Concrete Construction for Social Housing in Colombia: Towards a higher productivity supported by the use of Digital tools and off-site processes.

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Abstract. This paper presents the outcomes of a collaborative project between UK and Colombian researchers, aimed at increasing productivity and lowering emissions for the construction of social housing in Colombia, particularly when using concrete as the main building material. Based on the findings of a previous project that focused on the automation of concrete construction within the UK context, and following the implementation of interviews with local industry experts, the researchers analyzed the opportunities and challenges of incorporating digital technologies in order to improve the construction process, and found out that there was higher potential in the design and management areas rather than in the actual production of components, where standard prefabrication was perceived as the most fitting solution. This paper will introduce some of the advances in the project, which include a diagnosis of the challenges and obstacles of prefabricated systems used in construction, obtained from interviews with leaders and actors in the sector, a meta-analysis of barriers and opportunities of the use of concrete prefabrication in other contexts, the development of a typology as an example of an application developed as part of the project development, and finally a software tool to support the proposed case of application.

Keywords: Concrete construction, Prefabrication, Social housing, FEA Analysis, Generative tools

1 Background and Research Problem

The project presented here is the result of an ongoing collaboration between Colombian and UK academic and industrial institutions, with support from the UK's Royal Academy of Engineering. The project addresses a particular challenge in the Colombian construction sector, that of optimizing concrete construction for social housing applications. By partnering with a larger research project with similar goals, and by involving local industry, this project advanced the state-of-the-art in concrete construction, and is currently building a network group of stakeholders working towards sustainability and economic benefits.

The partner project, titled Automating Concrete Construction (known as ACORN), was a three-year project carried out in the UK by the Universities of Bath, Cambridge, and Dundee, in collaboration with 12 Industry Partners and 14 Industry Affiliates, and funded by "UK Research & Innovation" under the Transforming Construction programme. Its primary objective was to drive acceptance of a new culture in the construction industry, one that embraces the concept of only putting material where it is needed, to enhance sector-wide sustainability and productivity. Its solution was to move concrete production off-site and use computer-controlled robotics and adaptable molds to optimize geometry and reduce material consumption (Oval et. al., 2021). Previous research had shown that it is possible to remove more than 50% of the concrete from a typical office building via this approach (Hawkins, et. al, 2020). The more recent full-scale physical ACORN demonstration (Figure 1) used form-found geometries (Costa et. al, 2020; 2021) to ensure concrete was predominantly used in compression, with therefore minimal bending and reduced reinforcement. This shell-floor needed only 25% of the concrete of an equivalent flat-slab for the same load-case, with only 40% of the embodied carbon.

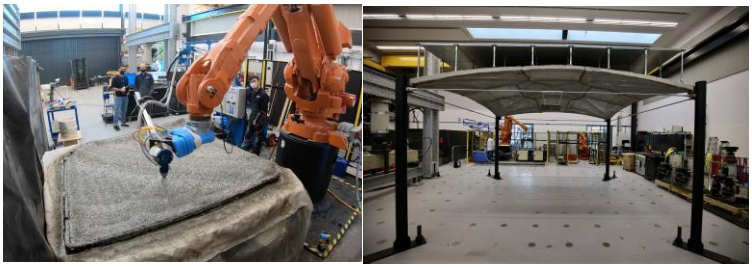

Figure 1. Robotic thin-shell spraying system and adaptable mold (left) with the resulting final 4.5m span demonstration shell (right)

The aim of the Colombian project detailed in this paper was to explore ways in which the same philosophy might be translated into the very different social and economic contexts of Latin America, with a focus on social housing.

2 Methodology

Three differentiated stages were implemented. The first one, "Planning" involved a literature review of meta-analysis concerning the application of novel concrete construction technologies in different countries, but also implemented 30 interviews with representatives of Colombian concrete construction stakeholders, namely Developers, General contractors, Structural and design consultants, Manufacturers, Governmental institutions, and Academics working on the specific field. The second stage, “Development”, entailed extensive use of structural simulations in conjunction with economic analyses to select possible design configurations for prefabricated components. It also included the development of an online application and the production of real scale prototypes of the main construction components proposed. Finally, a “Dissemination” stage, currently in progress, includes the execution of a focused conference with local stakeholders, as well as the publication of project results in international conferences.

