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The Effects of Technological Developments in the Construction Sector on the Housing Market: The Case of Ankara Province*

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Abstract: *The housing sector constitutes one of the fundamental components of the construction industry which holds a significant share within national economies. The ability to make successful housing investments is related to the thorough analysis and predictability of housing markets. Recent technological advancements in the construction sector are anticipated to lead to shorter construction completion times. In the study, the potential impact of the shortened construction completion times resulting from technological advancements in the construction sector on housing markets is investigated with a system dynamics approach. The research, limited to Ankara housing market, utilizes quantitative data such as the number of newly sold primary housing units, population and household numbers, building permit statistics, construction cost index (CCI), and domestic producer price index (D-PPI) for the period between 2013 and 2021, alongside qualitative data related to the region. According to the analysis findings, it is determined that in case construction completion times decrease to 3.5 months, fluctuations in monthly housing sales volume will occur within a narrower range. The expedited construction of housing units through evolving construction technologies suggests an alternative path towards achieving more predictable market conditions.*

Keywords: Construction Sector, Housing, Housing Market, Construction Technology, System Dynamics

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1. Introduction

When examining the relationship of the construction sector with more than 200 subsectors and especially its impact on labor force and employment positions, it is determined to have a significant position within national economies (Akil, 2019). The housing sector stands out as an essential component of the construction industry. The predictability of the housing market can influence the success of investments made. Therefore, the examination of real estate markets within the framework of housing markets in particular, which can be considered as examples of complex systems, has great importance in terms of national economies.

The importance of the housing market in terms of the country's economy, investors, users, and market intermediaries leads to detailed market analyzes and academic research in this field. Some academic studies focusing on research on developments in construction technologies and the housing market are as

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follows. Kothman and Faber (2016) have exhibited that 3D printing technology reduces supply times, labor and material usage required for production in the construction sector and that it provides more efficient production methods. Tay et al. (2017) have expressed that there is an incremental increase in computer-driven technologies such as three-dimensional (3D) printing in the past few years and pointed out that these technologies reduce the need for human resources, high capital investment, and extra molds in the construction sector. Furthermore, it was highlighted that this technological advancement also contributes to improving traditional construction strategies. Hossain et al. (2020) have stated that the construction industry, one of the world's major sources of employment, is labor-intensive and that there is a growing interest in various automation technologies in this sector, including 3D printing. In addition, it was also indicated that these advancements in construction technology could have an effect on the labor market, potentially reducing the labor issues in the construction sector. Ali et al. (2022) have highlighted that there is an increasing usage of 3D printing technologies in the construction industry in recent years and that this technology saves on labor and materials, shortens construction times, and enhances workplace safety. Furthermore, it was indicated that these technologies will contribute significantly to the development of high-performance materials and play a vital role in achieving the objectives of Industry 5.0.

In their study, Hong-Minh and Strohhecker (2002) applied a system dynamics model for analyzing the private housing sector in the United Kingdom and evaluating the impact of re-engineering policies on dynamic performance in housing construction supply chains. It was also emphasized that changes need to be undertaken to improve the performance of the housing construction industry in England and that the housing companies should focus on their supply chains and possess all pre-requisites for managing an integrated supply chain. Özbaş et al. (2014) on the other hand, created a system dynamics model with a focus on the economic equilibrium dynamics between supply and demand to model and analyze the fluctuations in housing prices. This model was developed using parameters specific to Istanbul province to represent developing cities and the following three main balancing feedback loops were identified as the model behavior created with the parameters of the city of Istanbul: supply-demand, demand-price, and supply-price cycles. The research concluded that by reducing construction times and considering the number of housing units in the construction phase when initiating a project, the oscillations in housing prices could be significantly reduced, leading to more stable behavior in housing prices.

A system dynamics model was developed by Ali et al. (2020) to examine the effects of climate change on the housing market, building upon existing literature on housing market models the study revealed that in many developed countries, housing market dynamics are determined by the interaction of supply and demand. However, in California and Australia, the increasing risk of forest fires has been emphasized to influence housing market behavior. The study suggested that risk perceptions resulting from climate change should be taken into account when determining policies related to housing use, especially in insurance planning, awareness programs, and the regulation of support and incentives.

