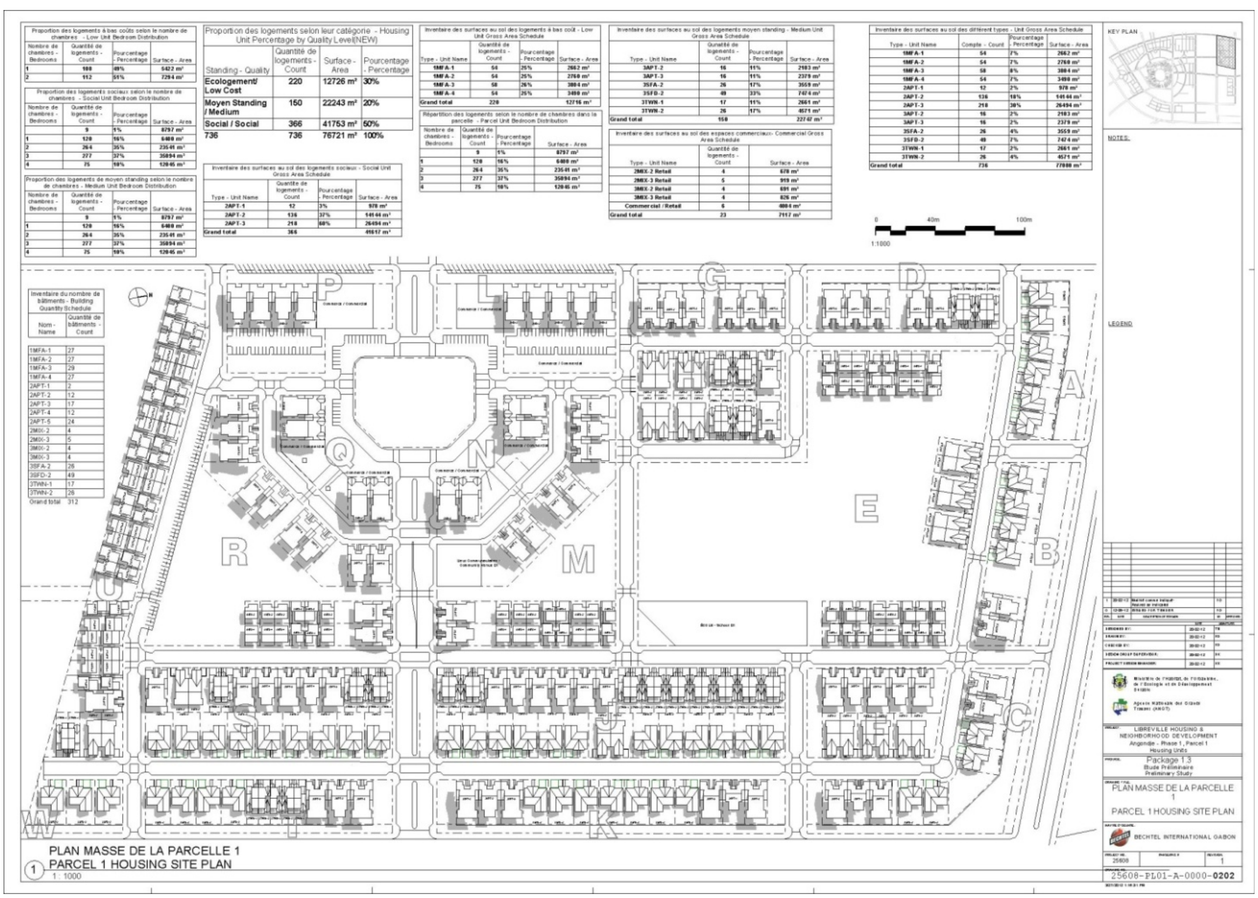


**Figure 21. Parcel 1 Housing Site Plan**

In addition to using the SmartCode for master planning the community, many requirements were added by ANGT to design certain quantity percentages based on quality level of buildings as well as constraints about adjacency of various quality buildings on the site. As the schedules are real-time views into the database, we were able to use the schedules as design tools to maintain conformance with all requirements. A sample of the Parcel metrics are shown in Figure 22.

| Distribution des numéros des chambres pour le logement bas couts - Low Unit Bedroom Distribution | | | |
|---|---|---|---|
| Chambres - Bedrooms | Compte - Count | Pourcentage - Percentage | Surface - Area |
| 1 | 108 | 49% | 5422 m² |
| 2 | 112 | 51% | 7294 m² |

| Distribution des numéros des chambres pour le logement sociale - Social Unit Bedroom Distribution | | | |
|---|---|---|---|
| Chambres - Bedrooms | Compte - Count | Pourcentage - Percentage | Surface - Area |
| 2 | 136 | 38% | 14144 m² |
| 3 | 218 | 62% | 26656 m² |

| Sommaire du Surface du sol pour le logements du niveau moyen - Medium Unit Bedroom Distribution | | | |
|---|---|---|---|
| Chambres - Bedrooms | Compte - Count | Pourcentage - Percentage | Surface - Area |
| 2 | 19 | 13% | 2450 m² |
| 3 | 51 | 34% | 7445 m² |
| 4 | 78 | 53% | 12479 m² |

| Percent âge du logements par niveau du qualité - Housing Unit Percentage by Quality Level | | | |
|---|---|---|---|
| Standing - Quality | Compte - Count | Surface - Area | Pourcentage - Percentage |
| L | 220 | 12716 m² | 30% |
| M | 148 | 22374 m² | 20% |
| S | 354 | 40800 m² | 49% |
| Grand total | 722 | 75891 m² | |

| Distribution des numéros des chambres dans le parcellé 1 - Parcel 1 Unit Bedroom Distribution | | | |
|---|---|---|---|
| Chambres - Bedrooms | Compte - Count | Pourcentage - Percentage | Surface - Area |
| | 9 | 1% | 8797 m² |
| 1 | 108 | 15% | 5422 m² |
| 2 | 267 | 37% | 23889 m² |
| 3 | 269 | 37% | 34102 m² |
| 4 | 78 | 11% | 12479 m² |

**Figure 22. Example Parcel Metrics**

## UNIQUE UNIT IDENTIFICATION

The construction management team in Gabon required a unique identifier for each unit in Phase 1 as well as parameters to track the progress of construction on each unit. Unfortunately, Revit does not treat model links as objects to which parameters can be attached, nor is there a way to create a relationship between a Revit model link and another object. The only option until these missing features exist was to create new objects that would represent each individual unit.