The planning stage, which defined the scope of the project, yielded the first important result from the analysis of interviews with stakeholders, which determined the advantages of prefabrication using conventional techniques over the employment of more advanced customized digital production processes. However, digital processes were particularly valued as design tools to assist both the designers and final users of the system, i.e., developers.

An expert analysis carried out by the researchers in collaboration with relevant Colombian concrete construction stakeholders, following a material-design framework (Ashby, 2005), highlighted significant aspects of comparison between the UK and the Colombian projects, as seen in Figure 2. Two main characteristics appeared as distinctive and with central consequences on the work to be carried out. Firstly, the repetitive nature of housing projects as opposed to custom office buildings, reinforced by the extreme low budget for social housing as given by the law and the market, but secondly, the high relative cost of digital manufacturing methods and the general lack of specialized production and transportation infrastructure, meant that standard prefabrication had highest potential for development.

	UK PROJECT		COLOMBIA PROJECT		
USE	MULTIPLE FUNCTIONS, STRUCTURAL FRAME SYSTEMS	≠	SOCIAL HOUSING IMPLYING LOW COST REQUIREMENTS AND REPETITION	>	MID RISE BUILDINGS EMPLOYING MIXED CONSTRUCTION SYSTEMS (OFFSITE + IN-SITU CASTING) TO ALLOW FOR LOCAL SEISMIC REGULATIONS
MATERIAL	HIGH PERFORMANCE CONCRETE, WITH FIBRE REFORCEMENT - CFRC	≠	HYBRID LOW COST MATERIALS, INCLUDING RECYCLED AGGREGATES	>	CONFIGURATIONS THAT CAN ALLOW FOR FUNCTIONAL REQUIREMENTS INCLUDING SOUND INSULATION AND THERMAL MASS
SHAPE	STRUCTURALLY OPTIMIZED CONFIGURATION TO REDUCE MATERIAL USE	=	STRUCTURALLY OPTIMIZED CONFIGURATION TO REDUCE MATERIAL USE	>	SURFACE ACTIVE ELEMENTS TO ALLEVIATE STRESS CONCENTRATIONS AT JOINTS
PROCESS	AUTOMATED PRODUCTION ALLOWING FOR CUSTOMIZATION	≠	REPETITION AND LOW COST REQUIREMENTS, ALLOWING FOR STANDARD PREFABRICATION	>	PANEL SYSTEMS PREFERRED, AS MODULAR SYSTEMS ARE NOT VIABLE DUE TO LACK OF LOCAL TRANSPORTATION INFRASTRUCTURE, AND DO NOT COMPETE WITH LOW WAGES

Table 1. Comparison of projects according to scope and environment.

3 Results

Optimized component configurations were produced from the correlation of Finite Element Analyses with material, production, and estimated costs, which resulted in the fabrication of prototypes, still in progress, and an online design tool to generate possible residential project layouts using the proposed construction system in specific plots of land given by the user is already available.

Though still work in progress, a detailed analysis of the production process as well as testing of prototypes should be available for presentation of the present paper. Additionally, a report of the network group created should also be available for presentation.

The first round of interviews with experts along with an initial literature review indicated five crucial areas to take into account when introducing prefabricated concrete building systems in developing economies, those were: Cultural and information related, Structural and construction regulations related, Functional and architectural related, Onsite- construction management related and Financial and business model related

All of them entailed specific barriers to the introduction of prefabricated concrete systems, as described below.

-Cultural and information related: Lack of clear information (structural, construction, costing) for designers to specify such systems, Lack of qualified labor to build with them.

-Structural and construction regulations related: Joints among components require very specific technical solutions, the current local regulation penalizes de use of such systems

-Functional and architectural related: These systems restrict flexibility in design, require very specific and non-standard design solutions, if completely prefab, do not allow for high rise constructions

-Onsite - construction management related: Local general contractors do not have the infrastructure to build using prefab components, Transportation and storage are perceived as highly problematic in terms of site logistics, Quality control is challenging due to the significance of certain details.

-Financial and business model related: There are not enough suppliers in the market to allow for variety and competitive prices, with specialized-partial suppliers it is difficult to allocate responsibility and provide insurance, Local regulations to tax construction penalize the inclusion of external subcontractors.

The last three areas, however, also indicated specific advantages of such systems.

-Functional and architectural related: Better quality finishes of components, Possible shape complexity of components, Less weight of construction

-Onsite- construction management related: Higher construction productivity implying lower construction time, less waste and better control

-Financial and business model related: Possible economies of scale.