In the study conducted by Morshedi and Kashani (2020), a system dynamics model was constructed to simulate shifts in demand for housing with varying levels of seismic vulnerability, policy-induced shifts, landlords' responses to these demand shifts, and resulting price movements. The model consisting of low and high-risk housing prices, supply of low and high-risk housing and incentives was developed by taking into account the specific building stock. The study assumed that only a portion of landlords can cover housing maintenance and strengthening costs and determined that policy-supported and incentivized housing strengthening costs could contribute to stability in the housing market.

It is an indisputable fact that technological advancements which influence every aspect of life and shape people's lifestyles, will also have its effects on housing markets. Technological advancements, particularly those occurring in the construction sector, are expected to lead to shortened construction completion times. This study investigates how technological developments in the construction sector will impact housing markets. The purpose of the study is to determine and evaluate the potential effects of shortened construction completion times resulting from technological advancements on the housing sector. In this context, utilizing the system dynamics approach suitable for modelling and analyzing complex systems, the study examines the influence of construction completion times on the housing market.

Comprehensive real estate market analysis studies necessitate the initial classification of real estate according to its types, followed by detailed examination and reporting for each specific real estate type based on classification made. This study is restricted to the residential real estate type based on the classification made. This study is restricted to the residential real estate type, specifically focusing on the primary housing market in the selected province. Thus, the primary limitation of the research should be indicated as the analysis and evaluation of the primary housing market. It is acknowledged that regional parameters play a significant role in housing market in the selected province. Regional differences lead to the emergence of distinct market characteristics for each region. The research area has been confined to the boundaries of Ankara province in order to identify and detail regional characteristics adequately.

Although the system dynamics model developed for the examination of the Ankara housing market primarily relies on quantitative data, essential inputs from qualitative data were also integrated into the modelling process. Therefore, in this study, a mixed research approach utilizing both qualitative and quantitative data was chosen. Quantitative data related to the Ankara housing market and national economic indicators for the period 2013-2021, such as the number of newly sold primary housing units, population and household numbers, building permit statistics, construction cost index (CCI), domestic producer price index (D-PPI) were obtained from the Turkish Statistical Institute (TSI) while mortgage interest rates as well as quantitative data for the Ankara housing price index were obtained from the Central Bank of the Republic of Turkey (CBRT). Qualitative data, on the other hand, were derived from literature reviews and expert opinions obtained through discussions with stakeholders in the housing market (Atasoy & Tursun, 2022; Tursun, 2023).

Within the scope of the study, the first section includes the importance of the subject, a brief summary of the academic studies, and explanations about the purpose, material and method. In the second section, technological developments in construction technologies and the possible consequences of these developments are mentioned. The third section includes creating a system dynamics model of the Ankara housing market, testing it and examining it under specified scenarios. In the last section, the findings are evaluated and suggestions are presented.

2. Developments in Construction Technology

In recent years, it is well-known that some construction companies have started exploring 3D printing as an alternative to traditional building components in the construction sector. For instance, Skanska JV planned to use 3D-printed concrete blocks for the construction of the HS1 rail project in the United Kingdom. Moreover, Icon, a construction technology company, designed a new 3,800-square-meter military barracks using its proprietary Vulcan technology right after a solid $200 million series (Anonimus, 2022a)

Modular constructions, where buildings are constructed off-site, transported in parts, and then assembled using cranes, represent an alternative construction method. These modular structures can be constructed up to two times faster compared to traditional projects (Barut, 2022).

ISTON INC. has brought Turkey's first office building into service which was constructed using 3D concrete printing technology in 2021. They developed a mobile concrete batching plant capable of producing the concrete mixture used in the printer, as well as a specially formulated printable concrete mixture for the 3D printer technology. The concrete was manufactured layer by layer without the necessity for molds. The concrete, pumped in liquid form, hardens immediately after being printed by the printer, allowing it to support its own weight. The high-strength concrete falls under the C50/60 class of strength. It also stands out for its sound reduction index of 45 dB, highlighting its sound insulation features. The institution had previously completed the construction of a 155-square-meter building with 3 rooms and a living room using robotic 3D printer technology in just one week (ISTON, 2022).

In the last five years, 3D printing technology has been used to build a vast number of structures worldwide, including 3D-printed houses, cabins, offices, bridges, large-scale buildings, shelters, and more. The most significant advantages of 3D-printed structures can be indicated as their construction speed, as well as being more cost-effective, requiring less labor, and being more environmentally friendly (Anonimus, 2022b).

