

# Social Housing in Colombia: A case for Social Systems Engineering

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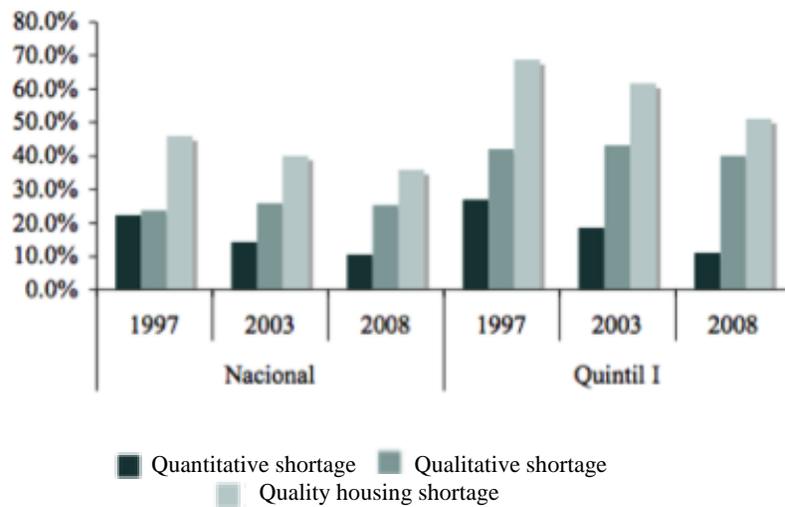
*Abstract*— To engineer a system means to create complex artefacts, such as policies, that should help achieve the purposes of the system. The more complex the system—as in the case of social systems, the greater the challenge. Social housing is one of the deepest felt needs in Colombia. In 2011, the number of families without quality housing reached 3.5 million. Statistics reflect the severity of the problem, yet its real dimension is deeper and much more complex as it interconnects actors with diverse motivations. Unfortunately, the policies that are currently being applied in Colombia follow a simple linear cause-effect type of thinking, for instance simply granting more subsidies or imposing severe minimum laws. Such policies do not take into consideration the complex structure of a social system. Seen from a systems perspective, it is possible to propose structural policies that will modify the dominance of different potential feedback loops to accomplish systemic improvements. Some of the opportunities to empower the virtuous loops are found in the community networks, economies of scale and the quality of the housing as a way to impulse progress. The greatest dangers that should be treated are the high economic and social costs generated by informal and low quality housing. Our proposal thus recognizes the social housing system as driven by motivated actors that form feedback loops, which explain and ‘produce’ the problem. Policies should be designed accordingly with such complexity. We understand such type of intervention as an example of social systems engineering.

*Keywords*— housing, model, policies, simulation, engineering, social systems

## 1. INTRODUCTION

Even if the housing shortage in Colombia has decreased at a very low pace since 1997, a high portion of the population still remains without access to appropriate housing (**Figure 1**). This is not only a problem for families in search of proper housing; it is a problem that transcends and thus affects the rest of society. For instance, the lack of legal housing solutions opens the way to marginal neighborhoods that will eventually generate urban misery belts with social and safety problems that negatively affect the sustainability of urban settlements and the competitiveness of the country. Additionally these neighborhoods do not have infrastructure or access to basic services and

therefore the government must incur in de-marginalization expenses 6.5 times greater than the cost of a formal housing solution [1].



**Figure 1.** Housing Shortage in Colombia [2].

In Colombia this problem has been simplified to a point that it is understood as a simple cause and effect situation: there is a housing shortage, therefore more social housing must be built and more subsidies and mortgage credits should be issued so that formal social housing (“VIS”, for its abbreviation in Spanish) becomes accessible to Colombian low-income families [3], see Figure 2.



**Figure 2.** Current Rationality for tackling housing shortage in Colombia

Consequently, following such a rationality, the Environment, Housing and Territorial Planning Ministry and the Mayor of Bogota, have set quantitative goals: to generate 900 thousand housing unities between 2006 and 2019 and 100 thousand unities for Bogota between 2008 and 2011 [4]. Additionally, we underline that up to now the focus given to housing policies has been limited to the study of each component of the system separately; for example the problem of construction companies is that they build very small housing unities and the reaction of the government is to impose a law that establishes a minimum area. Another example: the lower income families do not have enough economic resources for a housing solution, as a reaction the government issues subsidies. As Jay Forrester explained in Urban Dynamics, simply granting low cost housing could worsen urban conditions[13]. In order to produce robust urban solutions it is necessary to take into action systemic policies that take into account the interactions between different stakeholders. It is possible to generate solutions that make the best out of these interactions, where the government assumes a role of coordinating solutions managed by the system itself. Such a synergy between policies and actions of different stakeholders leads to effectiveness, flexibility and sustainability.

This article examines the housing shortage as a product of the structure of the social system that gives place to the housing in Colombia, hence, as a result of the decisions and actions that are produced in the continual interaction between the stakeholders that make up the system. This understanding, backed up by the construction of models and computational simulation, is necessary in designing policies that attain sustainable transformations. Such goals of designing and redesigning systems of actors so as to aim at transforming and improving whole systems become an example of engineering a social system.

## 2. SOCIAL SYSTEM

The stakeholders are the groups of people whose interests are affected by or whose decisions have an effect on the system of social housing in Colombia. **Table 1** describes them.