The defined areas were revised with meta-analyses found in literature, including studies previously carried out in India (Verghese & Thomas, 2021), where all areas were represented, and financial factors appeared with more relevance in terms of barriers, China (Gan et al, 2021), where again all areas were represented, but management aspects had particular relevance, Malaysia (Nawi et al, 2011) where design factors were not taking into account but it was assumed that it may had been due to the supplier emphasis of the research, Australia (Steinhardt et al, 2013), where cultural factors were less important presumably due to a more mature nature of the market, and Egypt (Bakathy & Kalaurachchi, 2020), where all factors were marked as relevant.

Additionally, 30 interviews to representatives of the main local stakeholders (Suppliers, General contractors, Consultants, Academia, Government) were carried out during the first stage of the project, giving further support to the previous analysis as shown below.

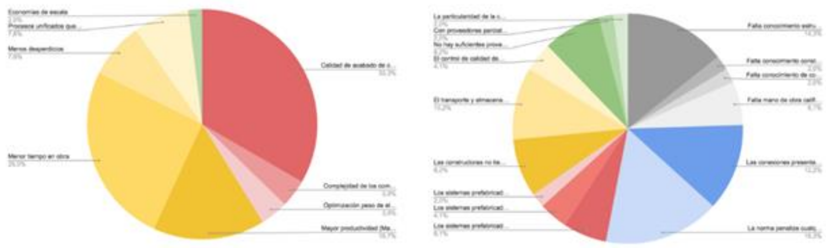

Figure 2. Perceived barriers and advantages of concrete prefabrication for housing in Colombia as resulting from interviews (Color coded by areas - Grey=1, Blue=2 Red=3 Yellow=4 Green=5)

3.1 Structural and production analyses

Based on the results obtained from the interviews and with the aim of implementing prefabricated systems in the mezzanines, an architectural distribution of an apartment tower with 12 levels and 4 bays was proposed, with structural cores at the ends of each apartment, with the objective to provide a large available space that the end user can distribute at their convenience, as shown in Figure 3.

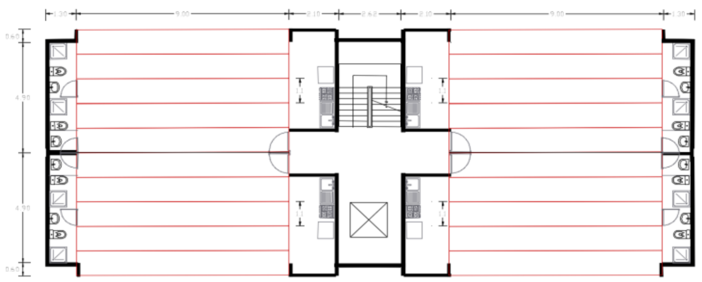

Figure 3. Architectural proposal for an apartment tower

From this architectural distribution without walls within each apartment, the need arises to use prefabricated modular elements that allow saving the length between walls of 9 m, for which a total of 7 prestressed modular mezzanine systems were proposed that would give solution to the developed architectural proposal, these are observed in Table 2.

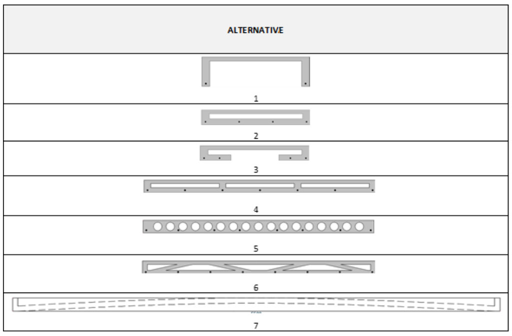

Table 2. Proposed alternatives of modular mezzanine systems

These modular prefabs will be supported by prefabricated elements embedded in the walls, which will make up the wet area of each apartment (bathrooms, kitchen, and laundry area). Similarly, between modular prefabricated elements, a shear connection must be designed to ensure the behavior of the entire mezzanine as a rigid diaphragm.

Due to the fact that in wall-slab systems the slab does not support seismic loads, the prefabricated elements will only support vertical loads, 3.64 kN/m2 for dead load and 1.8 kN/m2 for live load in accordance with NSR-10 depending on their use.

