CS500106

A Digital Revolution in Resilient Housing: Build Change and Autodesk

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Learning Objectives

- Learn how Autodesk products can impact infrastructure resilience, particularly in housing in emerging markets
- Learn how to implement digital solutions for infrastructure resilience
- Learn how to develop flexible, adaptable BIM tools for many different use cases
- Learn how to solve bottlenecks in the construction value chain using digital tools

Description

From designing retrofits in AutoCAD to automating Revit workflows using Dynamo, and now exploring the many uses of Forge, Build Change has been using Autodesk products for 17 years to revolutionize the design of resilient infrastructure, particularly in the housing sector, and successfully reach national scale in many countries. By leveraging the latest Autodesk tools, Build Change is making home retrofits safe and possible in the COVID-19 era. In this session, we will explore Build Change's 17-year history of using Autodesk products to impact 600,000 lives across 24 countries, providing an integrated solution for improving the resiliency of homes and communities and preventing loss of life in natural disasters. This session will feature a case study of the work Build Change is doing in Colombia, one of our largest country programs, and the Autodesk technology being used to scale housing retrofits there.

Speaker(s)

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Allie helps develop BIM tools for use in the disaster resilience sector, to automate BIM workflows and rapidly generate retrofitting designs for informal housing in earthquake prone regions. She is passionate about leveraging technology to scale impact in the international development sector and received her Bachelor's degrees in Civil Engineering and Global Development from the University of Western Ontario, Canada.

Andrés Robles – BIM Engineering Specialist – Build Change
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Andrés works with the technology team of Build Change, helping with the development of BIM tools for their use in retrofitting projects. He is very interested in technology as a tool to automate procesess and has strong coding background. He graduated as a civil engineer from Universidad de los Andes in Bogotá, Colombia

Introduction
Substandard Housing: a Global Problem

According to the World Bank, by 2030, more than 3 billion people worldwide will be living in substandard housing conditions. This means that approximately a third of the global population won't have access to safe housing. In addition, climate change and rapid urbanization are contributing to increased levels of risk in countries in the Global South. One of the main causes of substandard housing is informal construction, which can occur when low-income families move from rural to urban areas and build their homes without technical guidelines. This results in massive, unplanned neighborhoods filled with poorly built houses that lack structural components necessary to withstand natural events such as earthquakes, floods and windstorms.

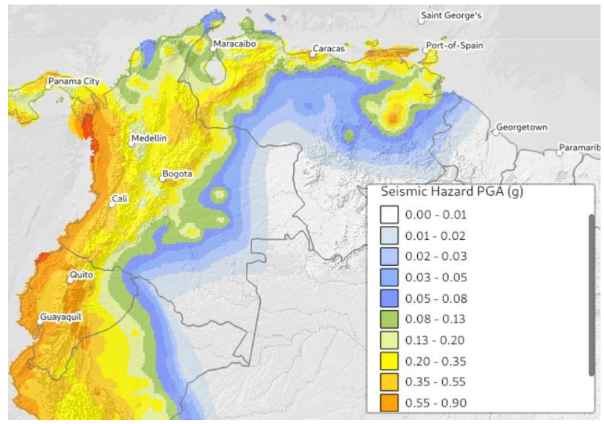
Panoramic view of one of the informal neighborhoods in Medellin, Colombia

Substandard Housing in Colombia

In general, rick is understood to be the combination of vulnerability and hazard. Vulnerability refers to the level of exposure, quality of infrastructure, and how prepared a city or a country is in terms of safety. On the other side, hazards are attributed to natural events and uncontrollable variables, like earthquakes and windstorms. In other words, **vulnerability is a variable controlled by humans, and hazard is not. The overlapping of these two gives a measure of the risk status.**

Additionally, the two sides of the risk level can vary depending on location and context. For example, Japan has a substantial seismic hazard as it is located in an active seismic zone. However, Japanese building codes and regulations are stringent and their infrastructure is well suited to withstand these natural events. In total, Japan is low risk with regard to earthquakes. Now, if we compare this scenario with a Latin-American country such as Colombia, the situation changes. Like Japan, Colombia is an active seismic zone as it is located at the intersection of 3 tectonic plates. On the other hand, Colombia has experienced uncontrolled urban growth, leading to informal settlements and the rise of buildings that fail to meet safety standards. Overall, this situation creates a considerable seismic risk that could affect 80% of the total urban population because the larger concentration of buildings coincides with the higher seismic hazard zones.

Informal settlements in Bogotá, Colombia



Map of seismic hazard in Colombia

Introduction to Build Change

Build Change is a non-profit organization founded in 2004 by Dr. Elizabeth Hausler, with the mission to prevent housing collapse, deaths, and economic losses due to natural disasters in the Global South. With a focus on earthquake-resilient design, Build Change has contributed to hundreds of thousands of people worldwide living and going to school in safer buildings.

We are currently operating in several countries, including Colombia, the Philippines and Indonesia and have previously worked in many other countries such as China, Mexico and Nepal.

Build Change's Approaches to Disaster Resilient Construction

Build Change has pursued its mission in many different ways, including training builders and government on best practices for earthquake-resilient housing and creating guidelines for seismic retrofitting that are replicable and easily deployable in different contexts.

For more information on Build Change's specific initiatives in its various country programs, you can visit www.buildchange.org.

One of the approaches taken by Build Change to address the issue of unsafe housing is through the actual construction of earthquake-resilient housing. In general, Build Change has pursued two main approaches for this type of construction:

1. **New Construction:** designing new, replicable houses that are earthquake-resilient and constructed based on seismic guidelines

2. **Retrofits of Existing Housing:** structurally reinforcing existing housing to improve its behaviour in earthquakes/natural disasters and prevent collapse

Both new construction and retrofitting projects rely on **Type Designs** – designs of a specific type that are replicated to maximize impact.

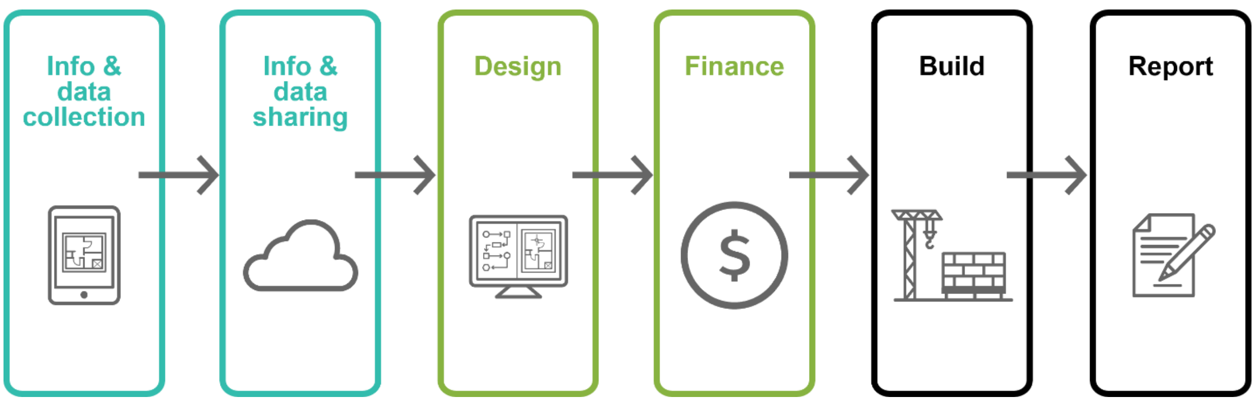
Build Change has participated in new construction and structural retrofitting in both post-disaster contexts such as Nepal following the 2015 earthquake and Haiti following the 2010 earthquake. In addition, Build Change has worked on prevention programs in contexts such as Colombia where there is a risk of a significant seismic event in the future.

Autodesk Technology at Build Change

Build Change has employed Autodesk technology since the beginning. To understand the many situations in which we deploy technology, it's necessary to understand the steps of the construction value chain in which technology can be leveraged to make processes more efficient.