<b>Households without quality housing.</b> Interested in fulfilling their right to a proper housing solution, but do not have sufficient resources. Need the support of other stakeholders.
<b>Developers.</b> Private organizations that administer and construct the housing projects. Tendency to reduce the quality of social housing in order to optimize utilities.
<b>Financial entities.</b> Private organizations that issue mortgage loans. Generally not motivated to participate in social housing loans because they must face very high risks.
<b>Design firms.</b> Private organizations in charge of designing the housing solutions. Through innovative design they could create quality and comfort without increasing costs.
<b>National government.</b> They must make sure that the right to proper housing for all citizens is respected and can demand collaboration from private organizations.
<b>Local governments.</b> Understand the needs of the local community. In charge of issuing construction licenses, but with tendencies of not wanting social housing in their municipality because they are scared that it will generate safety problems and lower the status of the municipality.
<b>Community.</b> Social support network with genuine interests to support their members.
<b>Illegal developers.</b> Offer informal social housing, more feasible in a short term but with high social and environmental costs. Informal housing is usually constructed in risky areas without any type of urban planning and with no access to public services.
<b>Landowners.</b> Determine the price of the land according to the market, or the amount of land available at the moment.

*Table 1. Stakeholders.*

## 3. CONCEPTUAL MODEL

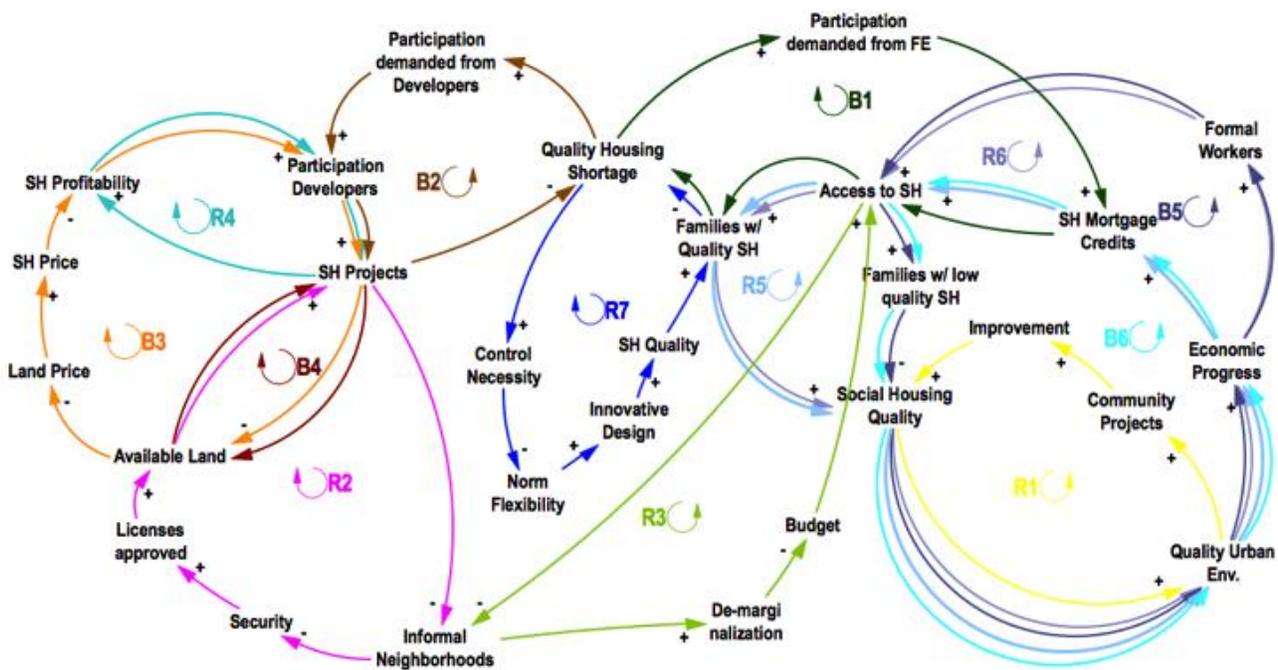
After studying an integral spectrum of published theories by experts of different disciplines and interviews with representatives from each group of stakeholders, a conceptual model of the social housing system in Colombia was created.

Academic studies on housing in Colombia and other Latin American countries were used as a reference, such as Bonduki's [5] on policies in Brazil, Held's [6] comparing policies in Chile, Costa Rica and Colombia, and Florian's [7] and Figue's [8] dissertations on housing in Colombia. Representative members of each group of stakeholders were interviewed. The people interviewed were Clemencia Escallón, who has published several studies on social housing quality from an architectural point of view, Eduardo Pizano who was Minister of Housing and published a book on housing financing in Colombia, a representative from the Rural Bank was interviewed on the rural housing subsidy, several representatives from important construction companies in the country, the architect Nora Aristizabal former director of Bogota's District Planning, a member of Soacha's communal council (a suburban district in Bogota), and Ximena Samper former director of the Colombian Society of Architects. Documentation provided by Asocajas, Camacol (Colombian Chamber of Construction) and BID (Interamerican Bank of Development) was also used.

Based on the understanding of a social system as a collection of interdependent actors and the emerging variables that capture the actions and interests of those involved, a feedback loop diagram was constructed to illustrate the relations between these variables. The objective is to design

policies that will have an effect on the structure and therefore modify the behavior of the system, behavior that arises precisely from a dominance game between the diverse feedback loops through time, that are affected and changed by decisions and actions of social agents.