These alternatives were optimized manually based on their dimensions, and the number, diameter and location of their prestress tendons from the SAP2000 software, which allows the use of finite elements and prestress cables, taking as a sample the model of Alternative 1 presented in Figure 4.

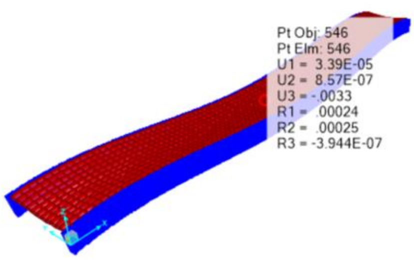

Figure 4. Alternative 1 structural model for maximum deflection in the final stage of service

The optimized sections present the following maximum deflections.

DEFLECTIONS FOR EACH LOAD CONDITION					
LOAD CONDITIONS	**1. CONSTRUCTION**	**2. LIFE LOAD**			**3. LONG TERM**
MAXIMUM DEFLECTION	**3/4 in (m)**	**L/360 (m)**	**INITIAL PRESTRESS**	**FINAL PRESTRESS**	**L/480 (m)**
ALTERNATIVE	**0.020**	**0.025**			**0.019**
1 - U Section	0.0180	0.0125	0.0026	-0.0033	-0.0059
2 - Box Section	0.0075	-0.0027	-0.0157	-0.0197	-0.0039
3 - C Section	0.0130	0.0030	-0.0202	-0.0250	-0.0048
4 - Composite Box Section	0.0144	0.0073	-0.0171	-0.0209	-0.0037
5 - Alveolar Section	0.0176	0.0067	-0.0169	-0.0247	-0.0079
6 - Truss Section	0.0136	0.0047	-0.0182	-0.0250	-0.0068
7 - Curved Section	0.0187	0.0084	-0.0125	-0.0222	-0.0097

Note: Negative deflections indicate sag deflection and positive deflections countershaft

Table 3. Maximum deflections in each load condition

Having optimized the different alternatives, an analysis of alternatives was carried out to determine the optimal option based on the following parameters:

Material Cost: Corresponds to the total cost of concrete and prestressing steel necessary to build the mezzanine system with the proposed section, measured in COP.

Manufacturing Cost: This includes the cost of the skilled labor required to manufacture the element, the space, the formwork, the prestressing equipment, the time and the minor tool required, measured in COP.

Transportation Cost: Approximate cost of transporting the element from the Prefabricated Plant to the city of Bogotá, measured in COP.

Placement Cost: Cost involved in placing the element on site, includes labor, crane service to the highest floor of the tower and material for anchoring between elements, measured in COP.

Cost of Walls: Cost associated with the additional height of construction of walls necessary for the implementation of the mezzanine.

Acoustic insulation: Evaluates the difficulty generated by the precast to a wave that crosses the mezzanine system.

CO2 emissions: Evaluates the amount of CO2 emissions that would be generated on average with the manufacture, transport, and placement of prefabricated elements.

The total cost of implementing the mezzanine has an influence of 75% on the final score, acoustic insulation of 15% and CO2 emissions of 10%.

MATERIAL COST								
ID	**CONCRETE VOLUME (M3)**	**MODULES PER APARTMENT**	**PRESTRESSED TENDONS**	**CONCRETE COST ($)**	**STEEL WEIGHT (KG)**	**STEEL COST ($)**	**TOTAL COST ($)**	**SCORE**
FE-UI	4.09	5	2 x 0.6"	$ 1,896,257	104.4	$ 819,579	$ 2,715,836	3.7
FE-CR	5.61	5	4 x 0.5"	$ 2,601,841	147.2	$ 1,155,607	$ 3,757,448	2.7
FE-CI	4.23	5	4 x 0.5"	$ 1,962,638	147.2	$ 1,155,607	$ 3,118,244	3.2
GF-CR	5.53	2	7 x 0.6"	$ 2,566,562	146.2	$ 1,147,411	$ 3,713,973	2.7
GF-AL	5.3	2	8 x 0.6"	$ 2,460,724	167.0	$ 1,311,327	$ 3,772,051	2.7
GF-CH	5.34	2	8 x 0.6"	$ 2,478,364	167.0	$ 1,311,327	$ 3,789,691	2.6
GF-BV	8.17	1	16 x 0.6"	$ 3,792,514	167.0	$ 1,311,327	$ 5,103,841	2.0

Table 4. Material Costs of the Proposed Alternatives

The cost of the materials required for its construction is initially determined, which are shown in COP in Table 4.