The Construction Value Chain

The construction value chain is a series of phases a new construction or retrofit project must go through to reach completion. Build Change adds value to every step in the chain by leveraging our expertise in disaster-resilient design and implementing technological innovation and automation. The following is a graphic outlining the steps in the construction value chain:

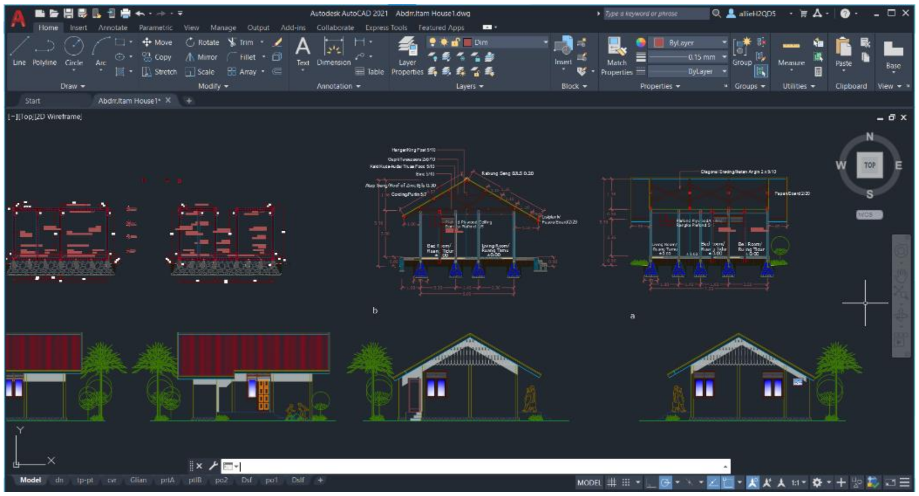


1. **Info and data collection:** collecting data on the house and its inhabitants. Includes collecting the geometric data about the house and other essential data for the design process.
2. **Info and data sharing:** Storing that data and sharing it with our partners, ensuring the accuracy of the data.
3. **Design:** Using the data collected to design a retrofitting solution for the house or create a design for new construction, typically based on one of our Type Designs.
4. **Finance:** Supporting the homeowners in accessing financing for their house's improvements from sources such as government and microfinance institutions.

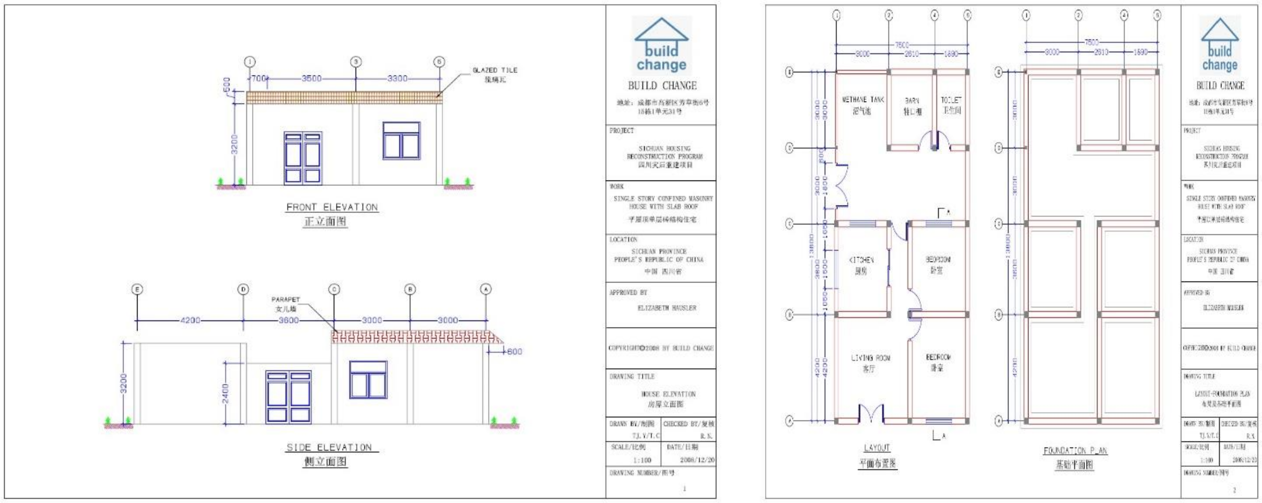
5. **Build:** Participating in the construction of the new construction or structural retrofit and implementing technologies for construction supervision.
6. **Report:** Reporting to our partners on the results of the project and the impact of the work.

In the beginning: an AutoCAD-based workflow

In the 2000s and early 2010s, Build Change employed a workflow that relied entirely on AutoCAD from start to finish. New construction projects were designed based on a selection of Type Designs and drawn in AutoCAD, with slight modifications made to each design based on the homeowner's needs and the size and shape of the lot. Examples of some drawings from projects in China and Indonesia are included below.



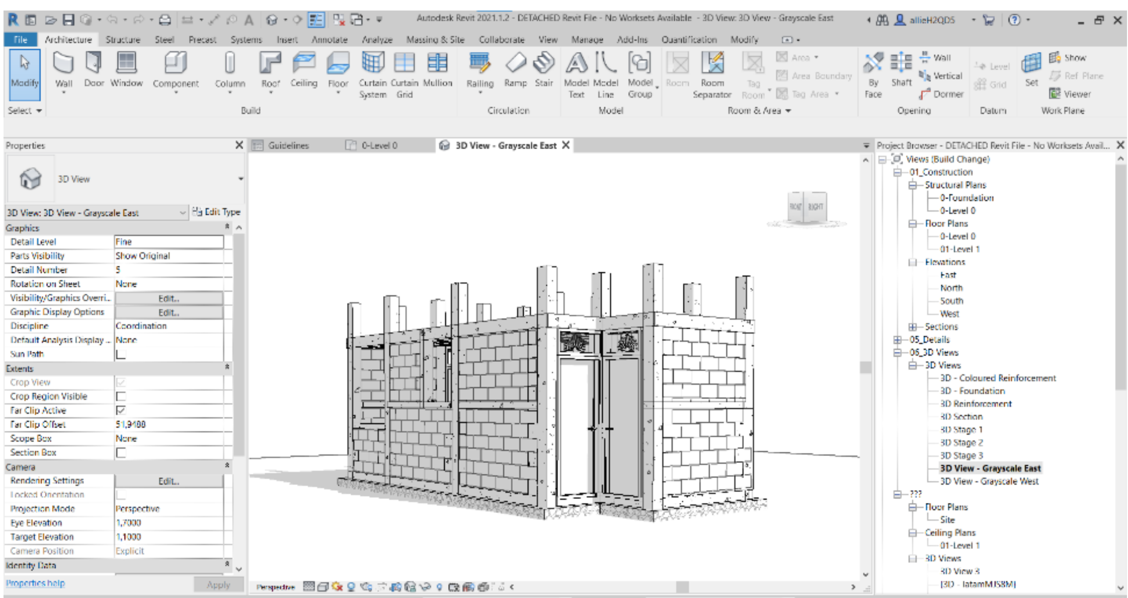
Example of a newly built home in Indonesia and type designs of said home, circa 2006, drawn in AutoCAD

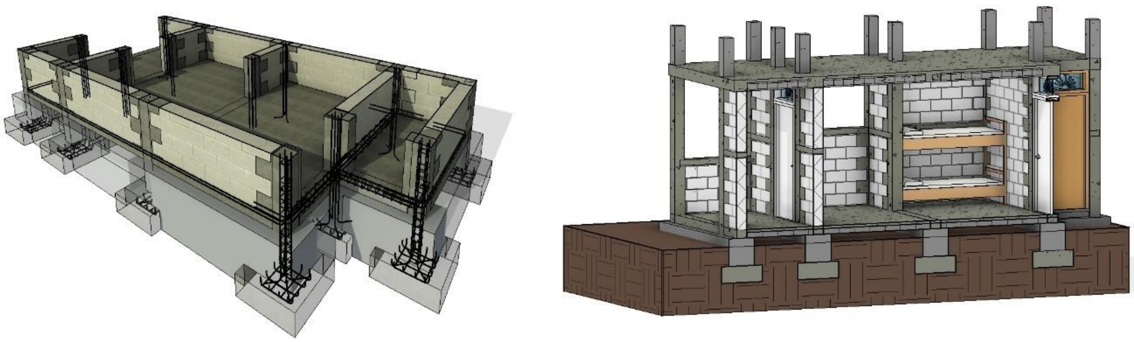


New construction type designs in China, circa 2009, drawn in AutoCAD

A shift to Revit

Revit was first introduced to the Haiti program in 2015 with the creation of the first template and, eventually, to the Colombia program in 2017. This implementation of Revit was still rudimentary and lacked automation. These Revit templates took the Type Designs that previously existed in AutoCAD and brought them into a 3D environment.