The feedback loop diagram (**Figure 3**) illustrates how, on one side, developers decide how many social housing projects will be pursued each year depending on the profitability that they offer. Financial entities will also establish their level of participation according to the risk they perceive in social housing clients. Landowners define the prices based on the current state of the market. The government's efforts go towards controlling the housing shortage by imposing minimum standards of participation for developers and financial entities. Design firms can innovate in their designs and therefore increase quality, but are limited by the restrictive laws that are born from the government's necessity of control. The families without proper housing, depending on their circumstances, can have access to quality or low quality formal or informal housing. Households whose members have a formal job may request a subsidy from the government through the Familiar Equalization Funds (Cajas de Compensación Familiar- CCF in Spanish). Households can also apply for a mortgage credit at a bank that will evaluate the situation of the family and determine whether or not the credit will be granted. Local government's decision on the number of social housing licenses issued depends on their perception of social housing and the safety issues generated by social housings's presence in the municipality. Finally the communities decide whether or not they will organize housing improvement or construction projects according to the tools they dispose and the communal unity.



*Figure 3. Feedback loop diagram*

Each one of the feedback loops composing the model will be explained next. To begin, we will examine the housing system as a market in which economies of scales apply.



The loop R4 reinforces developer's participation in social housing (SH) projects due to the optimization of costs at bigger scales. This loop could also work in the opposite direction, just like the rest of the loops.



The loop B3 regulates the amount of social housing projects developed depending on the price of the land that affects the profitability of social housing projects.



The loop B4 regulates the number of social housing projects developed, according to the amount of land available for this type of projects.

The lack of possibilities, for many families, of attaining a formal housing solution has generated a disturbing phenomenon: informal housing. This informality creates dynamisms that are not convenient and if not treated accordingly will continue worsening the quality housing shortage.



The loop R2 reinforces the amount of social housing projects through safety issues. As long as local governments relate insecurity with low-income neighborhoods, due mainly to phenomena generated by low quality urban settlements mostly found in informal urbanizations, they are less willing to grant licenses for social housing projects in their municipalities.



The loop R3 reinforces the creation of informal neighborhoods due to the high costs in which the government must incur in the process of de-marginalization. As informality increases, the government will have to assume even higher costs (improving urban space, integrating public services such as water and electricity, compensating environmental damages, etc.) that will have a negative impact on their budget.

As a way to confront the situation, the government's reaction is to generate a control mechanism with the goal of decreasing the quality housing shortage. However, without even knowing, this control may end up worsening the situation.



The loop B2 illustrates how the government regulates the participation of developers by imposing a minimum participation in social housing projects, according to current housing needs.



Just like the previous one, the loop B1 shows how the government regulates the minimum amount of mortgage credits, issued by financial entities, which should be destined for social housing.



The loop R7 reinforces the quality housing shortage through the control necessity that incites the creation of rigid norms, which limit the possibilities of innovative designs that could increase the quality of the housing. One can see how a good intention may become a vicious cycle.

Next we will examine the financial factor that families must consider in order to have access to a housing solution. Families could request a loan from the bank or apply for a subsidy granted by the government.

It is important to analyze how the quality of the urban environment influences the possibility of families having access to bank loans.



The loop R5 reinforces the amount of families with access to proper housing through the economic progress. Families within a high quality urban environment will tend to progress financially and therefore have easier access to loans.



The loop B6 controls the amount of families with access to proper housing. As far as the social housing offered in the market has a low quality, low-income neighborhoods' urban quality will be affected and therefore families will have less opportunities to progress. This traduces into less access to bank loans.

The dominance game between these two loops will depend on the average quality of the social housing being offered in the legal market.

The quality of the urban environment can also influence the amount of formal workers, and therefore the amount of families belonging to the Familiar Equalization Funds (CCF- abbreviation in Spanish) with access to housing subsidies.



The loop R6 reinforces the access to social housing through labor formality. Low-income neighborhoods with high quality will stimulate better life standards and therefore increase the number of people with formal jobs that will be subscribed to a CCF and therefore receive housing subsidies from the government.



The loop B5 controls the amount of people with access to social housing through labor formality, it is contrary to loop R6. When the social housing that is being offered in the market is predominantly of low quality, a greater number of social housing projects will traduce into a worsened urban environment that will slow down the progress for families living in these neighborhoods and therefore discourage formal labor.

Just like in the last pair of loops explained, one can identify a dominance game between the reinforcing and balancing loop that depends on the average quality of the social housing offered in the market.

Community also plays a very important role in this system; the neighborhoods with a quality urban environment create an ideal scenario for united and active communities.



The loop R1 reinforces the quality of the social housing through community projects. The good quality of the housing arouses better surroundings. This way the community will be able to put together more action groups that will develop more housing improvement and construction projects.

#### **4. MODEL EVALUATION**

To examine the consequences of this complex configuration of multiple loops constantly being re-created by motivated actors, a simulation model was created with the software *iThink* in order to understand the relationship between the system's structure and its behavior. The simulation model can be found in Appendix 1. Multiple technical robustness and sensitivity tests were applied in order to finally achieve a reliable model. The following technical tests were applied: robustness in extreme conditions, integration error, and sensitivity analysis. The purpose of the evaluation is to determine the technical consistency of each one of the suppositions realized by the creator of the model. This way, when proposing policies, one can clarify which ones are subject to the suppositions and the specific data used in the model. The tests realized are explained in more detail in Apendix No. 3.

#### **5. POLICIES**

Finally, with the support of the model it is possible to design and formulate policies that respond to a complex configuration of loops. From this exercise it was possible to conclude that currently in Colombia there are not enough robust policies that will slow down the increasing shortage.