In the same way, the costs associated with manufacturing in the plant, transport, and placement of the prefabricated element in its final disposal were defined, obtaining the associated costs and scores observed in Table 5.

ANALYSIS OF ALTERNATIVES - COST AND SCORES

ID	MANUFACTURING COST	MANUFACTURING SCORE	TRANSPORTATION COST ($/100 km)	TRANSPORTATION SCORE	PLACEMENT COST	PLACEMENT SCORE
FE-UI	$ 1,750,805	2.9	$ 391,667	2.6	$ 1,385,566	2.9
FE-CR	$ 2,982,325	1.7	$ 341,667	2.9	$ 1,118,360	3.6
FE-CI	$ 2,880,125	1.7	$ 333,333	3	$ 1,118,360	3.6
GF-CR	$ 2,915,394	1.7	$ 303,333	3.3	$ 1,293,554	3.1
GF-AL	$ 4,442,452	1.1	$ 303,333	3.3	$ 1,293,554	3.1
GF-CH	$ 4,442,452	1.1	$ 303,333	3.3	$ 1,293,554	3.1
GF-BV	$ 3,986,518	1.3	$ 816,667	1.2	$ 1,590,281	2.5

Table 5 Manufacturing, transportation and placement costs and scores

Adding some other criteria such as acoustic insulation, the need to increase the height of walls and CO2 emissions, the final analysis scores for each alternative were obtained, as shown in Table 6.

ANALYSIS OF ALTERNATIVES - TOTAL SCORE

ID	MANUFACTURING SCORE	TRANSPORTATION SCORE	PLACEMENT SCORE	ACOUSTIC ISOLATION	WALL HEIGHT NEED	CO_2 EMISSIONS	COST OF SUPPLIES	COST SCORE	WEIGHTED OVERALL SCORE	SCORE %
FE-UI	2.9	2.6	2.9	1	2	3.7	3.7	4.5	**3.87**	77%
FE-CR	1.7	2.9	3.6	3	3.9	2.7	2.7	4.2	**3.88**	78%
FE-CI	1.7	3	3.6	1.5	3.9	3.2	3.2	4.3	**3.78**	76%
GF-CR	1.7	3.3	3.1	3	3.9	2.7	2.7	4.2	**3.84**	77%
GF-AL	1.1	3.3	3.1	3.5	3.9	2.7	2.7	3.2	**3.2**	64%
GF-CH	1.1	3.3	3.1	4	3.9	2.6	2.6	3.2	**3.27**	65%
GF-BV	1.3	1.2	2.5	4	2.4	2	2	2.9	**2.95**	59%

Table 6. Total Scores per Alternative

Finally, alternatives 1 and 2 were chosen as the ones that obtained the highest score within the analysis of alternatives, however, Alternative 1 was chosen as the most viable since Alternative 2 requires the use of a lost form for its construction, which would increase production costs significantly.

ANALYSIS OF ALTERNATIVES

ID	WEIGHTED OVERALL SCORE	SCORE %
FE-UI	**3.87**	77%
FE-CR	**3.88**	78%
FE-CI	**3.78**	76%
GF-CR	**3.84**	77%
GF-AL	**3.2**	64%
GF-CH	**3.27**	65%
GF-BV	**2.95**	59%

Table 7. Final Scores per Alternative

Once the optimal section was defined for the specific case of application, a production process was proposed in two phases: the first consisted of the manufacture of a scale prototype that allowed studying the manufacturing process of the element, and the testing of its supports and connections, which is shown in Figure 5.

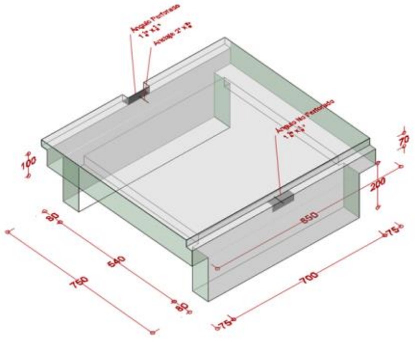

Figure 5 Proposed Prototype Isometric

The full-scale model has the same characteristics as the prototype, but with a width of 1.1 m and a length of 9 m, as shown in Figure 6.