3D Views from the Build Change's first Revit template, showing a Type Design in Haiti

The automation power of Dynamo

Dynamo was first introduced to the Build Change team in Nepal by a team of Autodesk consultants who saw the potential for automating our workflows. The idea was to **leverage Dynamo to automate our retrofit Type Designs**. Before these Type Designs, retrofit projects were previously designed on a case-by-case basis which was a lengthy process that required a unique retrofit solution for every house.

In rural Nepal, the dominant housing typology is very prevalent, meaning the same style and type of house can be found repeatedly within a specific region. Most houses are constructed with stone and mud mortar and are often 1-2.5 stories tall, featuring a ground floor used for housing livestock, a second floor used for living space, and a half-floor/attic space for storing grain and other food items. In addition, the houses were typically rectangular in shape. Because of the prevalence of this housing type, the retrofitting solutions for each house were very similar. By creating a Type Design for houses that met specific criteria, that design could be replicated repeatedly to maximize the number of houses retrofitted.

For more information on Type Designs and their use in the Reconstruction effort in Nepal following the 2015 earthquake, see this link from the Build Change website with more information:

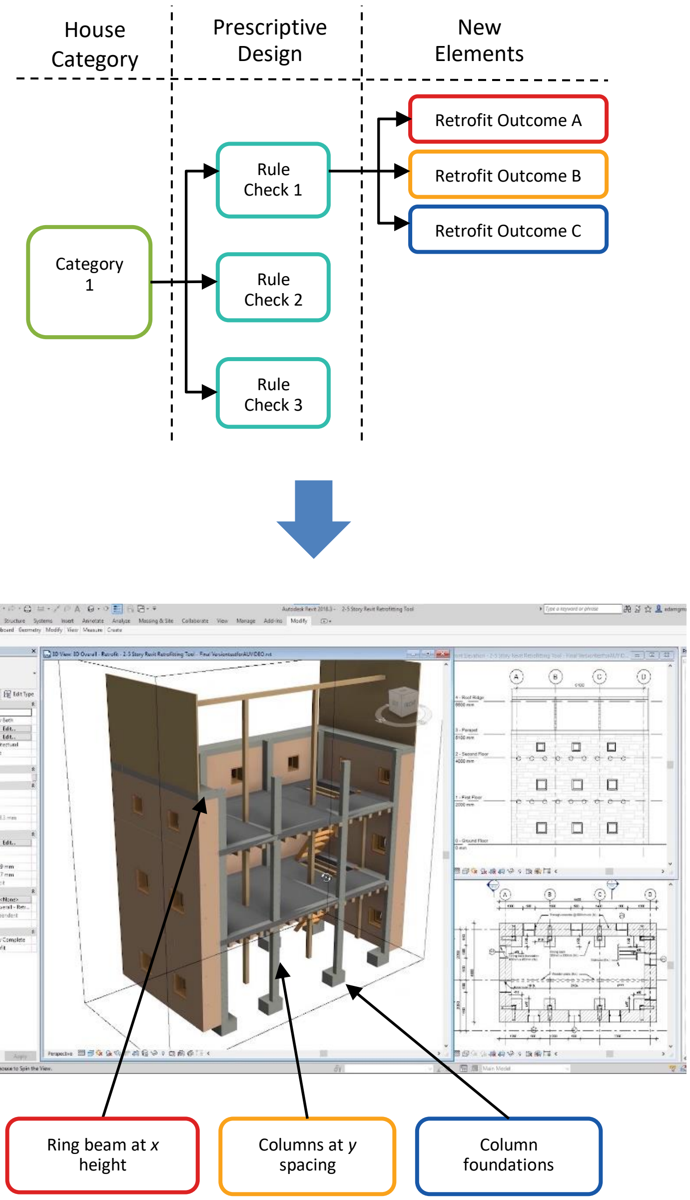
https://buildchange.org/retrofit-type-design-approved-a-turning-point-in-nepals-reconstruction/

A specific type design used in Nepal, featuring strongbacks (columns) connected to a ring beam on top of the walls and a lightweight roof.

Engineering methodology meets technology

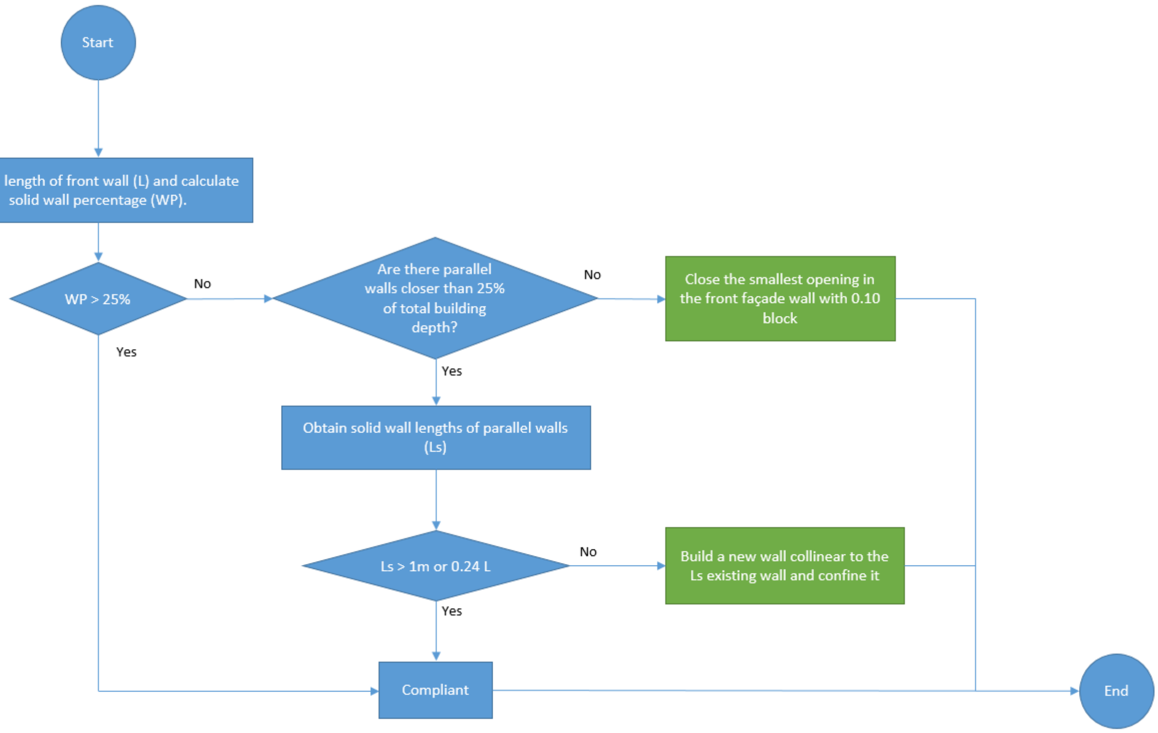
To automate the retrofit process in Revit, retrofitting “rules” were created and programmed into Dynamo scripts based on the solutions prescribed by the Type Designs. The Dynamo scripts would evaluate the house’s geometry and modify the Revit model if certain conditions were met. This approach is called **prescriptive design**, **when a specific design is prescribed to a house that meets certain criteria**, for example, if it is a two-story, rectangular-shaped house. The scripts would place specific elements such as columns, beams, and foundations correctly according to rules outlined by the perspective design in a document called the **Retrofit Card.** A Retrofit Card is a document that outlines the specific conditional statements evaluated within each retrofitting script and the retrofitting elements to be used based on the outcome of those conditionals.