Therefore we proceeded to formulate a series of policies whose design was based on an experimental simulation by deactivating or modifying loops' strengths through a systematic alteration of parameters. These policies seek to strengthen loops with great potential to decrease the shortage that are however being under-exploited, and take strength away from those that are acting in a vicious way. The purpose is to create proactive strategies that are more effective than a simple linear and reactive control consisting on demanding a certain minimum participation from some actors.

### **5.1. PARTICIPATORY PROGRAMS OF IMPROVEMENT AND SELF-CONSTRUCTION OF HOUSING**

This policy will impulse participatory programs of improvement and self-construction of housing in which the community will assume a protagonist role, the government will assume coordination and financing roles, and the private companies and ONGs will participate by offering training and financial support. This policy will strengthen the R1 loop that reinforces the quality of social housing with community improvement projects, which has a great potential that however is currently being ignored.

The formulation of this proposal is based on the PAR methodology (Participatory Action Research), that incentives a collaboration between the affected community and the rest of the actors [10]. The main idea is that the community receives a an integral support, not only in the financial scope, but also in the human training and the disposition of tools that will help achieve a greater number of effective projects that will multiply, improve and sustain over time.

In terms of the model, the creation of community networks in the affected neighborhoods will be incentivized; additionally it is important to design a program that will help these networks achieve a greater number of improvement and basic housing construction projects that are effective and will replicate, multiply, improve and sustain over time. The goal is that this strategy becomes homeostatic in the long term, by creating an auto regulating system that has inertia and generates that the benefit received will pass on. In this way, the loop R1, with the passing of time, will gain more dominance and will therefore reinforce more and more the quality of social housing.

The policy consists on creating an integrated support group composed of architects, engineers and trainers working together with the community. The beneficiaries will assume leadership in the self-building or improvement of housing and the rest of the actors will serve as support. The support group could be composed of young professionals under a scheme similar to doctor's rural practice in which a social service is offered as a pre-requisite for graduation [11]. The national government can support through financing. Private companies could contribute with resources such as construction materials, capital, land, etc. The architects would be in-charge of supporting the community in terms of design advices to optimize spaces and create a comfort. More specifically, an option would be to prepare a portfolio with housing design prototypes that may serve as a reference. Engineers could offer support to the community in the structural design and the constructive systems in order to obtain a solid structure. The community could also count on government institutions such as the SENA or universities to train the community in construction methods and project managing.

### **5.2. IMPLEMENT THE BUILDING BY STAGES**

The phenomenon of informal housing creates vicious cycles that are very dangerous for the social housing shortage problem in Colombia. Firstly they create insecurity problems that will negatively affect the image of social housing, as shown in loop R2, and therefore local governments will be less willing to grant construction licenses for social housing. Additionally informal neighborhoods

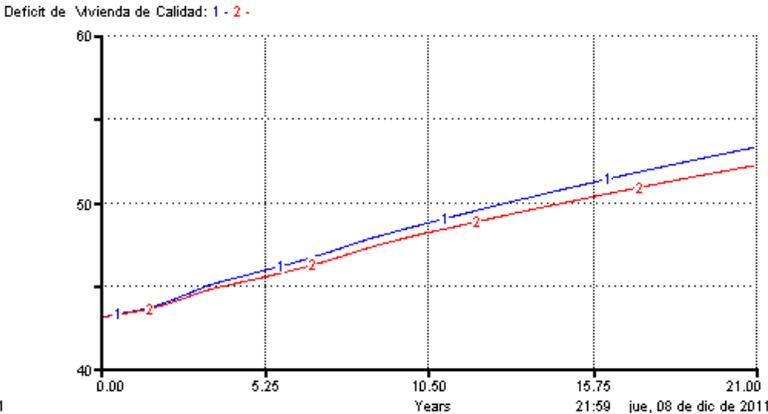
are usually located in difficult zones and do not have access to public services, which implies that the government will have to incur in very high costs in the future in order to improve and de-marginalize them, as shown in the loop R3.

Informality appears because many families cannot have access to formal housing, some because they don't have a subsidy and others even with the subsidy are not able to get a mortgage credit to cover the rest of the price. When analyzing the formation of informal neighborhoods, it is evident that families prefer housing solutions that they can pay partially throughout different stages; first they buy the land and later they start building the house in different phases as they progress economically. Unfortunately the illegal developers are taking advantage out of this situation to generate a profitable business, without any care for the wellbeing of society.

The third policy rises from this reasoning and proposes the creation of a subsidy for the construction of housing in various phases. The idea behind this policy is to create a legal option for the lower income families that are not able to have immediate economical access to a complete housing solution. The government would grant parts of the subsidy as the different phases of the housing solution are being built and the family on the other hand must keep a compromise of working and saving in order to continue having access to this benefit. Just like the first policy, this one is based on the PAR methodology in which the rest of the actors offer support to the beneficiaries of the housing in terms of architectural design, construction systems, structural design and input of resources.