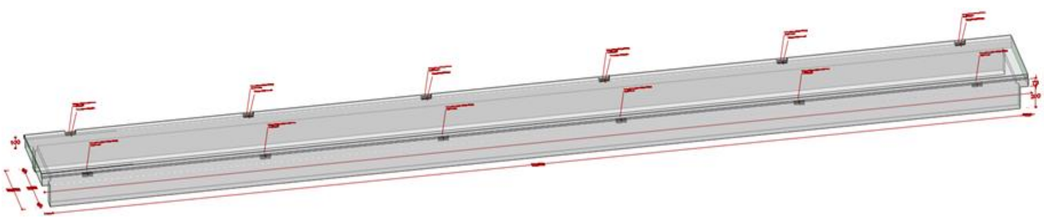

Figure 6. Isometric of mezzanine module

3.2 Online tool

The online application was developed and deployed with two primary aims; first to prototype a computational framework that enabled the generation of residential layouts, and second to develop a user interface that provides affordance to a diverse range of users to access workflows made using the framework.

The framework produces massing models that can be queried for basic programmatic data and evaluated according to a measure of access to natural light in the residential units. The primary parameter in the generative process is the precast unit defined above and how this is used to determine the archetypal floor plate (figure 3). The system is designed as an extensible framework into which different layout methods and analysis modules can be added.

The code base for the tool was developed as a Toolkit for the BHoM Framework(ref) using c# .net. This same Toolkit is leveraged by a Blazor (https://docs.microsoft.com/en-us/aspnet/core/blazor/?view=aspnetcore-6.0) + three.js(https://threejs.org/) web framework that defines an online generative platform with three-dimensional output. The BHoM Framework is software agnostic and provided developers follow basic architectural principles the code is available as visual programing components within the Grasshopper3d (https://www.grasshopper3d.com/), dynamo(https://dynamobim.org/) interfaces and as functions in Excel (https://www.microsoft.com/en-ie/microsoft-365/excel). Users already confident with one of the BHoM user interface applications may therefore use the project tools in a non-web environment (https://github.com/rolyhudson/TSP_Toolkit).

A BHoM Toolkit requires an object model with classes containing properties only and a set of object modifier functions located in higher level classes according to the modification performed. This architecture means initial functional testing and development can be performed in one of the typical BHoM user interface platforms (such as Grasshopper3d) before using the framework within a web platform. Where higher-level functions were needed for the web interface, we simply created new functions that wrapped a series of lower-level modular elements. This wrapping provides direct and simplified access to complex workflows to users who do not want or are not interested in understanding the lower-level functionality of the system.

Within the scope of the project, we developed three specific layout modules (bar, parameter and hybrid) and the ability to configure facilities block that includes parking, social and communal spaces. The bar layout (Figure 7) takes a principal direction and generates collinear blocks. The height of the blocks is configured to try and minimize overshadowing between blocks. The perimeter layout (Figure 8) creates blocks of apartments that run parallel to the site boundary.

The hybrid layout combines the bars and perimeter layouts. The facilities block responds to the total number of apartments on the site as this determines the number of parking spaces and area of commercial and communal space. A maximum number of floors constraints the facilities block vertically, and the site boundary and surrounding apartments constrain it horizontally. A basic solver attempts to seek a working combination of the maximum number of apartments and permitted valid volume to contain the required facilities.

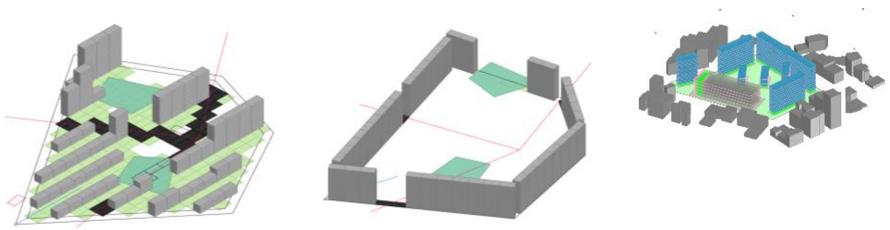

Figure 7. Bars layout method. Road network is shown in black and open areas in dark green, Perimeter layout method and Hybrid mode including facilities block

The underlying approach for both layout methods operates on a voxel space that is defined by the base units of the archetypal floor plate. The user provides geometry defining a site boundary, road networks, open areas and facilities parameters. Based on this a grid is generated within the boundary, grid cells intersecting roads or within open areas are tagged as not available for development. Space required for the facilities block is determined (or initialized in the first iteration). The perimeter layout fills all available grid cells along the boundary with units. The bars layout method follows a growth algorithm where each block ground plan is determined by 'growing' incrementally at either end. Each bar tracks its own curtilage and later bars are blocked from developing too close together.