The following graphic outlines the structure of the various “rule checks” performed on each house, and how they lead to specific retrofitting outcomes in the Revit model:



Rule check example

Each rule check verifies particular geometrical and configuration values in the existing model and compares them with the predefined design parameters of the prescriptive design. The outcome of a rule check might be compliant (the existing model doesn't present structural deficiencies), or non-compliant and new retrofit elements must be placed. There are rule checks that sequentially check different aspects of the building and output a particular solution depending on each case. This is the case of the Front Wall Rule Check that verifies if the front façade wall is rigid enough to withstand stress caused by torsion effects. The Front Wall Check is evaluated in 3 steps, each with different considerations on how to fix possible deficiencies as shown below:

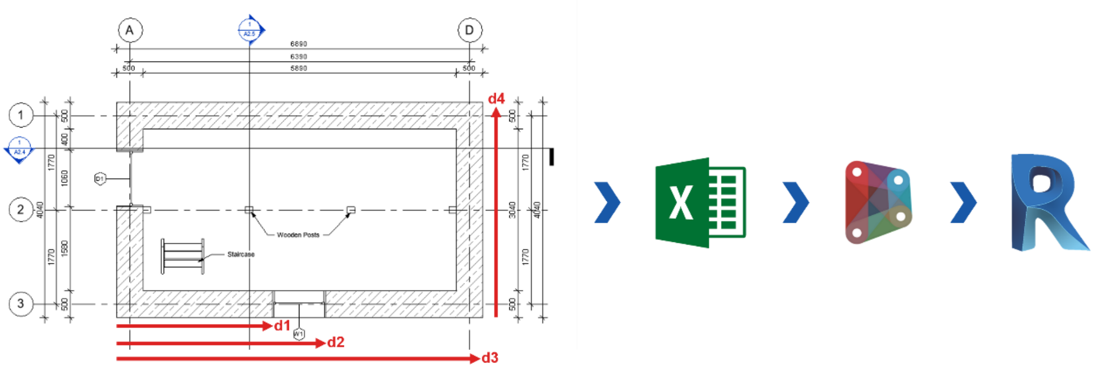


Simplified flow diagram of the front façade rule check and the sub-steps that define a retrofit solution depending on the existing house configuration.

Through a series of "if" statements within a Dynamo script, it is possible to program this logic into the script and replicate the above flow diagram.

The first model import process

In order to retrofit our houses in Revit using Dynamo scripts, we needed to generate an accurate model of the existing house before the retrofit. Thus our import process was born. The first Dynamo import scripts read dimensions from an excel file and generated a house based on those dimensions, including the position of the windows and doors.



A technician in the field would visit a house and measure the dimensions using a specific methodology: first starting at a corner of the house, then first measuring the distance from the corner to the first edge of the first opening, then the distance from the corner to the second edge of the first opening, and so on. These dimensions would be input in a simple form that would output a CSV file. Dynamo could then easily access this CSV file on a local computer, read it and construct the model in a series of scripts that would assemble it in Revit piece by piece, starting with the walls, then adding openings etc. These elements would be phased as created in the "Existing" phase, to differentiate between existing and retrofitted elements.

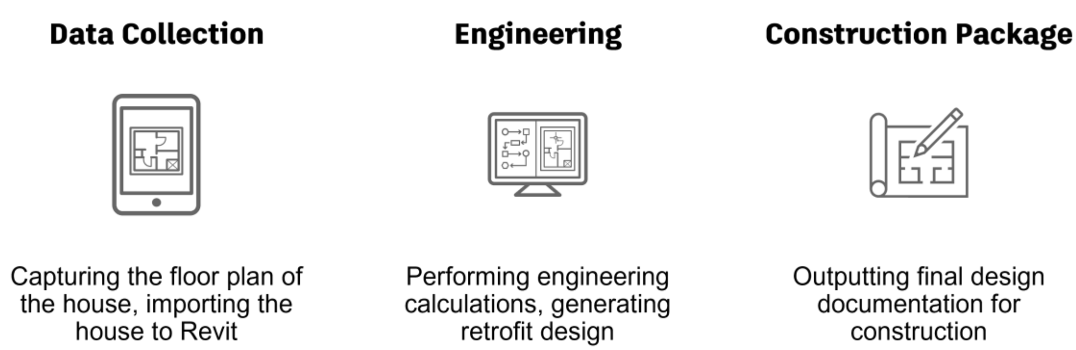
This was the beginning of our import process that has advanced significantly in the years since.

Autodesk Technology at Build Change: A Colombia Case Study

Build Change is working with several partner organizations in Colombia to tackle the city's informal housing issue, including the Ministry of Housing and Caja de la Vivienda Popular (The People's Housing Fund). Build Change provides technical support to these organizations in performing everything from basic habitability improvements on homes to performing full structural retrofits of houses and safely adding second stories to one-story homes.

Retrofit projects in Colombia, step-by-step

In Colombia, the primary steps in the Construction Value Chain that Build Change supports their partners with are the data collection through design phases. In the process of generating the final retrofitting designs, called the **construction package,** there are 3 main phases:



1. **Data Collection:**

   This part of the process takes place in the field, at the house intended to retrofit. It's done by trained staff, either civil engineers, architects or professionals instructed in earthquake-resistant construction. In this stage, two types of data are collected: A geometrical survey of the house, which records all the measurements of walls, windows, doors and floors in a hand sketch. Then, the second data type is homeowner information and seismic site parameters to calculate the vulnerability status.

2. **Engineering/Data Processing:**

This stage includes a vulnerability assessment, followed by a structural analysis which will establish the retrofitting techniques required. They breakdown as follows:

Vulnerability Assessment:

The factors that determine the degree of vulnerability of a house include site hazards (such as landslides or floods), seismic parameters intrinsic to the area and the structural configuration.

Structural Analysis:

Informal housing lacks a proper design and is often built without fundamental structural elements. Therefore, structural engineers must analyze the structural configuration and the materials used to calculate a seismic demand for the building.

Retrofit Proposal:

As a result of combining the vulnerability assessment and the structural analysis of the building, engineers come up with a retrofit proposal. This includes a set of structural elements such as columns, beams, ties, dowels and other solutions to ensure the building won't collapse during an earthquake.