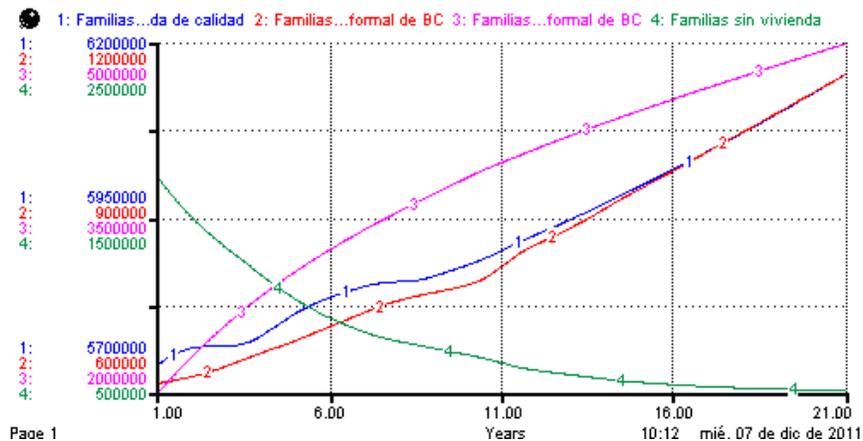
More specifically the policy would have two modalities: the house by phases and the apartment by phases. The first modality consists in giving the family a piece of land with public services and a basic structure initially, point from which the family can start building the house by phases. Just like in the last policy, the beneficiaries would be protagonists in the building process, counting however with the support of professional groups. The second modality is a little different since it regards apartments, however it is really attractive because buildings allow greater housing density and therefore the optimization of land use. In this case the family would receive an apartment with the basic services but without internal walls or finishings. In the later phases the beneficiaries would be in charge of finishing the construction of the housing's interior. In both cases, the government will give partial subsidies as the different phases are being built. Additionally this subsidy is complemented with an agreement in which the family must be committed to save and work in order to keep having access to the right of the economical support.

This policy seeks to take away strength from the loops R3 and R2 that are currently being dominant and therefore dangerous for the behavior of the housing shortage. The loop R3 reinforces the creation of informal neighborhoods due to the high costs in which the government must incur in the process of de-marginalization. Through the experimental analyses it was possible to conclude that the reinforcing loop R3 influences the velocity at which the housing shortage increases because when deactivating this loop (iteration 2) this velocity decreases, as illustrated in **Figure 9**.



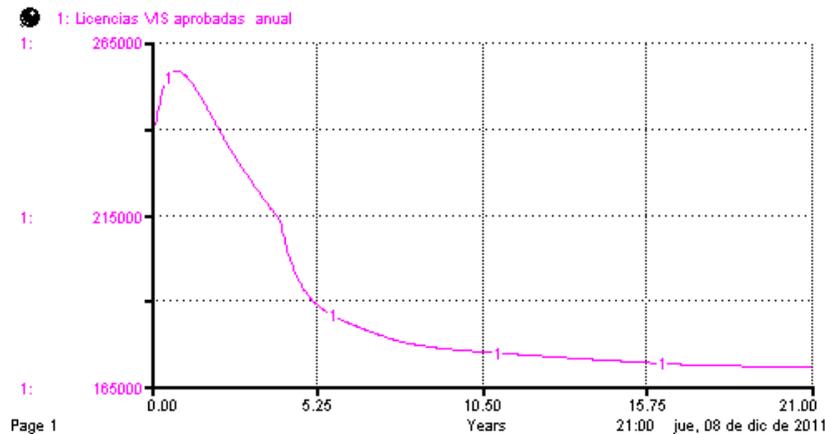
**Figure 9.** Behavior of the housing shortage when deactivating the loop R3

Moreover it was possible to confirm that this loop gains force to act in a vicious manner from the beginning of the simulation period. As **Figure 10** illustrates, the number of families with informal housing (pink line) grows rapidly, specially at the beginning, and this implies that the loop gains significant strength and therefore the housing budget is reduced, finally meaning that there are less families with access to formal housing.



**Figure 10.** Simulation behavior of number of families with informal housing

It was also possible to confirm that the loop R2 is currently reinforcing the housing shortage, as the amount of informal houses rises, it starts creating a negative effect in the perception that local governments have of social housing neighborhood's security and this implies that less and less licenses are granted, as can be seen in **Figure 11**.



**Figure 11.** Simulation of the number of social housing licenses granted each year

One may conclude that by offering a legal option that is viable for the families with the least economic resources, the problem is being attacked from its root, since there will be less families interested in buying what illegal developers offer. By fighting informality other problems that are giving strength to the loops R2 and R3 to act in a vicious way, such as the insecurity perception and the high de-marginalization costs are also being fought.

### 5.3. LAND POLICY

This policy proposes a better way to manage and regulate land in order to ease the development of social housing projects. In the same way that the government demands certain participation in social

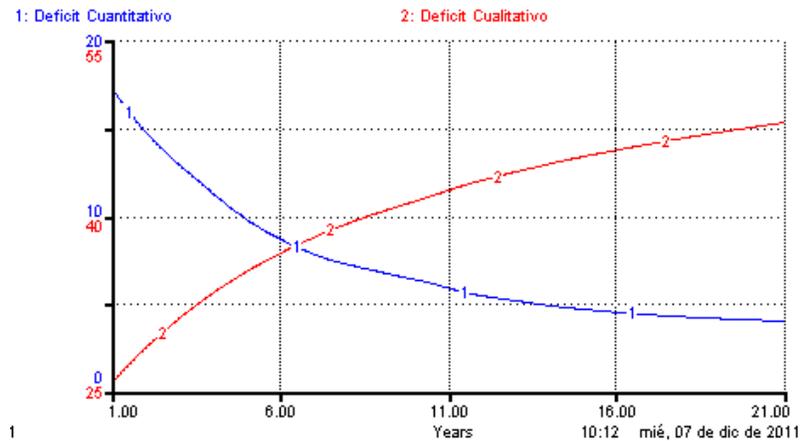
housing projects from developers, it should also apply some control mechanism to make sure that local governments include certain percentages of land for social housing projects in their Land-Use Plan (Plan de Ordenamiento Territorial –POT- in Spanish). This policy would take strength away from the R2 loop, in which licenses become a limiting factor in the development of social housing because local governments tend to not want this type of housing in their municipalities for safety, image and budget reasons. By facilitating the development of social housing in all municipalities, big and small, it would be possible to achieve a better balance in the land demand.