A case where Revit is able to "sense" a relationship is when an object of furniture is within a room volume. The furniture object can inherit all the parameters of the room in which it resides. With that relationship in mind, we created a special furniture object (unit-object) with all of the many parameters being tracked and turned the lots into rooms in the block models such that the lot rooms contained all of the parameters about the lot such as zoning, unique lot id and area.

Consequently, whenever a unit-object was moved into a lot, it would automatically inherit all of the lot information from the lot-room which was then used in automatically forming the unique unit identification tag. Given the quantity of units, we developed several schedules to check for and correct any errors.

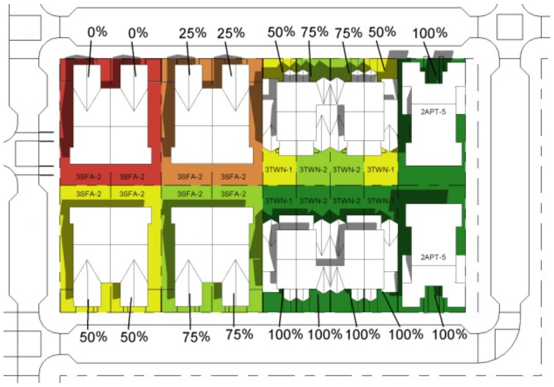


**Figure 23. Construction Progress Parameters**

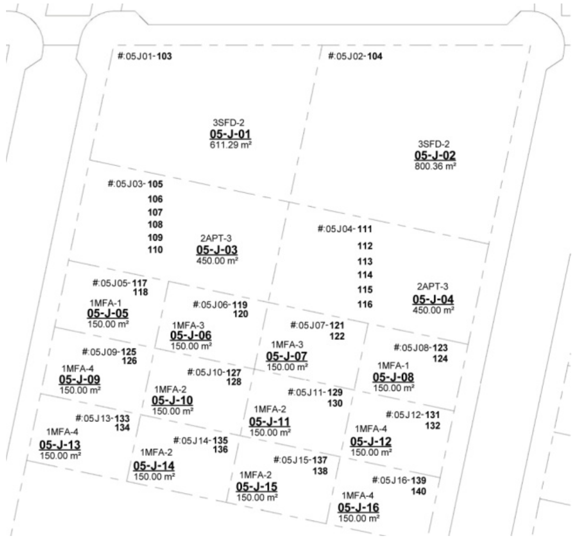


**Figure 24. Unique Unit Identification Tags**

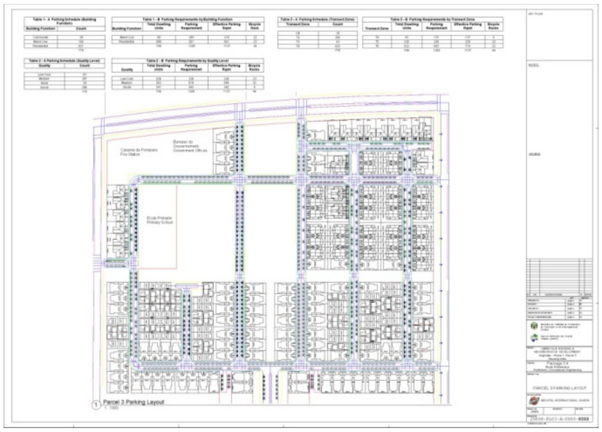

**Figure 25. Parcel 3 SmartCode Parking Analysis**

## CONCLUSIONS

A new modular approach to BIM requires less time for modeling while increasing the quality and scale of facilities modeled. This new approach can also lead to an increasing portfolio of well engineered BIM modules that open new opportunities in modular construction delivery.

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[1] "United States National Building Information Modeling Standard", National Institute of Building Sciences, Version 1 – Part 1 : Overview, Principles, and Methodologies, December 2007.

[2] "Managing Large Projects in Revit Architecture", Lonnie Cumpton, Autodesk University, AB100-1P.

## BIOGRAPHY

**Frederick Gibson**

Frederick is a senior architect in the Urban and Regional planning division of Bechtel Civil's Project Planning and Development group (PPD) as well as the active representative of the PPD BIM group and the Bechtel Corporate Revit User Product Manager. He has been working in the architectural profession for 26 years and practicing architecture for the last 15 years. Prior to joining Bechtel in early 2011, Frederick worked for Paul Rudolph Architect in Manhattan as well as KMD in San Francisco and HOK in San Francisco and Redmond and eventually founded Frederick Gibson + Associates Architecture in 1996 with work on many different building types internationally. The firm's first fully integrated BIM project was completed using Revit in 2003. Throughout his career, Frederick has pioneered the use of computer technology for design, design visualization, engineering documentation and project management.
Since joining Bechtel, in addition to the Andgondje project, he has worked on the master plan concept for the Port Mole area of Libreville Gabon as well as the master plan and prototype buildings for Waad Al-Shamaal City, a new industrial city in Saudi Arabia.