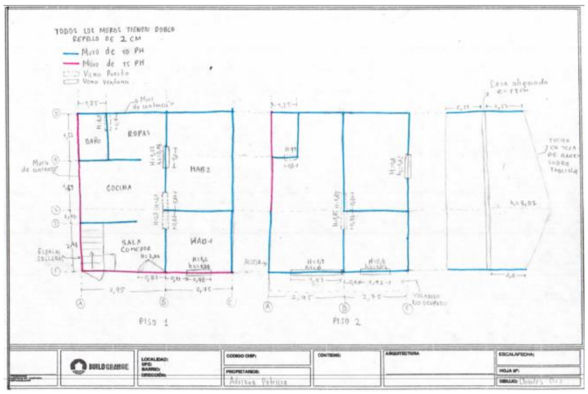
3. **Document Production**

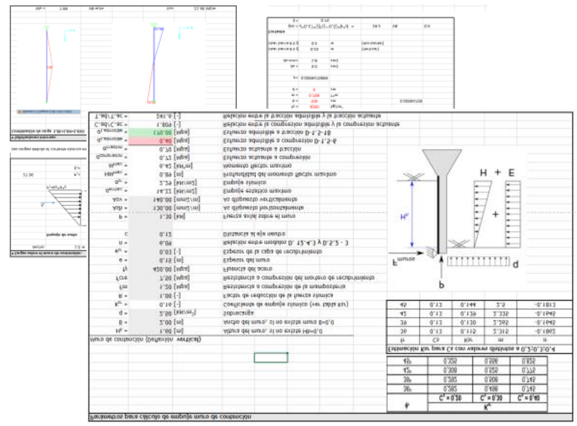
The third step of the process is crucial because it wraps up all assessments, analyses and designs in a concise package of information known as the Construction Package. In other words, this document portrays a timeline for the house intervention because it shows the initial conditions of the structure, the results of the analysis and what's needed to make it safer. In detail, this construction package includes:

- Existing plans of the building, including architectural and structural elements
- Results from the structural analysis that determine the intervention's scope
- Retrofit plans of the building, specifying materials and elements for the intervention
- Construction details of the retrofit elements
- Cost estimate or Bill of Quantities (BOQ)

In the beginning: retrofit projects in Colombia

In the beginning, many aspects of the data collection and design process were done manually in Colombia. Technicians were required to go to the field and manually draw the floor plan of the existing home, then transfer that drawing into AutoCAD. The engineer would then generate the retrofit design for the house using a series of Excel spreadsheets, then use AutoCAD to draw the final designs.





Handdrawn sketches of a house in Bogotá   Excel spreadsheets for engineering calculations

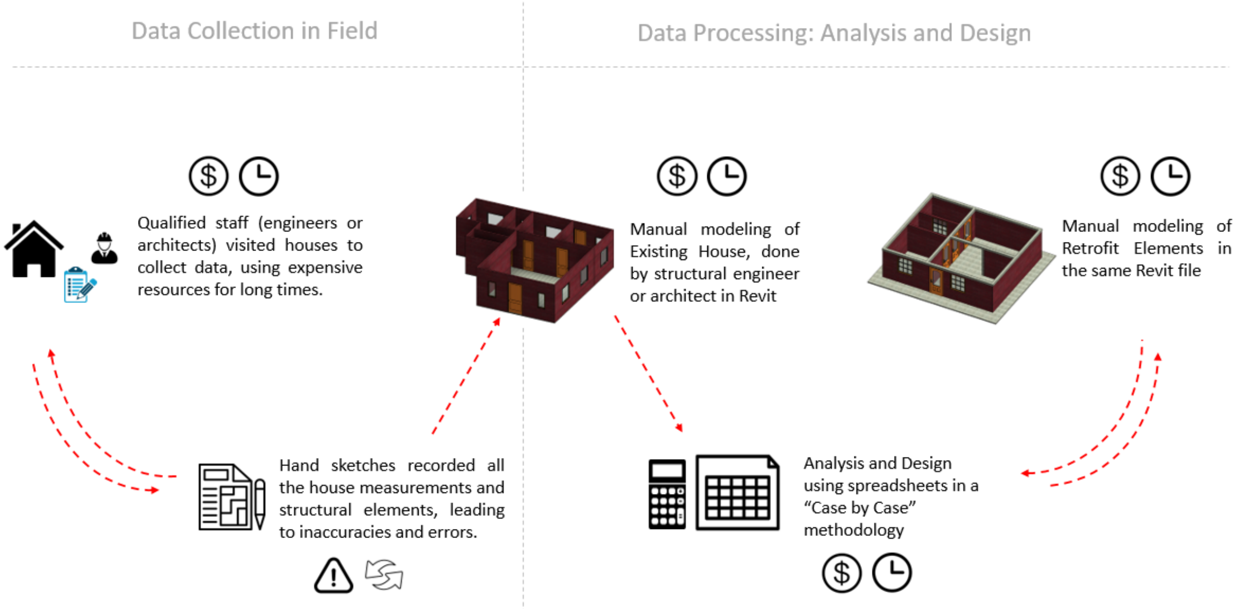
The introduction of Revit to the Colombia program

The introduction of Revit to the Colombia program in 2018 led to an improved workflow, albeit still a manual one. Hand-drawn plans of the house were transferred to Revit instead of AutoCAD and the Revit model of the existing house was manipulated to reflect the retrofit design. However, this workflow was still unautomated.

Existing Model   **Retrofit Model**   **Construction Package**

Bottlenecks and Limitations for Scalability

The previous retrofitting workflow has been implemented by Build Change in 7 countries. However, it has never been used in a large-scale retrofitting initiative, such as the ones being implemented in Colombia. With this in mind, to effectively implement a scalable program for retrofitting, this workflow had to be reassessed from a cost and time perspective. The image below shows a map of the workflow, focusing on processing time and information exchange:



Mapping of the existing workflow, focusing on time and resources spent in each activity.

A systems-based analysis of the traditional workflow revealed several bottlenecks that limited its use for a nationwide implementation. The stages that represented most of the inefficiency were Data Collection, Data Processing and Document Production. In the current workflow, information was not integrated on a single platform, and different data types implied extra work for conversion and processing. The most significant bottlenecks were identified below:

- Data collection implied using trained resources such as engineers or architects to visit houses to conduct the geometric survey and vulnerability assessment. A large-scale implementation would be extremely costly using this scheme, and the scarcity of trained staff could slow down the program.
- The process of collecting geometric data of the house using a hand sketch was time-consuming (it could take up to 3 hours) and produced inaccuracies down the line. For instance, during the design phase, an engineer could find a missing measurement, forcing the design process to stop until field staff confirmed the missing value.
- An engineer had to convert the hand sketch into a Revit model that represents the existing conditions. This required interpretation skills from the engineer and often led to errors in the model. Depending on the complexity of the house, this process could take up to 2 days.
- The structural analysis was done using Excel spreadsheets that calculated shear and gravity loads. The general behaviour of the structure was verified through static linear analysis, checking stress concentrations and different failure modes. This engineering methodology is not suitable for a large-scale implementation because it requires a case-by-case analysis.
- Once the analysis defined the retrofit intervention, engineers proceeded to add new structural elements to the model. This process involves a lot of Revit adjustments, dealing

with phasing, element parameters and graphics. The production of the Construction Package for one house could take up to 9 days, taking into account rework caused by data inaccuracies and retake of measurements in the field.

- As a whole, there wasn't a platform that integrates data from all stages to manage the project. Progress was tracked using an online spreadsheet, but there was no way to incorporate all data types into one platform to understand progress, delays, and performance globally.

In summary, the existing methodology for retrofitting houses was not optimal for large-scale deployment. The workflow heavily relied on qualified labour, which increased the cost considering the number of houses that would be retrofitted simultaneously. Also, the long processing times in the design and document production phases made the overall operation too expensive for scaling it up. For instance, a typical two-story house would need a team of 2 trained professionals to assess and take measurements on site (usually civil engineers or architects), plus a structural engineer in the office performing analysis and retrofit design, and a drafter (could also be an engineer or architect) who put together the set of plans, calculations and cost estimate in a construction package.

This whole workflow would **normally take from 5 to 9 working days** on a full schedule and varies depending on the complexity of the house. Considering the magnitude of the programs being carried out by our partners, we must consider the volume of houses to deal with, thus, this workflow is non-viable in terms of costs and time.