A second part of this policy consists in consolidating the mechanism of macro-projects, a very interesting strategy that makes the best out of the potential of the reinforcing loop R4 since the creation of big housing projects leads to an important cost reduction and therefore greater utilities, due to its big scale, that will further encourage developers to participate in social housing projects.

It is important to be careful when developing this type of projects, in order to avoid falling in the ghetto phenomenon that occurs when a massive housing project is developed in an isolated place far away from activity. This is why it is essential that the macro-project is integral, that it does not only include housing, but also offers places for sports, recreation, culture, education, and working activity. In terms of land this is an interesting solution since it is possible to use land in expansion zones and transform it into urban land by creating an integral project.

**5.4. INNOVATION IN DESIGN AND CONSTRUCTION**

Quality is an essential aspect that has been set aside in the social housing policies in the last years; in a rush to reduce the quantitative housing shortage space has been opened for a great deal of low quality solutions in the market. Through simulation it was possible to see that current policies are mostly directed to the reduction of the quantitative housing shortage (coverage) and therefore the qualitative shortage (quality) is ignored, as seen in **Figure 12**.

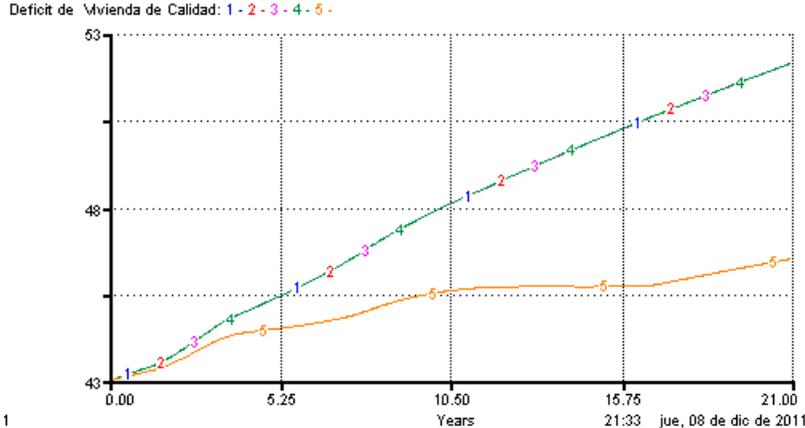


*Figure 12. Simulation behavior of qualitative vs. quantitative shortage*

When the low quality social housing predominates, the quality of the urban environment is affected and therefore economical progress is slowed down in low-income communities. In this case the regulating loops B5 and B6 are acquiring strength and therefore overshadowing the corresponding reinforcing loops R6 and R5. This policy is aimed at potentiating the loops R5 and R6 that are in charge of reinforcing the access to formal housing through the economical progress that generates more formal labor and a greater number of mortgage credits for low income families.

This type of constructive policies will replace limiting and control policies that sometimes become obstacles themselves. For example discouraging the tendency of creating inflexible norms that impede innovation, as seen in loop R7. Even though the government has a good intention to control

the housing shortage, its necessity for control is becoming counterproductive. Through an experiment it was possible to confirm that, when taking strength away from the loop R7, the housing shortage will stop rising so fast as can be seen in **Figure 13** (iteration 5).



**Figure 13.** Behavior of the housing shortage when deactivating the loop R7 (orange line)

More precisely this policy will incentivize innovation with contests organized by the government in which students and professionals will be invited to participate with innovative ideas on quality social housing that yet optimizes costs. However the most important part is the effective realization of the ideas, and therefore this contest will be done in alliance with a construction company that commits to develop the winning ideas.

**6. OUTLOOK**

System Dynamics is an engineering approach that allows the recognition of the housing system in Colombia as a whole., dynamic and complex social system, and not as a simple sum of parts. It is crucial to understand that the behavior of the housing shortage emerges from the feedback structure of the system: a game of dominance between the reinforcing and balancing loops continually produced by the actions and reactions of actors that interact to create the system dynamics. With this conceptualization as a starting point, it is evident that the current strategy to tackle the quality housing shortage in the country has a lot to improve.

This project proposes a reconceptualization of the problem that will enable the design of structural policies that consist on giving dominance to potential loops and taking away dominance from dangerous ones. For example, by stimulating the improvement of the quality of social housing it is possible to strengthen the loops that reinforce the quality of the urban environment and therefore impulse economic and social progress. Another initiative consists in potentiating the community projects by giving them organization and support. The informal housing is a problem that cannot be ignored and more than that it should be dealt with from its root, in order to stop the vicious cycles of insecurity and de-marginalization costs that it’s currently generating. Land is also a determining factor in this problem that should be managed wisely, because as it is a scarce resource it could limit the offer of housing projects. Finally, as any other project, housing needs the input of innovation in order to progress.