The daylight access assessment module is a quantitative and comparable measure. Users define the latitude of the site and a set of points on the annual sun path model is created. Rays from the façade of each apartment and each of the sun points are cast, any ray occluded by the surrounding blocks causes the daylighting score to be reduced by one point. Results of this analysis were represented using a colour scale to render the units (Figure 10).

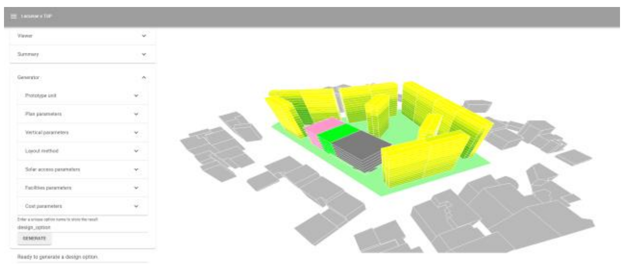

Figure 8. View of the online application (apartments coloured after daylight analysis)

References

Ashby, M. F. (2005). Materials selection in mechanical design. Amsterdam: Butterworth-Heinemann.

Mohd Nawi, Mohd Nasrun & Lee, Angela & Nor, K. (2011). Barriers to Implementation of the Industrialised Building System (IBS) in Malaysia. The Built & Human Environment Review. 4.

Wuni, Ibrahim & Shen, Geoffrey. (2020). Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. Journal of Cleaner Production. 249. 1-17. 10.1016/j.jclepro.2019.119347.

Gan, X., Chang, R., Zuo, J., Wen, T., & Zillante, G. (2018). Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach. Journal of Cleaner Production, 197(1), 8-8. https://doi.org/10.1016/j.jclepro.2018.06.184

Alan Verghese Ittyeipe & Anu V. Thomas (2021) "Barriers to Adoption of Precast Concrete Construction in Buildings", International Web Conference in Civil Engineering for a Sustainable Planet, Habilete Learning Solutions, India in association with American Society of Civil Engineers (ASCE), TKM College of Engineering, Kollam, and Baselios Mathews II College of Engineering, March 5-6, 2021

Erwin Hofman, Hans Voordijk & Johannes Halman (2009) Matching supply networks to a modular product architecture in the house-building industry, Building Research & Information, 37:1, 31-42, DOI: 10.1080/09613210802628003

Samad, Taimur, Nancy Lozano-Gracia, and Alexandra Patman, eds. 2012, Colombia Urbanization Review: Amplifying the Gains from the Urban Transition. Directions in Development. Washington, DC: World Bank. doi:10.1596/978-0-8213-9522-6

Hawkins, W., Orr, J., Ibell, T. & Shepherd, P., 2020, “A Design Methodology to Reduce the Embodied Carbon of Concrete Buildings using Thin-shell Floors”, Engineering Structures, 207, 110195, doi:10.1016/j.engstruct.2020.110195 accessed June 2022.

Costa, E., Oval, R., Shepherd, P. & Orr, J., 2021, “Fabrication-aware parametric design of segmented concrete shells”, International Conference on Spatial Structures (IASS) 2021, Available online from https://automated.construction/s/IASS2020-21-SURREY7_DES.pdf

Oval, R., Costa, E., Nuh, M., Thomas-McEwen, D., Orr, J. & Shepherd, P., 2021, “A path towards the off-site automated fabrication of segmented concrete shells for building slabs”, International Conference on Spatial Structures (IASS) 2021, Available online from https://automated.construction/s/IASS2020-21-SURREY7_FAB.pdf accessed June 2022.

Costa, E., Shepherd, P., Velasco, R., Hudson, R., 2020, “Automating Concrete Construction: Sustainable social housing in Colombia”, Sociedad Iberoamericana de Gráfica Digital (SiGraDI 2020).

Aouf, R. S., 2022, “New concrete vaulted floor suggests path to cutting carbon emissions”, Dezeen, available online from https://www.dezeen.com/2022/03/04/concrete-vaulted-floor-suggests-path-to-cutting-carbon-emissions/ accessed June 2022.

NSR-10, 2010. Norma de diseño Sismo Resistente colombiana.