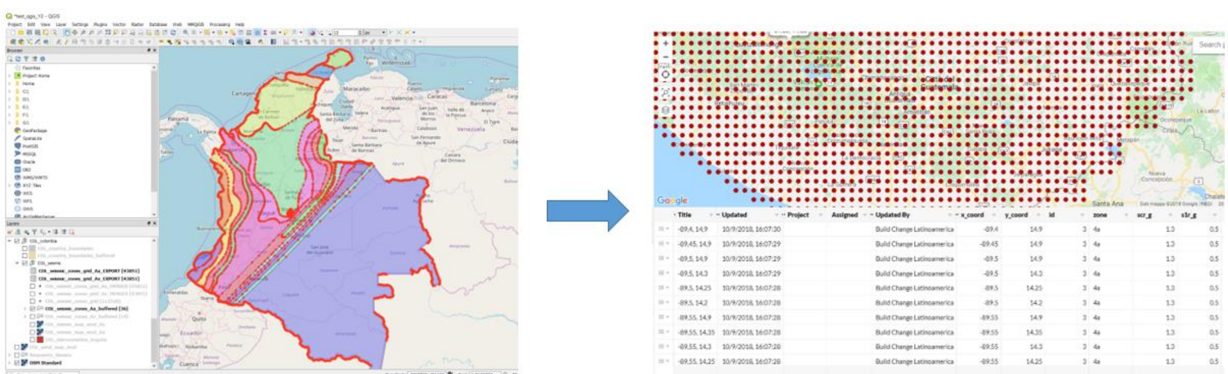
A new, automated, Revit workflow

The BIM team successfully automated the new Revit workflow through the implementation of Dynamo and other innovative technologies, including 3rd apps that allow for efficient and accurate data collection.

Over the years, the workflow has been automated in the following ways:

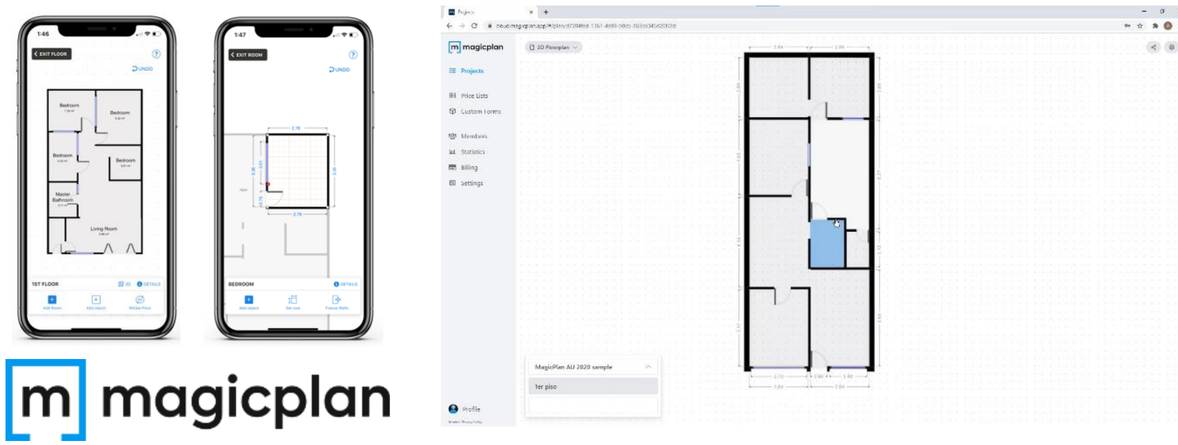
1. **Introduction of a 3rd party app for data collection:** the form-building application Fulcrum was introduced to allow the team to build custom forms and collect other data about the house, including data regarding the state of specific structural components of the house. The form-builder allowed us to design mistake-proof surveys that guided the surveyor through the questionnaire with adaptive responses and skip logic, making the process simple and efficient. More importantly, Fulcrum allowed integration with GIS that included seismic and vulnerability parameters from official databases. In this way, detailed information that used to be processed in the office is now preloaded in a digital form and ready to be filled in field.

Fulcrum



GIS databases of seismic hazard being converted to a grid of points to be linked through GPS coordinates into the form

2. **Introduction of a 3rd party app for floor plan capture:** the app MagicPlan was introduced to allow the team to draw the floor plan of the house only once. This mobile app allows you to draw house floorplans, including walls, windows, doors, floors, and other existing elements with your fingertips. Using predefined templates, we created a standardized protocol to draw house floorplans, including key elements for the design phase. Also, the app can be linked to a laser measure device to speed up the process. Once the survey is completed, and an internet connection is available, the plan is uploaded to the cloud where it can be downloaded from the office or any location.

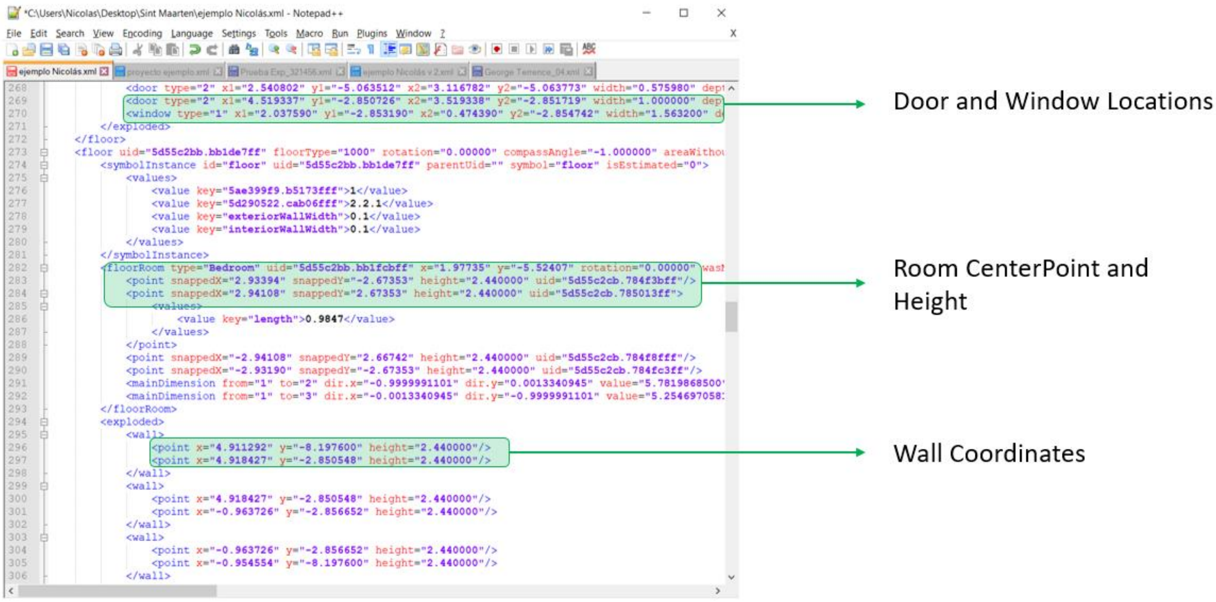


The MagicPlan app is available on phones and tablets, making it ideal for use in the field

3. **Creation of Import Scripts:** the Dynamo import scripts were developed to read data from the MagicPlan workspace and create a Revit model of the existing house based on that data.

   Traditionally the import process was done by looking at a hand sketch with measurements and annotations of the house and manually modelling it in Revit. Now, with the data collection digitalized and stored in our MagicPlan workspace as an XML file, this process improved substantially. To speed up the existing modelling, we designed visual programming scripts in Dynamo that automate the house creation in Revit.