To achieve the planning and execution of these policies, a cooperative work between the relevant actors should be advanced. Currently the conflicts of interests are not being handled correctly because the majority of existing policies and decision rules of different actors are based solely on their own perspective. This study is a beginning of a reflection about how to attain a future for Colombia with more access proper housing. With the participation of representative members of

each one of the sectors of interest, it will be possible to bring to life this initiative as a real and effective project.

The design of policies for transforming social systems involves the configuration of new complex arrangements and the promotion of new decision-making processes. This article shows how System Dynamics enables the acquisition of an integral perspective, which empowers public policy designers in their learning process to sustain a rationality behind the actions that are taken and therefore be beneficial for the government in its compromise to resolve, not only the housing shortage problem, but also the many complex problems that the country faces. System Dynamics has its origin in engineering. Engineers succeed because the ability to design requires the combination of diverse elements into a working whole with the aim of achieving preconceived ends [12]. However, engineering is not the usual discipline that one finds in the public policy arena. Nevertheless, its focus based on the development of specific models to achieve innovative and systemic designs reflects a significant contribution different to the one offered by economics and other social sciences. This project in itself is an example of the possibilities that such an approach can offer in the resolution of complex socio-economic problems.

**7. APPENDIX No. 1**

The simulation model in *iThink* can be found in the supporting materials folder.

**8. APPENDIX No. 2**

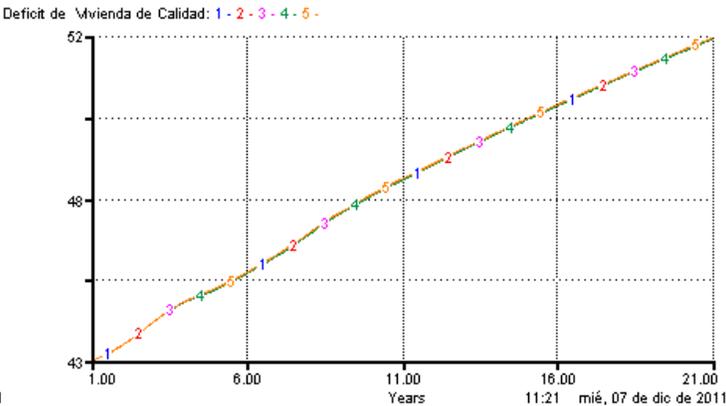
The feedback loop diagram in *Vensim* can be found in the supporting materials folder.

**9. APPENDIX No. 3**

The model evaluation tests are further detailed in this appendix.

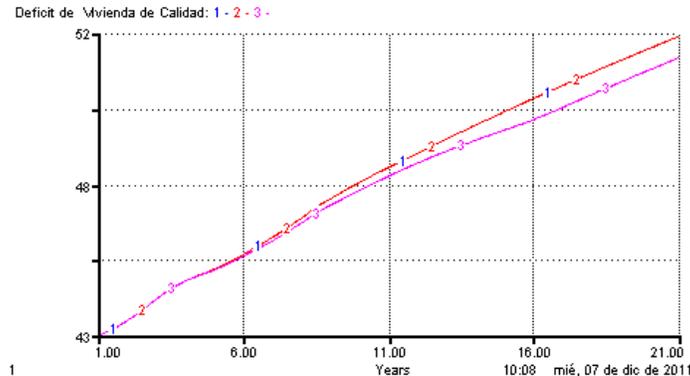
First the robustness of the model was verified under extreme conditions, in other verifying whether the equations and results keep having the same outcome even when the entry data takes extreme values [9]. Next the tests in which variables like the building sector internal product and the national budget for housing were set to extreme values, will be explained.

**Figure 4** illustrates how the behavior of the housing shortage does not change when the building sector internal product (IP) is set to extreme values by multiplying and dividing it by values between 1000 and 100000.



**Figure 4.** Behavior of the housing shortage when setting building sector IP to extreme values

When taking the government's annual housing budget to extreme values, the general behavior of the housing shortage stays the same, even though the values change. **Figure 5** illustrates the graph representing the behavior of the social housing shortage throughout the years slightly moves down when the government's housing budget is multiplied by one thousand (3<sup>rd</sup> iteration), however the general behavior doesn't change. When the budget is divided by one thousand (2<sup>nd</sup> iteration), neither the behavior nor the values change.



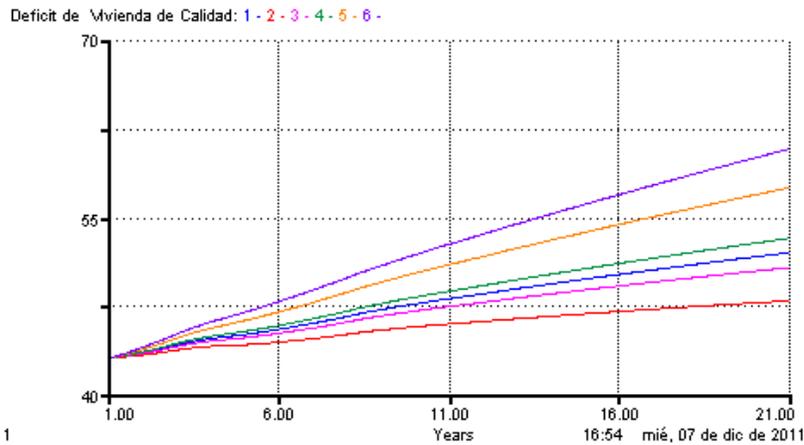
**Figure 5.** Behavior of the social housing shortage, taking the housing budget to extreme values

The second set of tests that was carried out seeks to determine whether the model is sensitive to changes in the method of integration and the DT value. For this purpose the Euler, Runge-Kutta 2 and Runge-Kutta 4 methods were applied, varying the DT value between 1 and 1/60. At the end it was possible to conclude that the behavior of the main variable (social housing shortage) is not sensible to changes in the DT, however other auxiliary variables present a strange oscillatory behavior for values of the DT greater than 1/5. For this reason the DT used for simulations was set at a value of 1/30.