   All the information gathered in the field is stored in an XML file, including the geometrical position and characteristics of all elements in the house. To extract this information, we used Python Dictionaries to parse the data and arrange it in a way that Dynamo can use it. The Python code goes through the hundreds of lines of code and obtains the required coordinates and element attributes for an automated modelling process. Some of the key info parsed by the script is shown below:



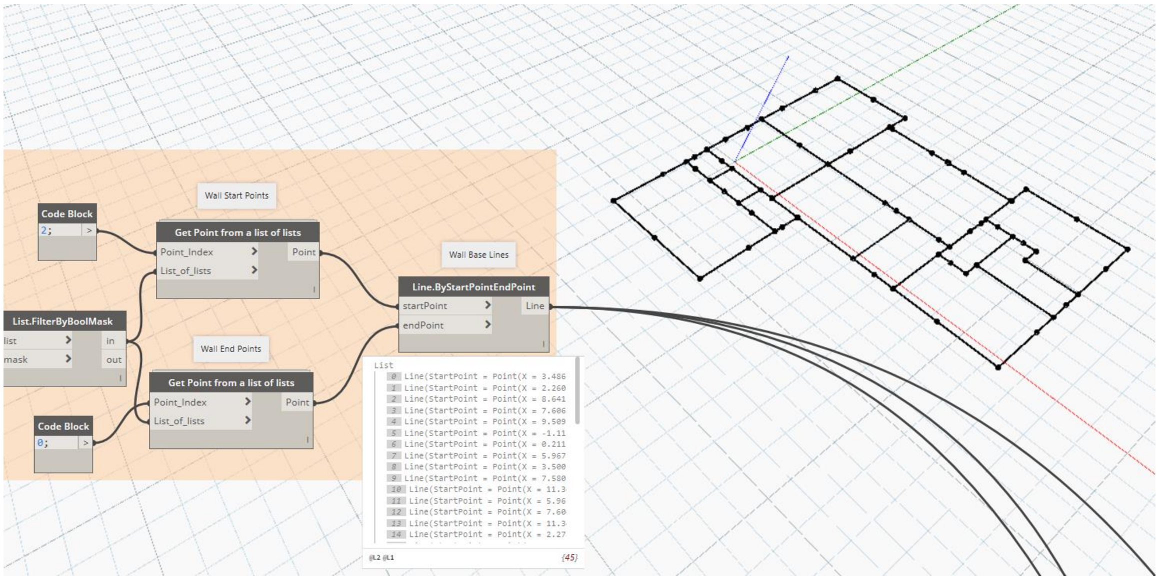
A Python script deconstructed the list of values in the XML file and arranged the values needed by Dynamo to model wall, windows, doors, floors and slabs. There are different values for each element, so they must be organized per type as follows:

- Walls
  - X and Y coordinates for start and endpoints
  - Wall height
  - Wall type (thickness and material)

- Windows and Doors
  - X and Y coordinates of the insertion point
  - Width, Height, Sill Height
  - Window/Door type

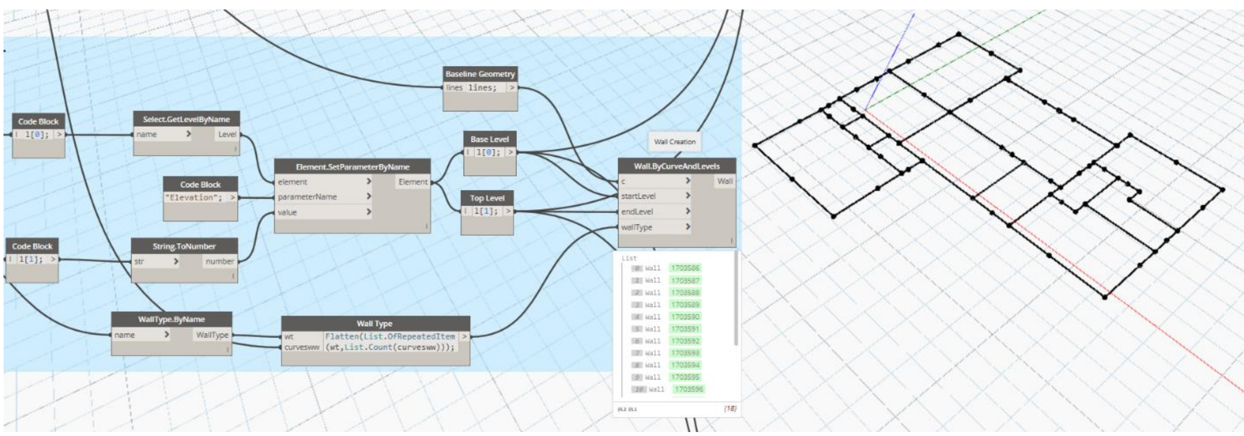
- Slabs and Floors
  - X and Y coordinates of perimeter points
  - Elevation from level zero
  - Floor type (thickness and material)

Then, information is read by the Dynamo scripts separately for each category. For example, to model walls through Dynamo nodes, we must obtain all the geometry from the parsed XML file and then organize it into start and endpoint coordinates. These can be represented as a point and then converted into a line with the “Line by Start Point End Point” node as shown below:



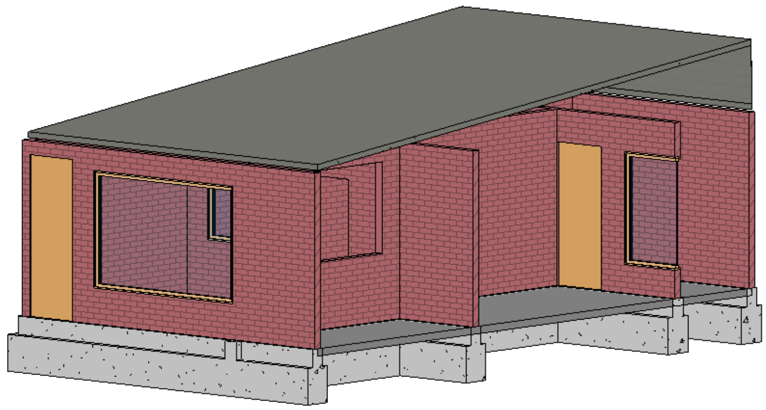
Start and end point coordinates converted into base lines for walls using Dynamo

The next inputs for wall creation are base and top levels. These are obtained from the parsed XML data, where each room created in the Magic Plan floorplan has an elevation. The Dynamo script then gathers this elevation and defines the levels accordingly. Finally, the wall type must be defined to the wall creation node to model the exact wall recorded in Magic Plan. This attribute is stored as a code which is replaced for the name of the wall family in Revit. The steps explained above are represented in the following portion of the script:



Existing wall creation using base line geometry, levels and wall type

Once the walls are modelled, similar scripts for windows, doors and slabs generate the rest of the existing house. Also, once Dynamo places these elements, the “Phase Created” parameter is set to “Existing” to ensure they won’t interfere when the new (retrofit) elements are modelled. The result of the existing model is shown below:

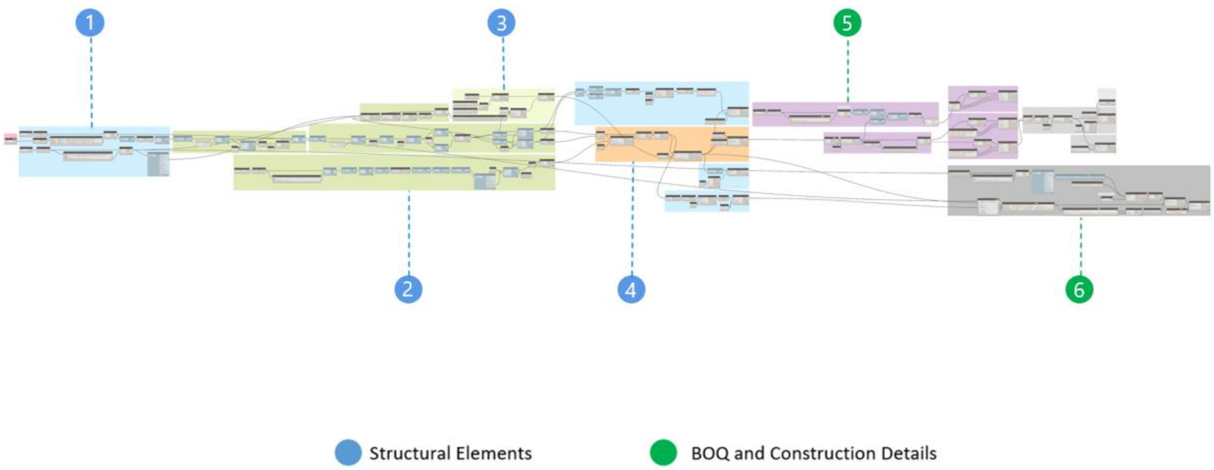


3D section of an existing house in Bogotá, Colombia, drawn in and imported from MagicPlan into Revit

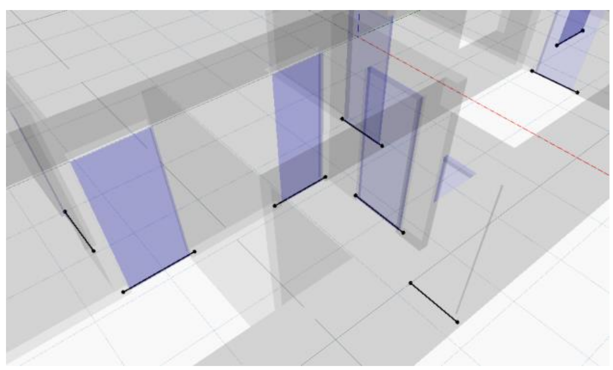
At this point, we've modelled the existing conditions of the house with exact measurements taken in the field using MagicPlan, and a vulnerability status that resulted from Fulcrum data processed with seismic and soil parameters. The time spent in the existing house modelling went from 1 or 2 days to 10 minutes. Now, the house is ready to begin the structural analysis to determine the best retrofit solution.

4. **Automating the retrofitting process using Dynamo scripts:** Type Designs for retrofits were created so that a prescriptive design approach could be applied and automated in Dynamo. The two primary Type Designs used in Colombia are an Unreinforced-Masonry approach and a Confined Masonry approach (for houses requiring increased reinforcement). A retrofit card for these two categories was created to outline each rule check and its subsequent outcome in the model. All rule checks were automated into a series of Dynamo scripts designed to be run consecutively on the model and would modify it according to the model's adherence to those rules. Afterwards, we would arrive at our final Revit model of the retrofit design.

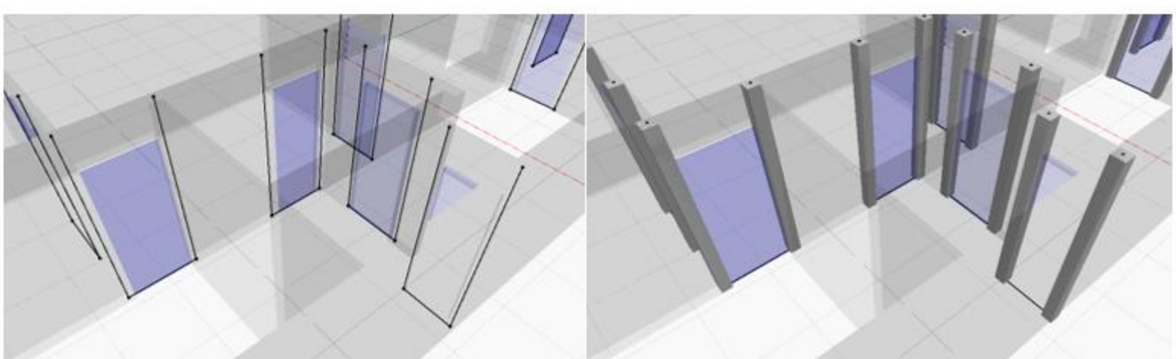
The following is an example of a retrofitting script that adds columns at the side of each door to confine the doors and improve their behaviour in a seismic event:



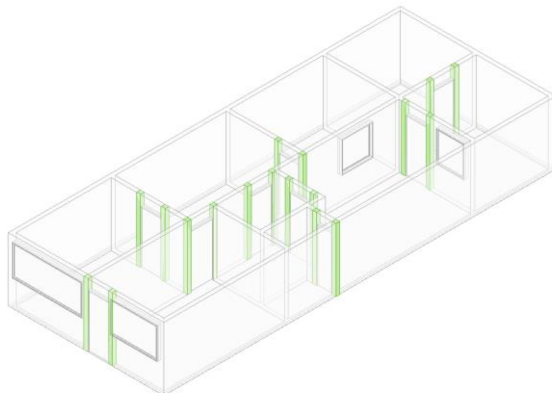
Group 1 gathers all the doors and walls in the Revit model and filters the walls by height. Then, Group 2 deconstructs the doors by geometry to get their start and endpoint at the base.



Then, Group 3 of the script takes these points and projects them on the positive Z direction until it reaches the top height of the existing walls. The second point represents the endpoint of the column. Following the projection, a node creates a line by start and endpoint and the base geometry for the column is done. Next, group 4 creates the actual columns using the lines, type of column and level as inputs.



As shown in the figure above, once the new columns are created, the “Phase Created” parameter should be set to “Retrofit” so it will display correctly in the set of drawings. Once this script is run, several tie columns have been created under the Retrofit phase. The picture below shows the result of the script.

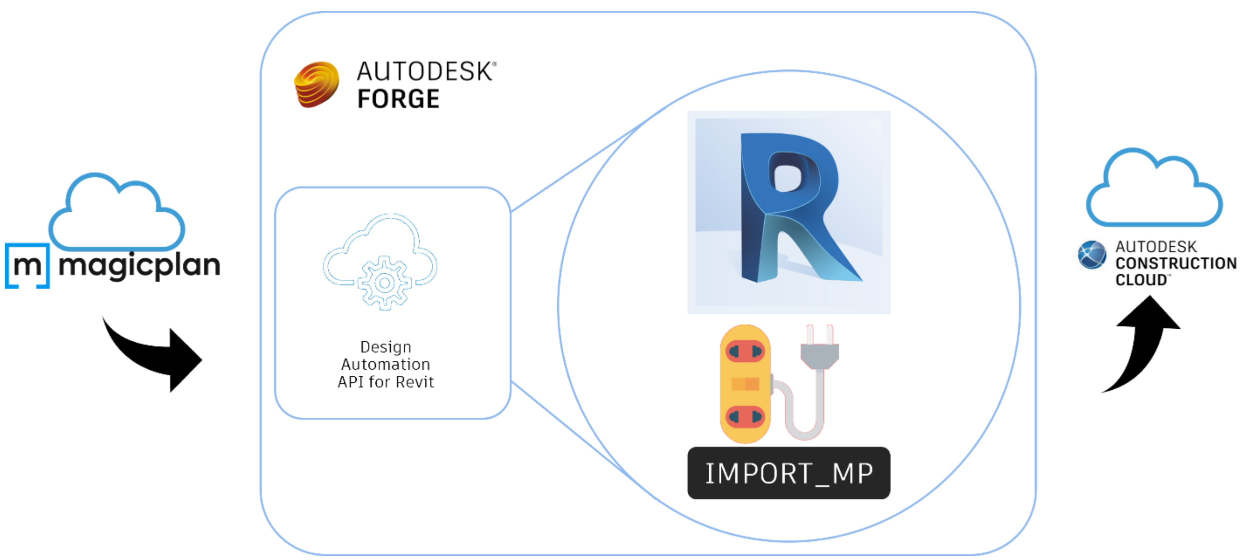


Future Developments: Leveraging New Autodesk Technology

The overall goal of the BIM team at Build Change is to create a fast and straightforward Revit workflow that is accessible to users with limited Revit experience. This means automating as many processes as possible within our workflow and, where possible, eliminating the need for users to interact with Revit.

Current Developments: Moving the import process to the cloud

The team is working on using Forge and the Design Automation API to move our import process to the cloud: instead of using Dynamo scripts to import the house from MagicPlan into Revit, this process will allow the user to send the house plan from MagicPlan directly to Autodesk Construction Cloud while still in the field, instead of requiring a computer to do so.



In the future: Moving the whole workflow to the cloud

In the future, the Build Change BIM team aims to re-write all our Dynamo scripts for retrofitting the house in C# language and create a new Revit plug-in through which to run the workflow. This plug-in will allow the user to run the scripts in the cloud, with limited user interaction within Revit.