Finally the tests with the greater relevance in relation to the conclusions that eventually led to the proposal of policies, were carried out: the sensitivity analysis. The purpose is to evaluate if the results and conclusions change significantly when varying certain suppositions. In the next paragraphs the most important tests will be explained, especially those that show certain sensitivity to changes in the parameters. There are three kinds of sensitivity: the numerical sensitivity is identified when the numerical values vary significantly, the sensitivity in behavior pattern, and the sensitivity in terms of policies that is identified when the recommendations change when suppositions or parameters vary [9]. In this case we are mainly interested in the last two types of sensitivity.

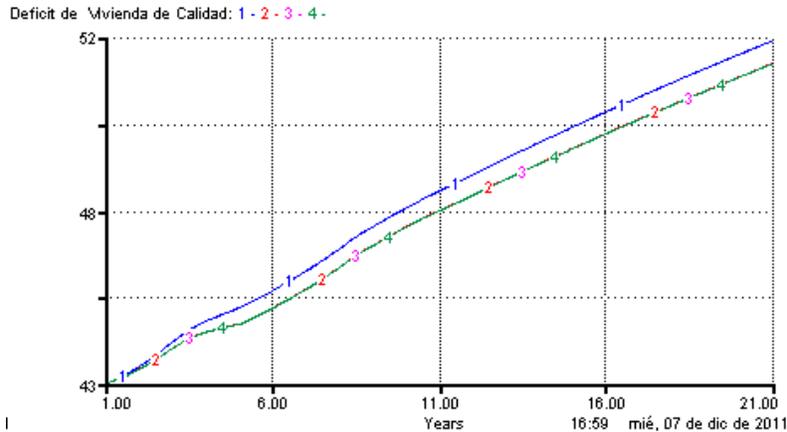
Tests were applied by varying parameters such as the amount of available land for construction of social housing at the beginning of the simulation, the amount of land required per house, the time of adjustment of the utility and security perception, the price of brute land, and the indirect cost of construction. Even though a small numerical sensitivity was perceived for some of these experiments, it was demonstrated that the results of the model were not sensible in terms of behavior or policies to changes in these parameters.

When the supposition of the initial percentage of new families without quality housing was examined, an important numerical sensitivity was identified. When varying this parameter between 0.3 and 0.9, as is shown in **Figure 6**, the behavior of the housing shortage changes. As this percentage increases, the growth in the housing shortage becomes steeper throughout the simulation time horizon. However the general behavior remains the similar. In terms of policymaking this supposition should not concern us because it doesn't present a behavior sensitivity.



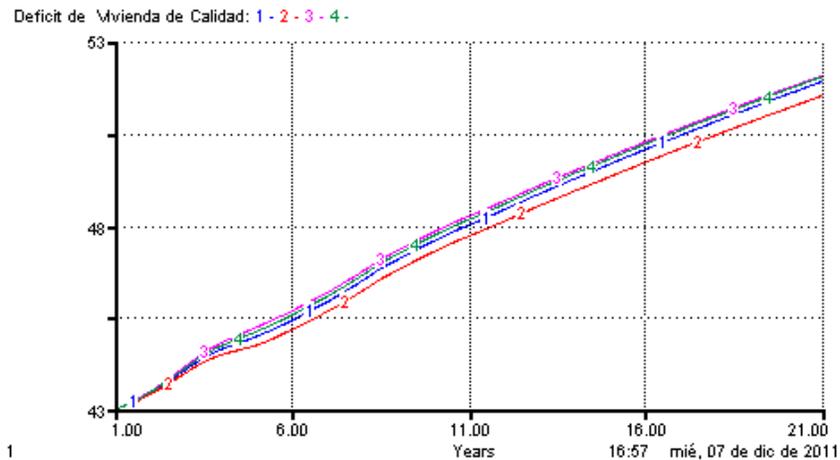
**Figure 6.** Behavior of the housing shortage, varying the percentage of new families that start without quality social housing

The model's sensitivity was also tested against certain changes in the decision rules. The most significant experiments will be explained. When the decision rule employed by the government to fix the minimum percentage of participation in social housing projects for developers is changed, it can be seen that the results are slightly sensitive numerically but the behavior of the housing shortage is not sensitive in its pattern. **Figure 7** illustrates how the social housing shortage graph changes as the government becomes more severe with the minimum participation demanded from developers.



**Figure 7.** Behavior of the housing shortage, varying the decision rule of participation demanded from developers

When there are changes in the decision rule applied by design firms when creating innovative designs depending on the inflexible laws that make them feel limited, one can perceive a numerical sensitivity as shown in **Figure 8**. However, just like in the past test, the behavior of the main variable does not change in a substantial way and therefore these suppositions should not concern us when formulating conclusions.



**Figure 8.** Behavior of the housing shortage, changing the decision rule of innovative designs

Beyond the technical tests, the purpose of creating of this simulation model is to gain a deeper understanding of the system's dynamic and how it is affected by its structure, during the process of creating and testing such model. Similarly the results of the simulation serve as a tool to experiment with the different loops, all of this with the ultimate goal of designing robust and systemic policies.

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