Technological innovations in the construction sector, such as augmented reality, advanced GPS usage, modular construction, self-healing concrete, wearable technologies, mobile technology, and cloud services, along with developments like 3D printing technology, assert that significant reductions in construction timelines could be accomplished in the future.

3. System Dynamics Model for Housing Market in Ankara

The model developed for the Ankara housing market has been designed by taking into consideration the regional characteristics of Ankara and the regional changes within the housing market. Furthermore, the components of the model and their interactions have been developed while considering the general theoretical framework of the real estate market.

3.1. Designing the Model

The scope of the model, the time period under examination, and the cycles used in the model were initially described when designing the system dynamics model for the housing market. Subsequently, the created model was divided into subsections and elaborated upon in detail. Furthermore, visual representations and the equations utilized in the complete model were also included.

3.1.1. Scope and Time Period of The Model

The variables used in the system dynamics model can be categorized as internal, external, and excluded variables from the perspective of the model (Kapourani & Kapmeier, 2017). While traditional econometric models mostly rely on external variables, the model created for the housing market in this study is primarily based on internal variables. Ongoing construction projects, completed housing units, sold housing units, demand, housing prices, and operating profit are among the internal factors that constitute the foundation of the model and guide its behavior. External factors that emerge outside the model but impact its internal factors, such as household numbers, construction costs, housing loan interest rates, and the durations required for various stages in the housing market, have been included in the model as external factors. In addition to internal and external factors, there are certain variables that are related to the housing market but have been excluded from the model for the purpose of designing a comprehensible and analytically suitable model. Variables such as household consumption habits, income, labor force and employment rates, the state of the financial sector, and various indicators related to the national economy have indirect effects on the included variables in the model. Therefore, it was decided to exclude them from the model (Tursun, 2023).

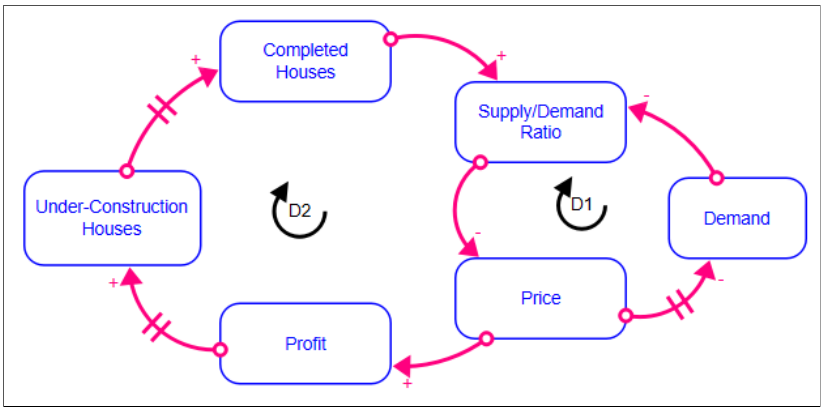
In the created model, a time period spanning from 2013 to 2030, covering 18 years, was reviewed. The period from 2013 to 2021, a span of 9 years, was used to identify certain characteristics of the Ankara housing market. While some of the obtained quantitative data date back further, it is important to consider the intersection of the data used in terms of the time frame. Therefore, it was determined to use data from the last 9 years. For simulation studies concerning the Ankara housing markets, examining a 9-year time period was deemed suitable to analyze the future behavior of the housing market. Thus, the time period was set as 2013 to 2030 (Tursun, 2023).

3.1.2. Simulation Model Loops

Supply and demand response for the Ankara housing market can be expressed with two balancing feedback loops. In the event that the supply exceeds demand, it will have a downward effect on prices. The decrease in prices will accordingly. Increase demand. In this case, increased demand will change the supply/demand ratio, causing the supply to decrease proportionally against demand. On the other hand, if supply is lower than demand, it will influence prices to increase, and higher prices will decrease demand. The decrease in demand will reflect in the supply/demand ratio, causing the supply to increase against demand. Thus, the response of demand (displayed as D1 in Figure 1) attempts to balance the price through negative balancing feedback.

The increase in housing prices will raise operating profit and eventually lead to an increase in the number of houses which are under construction. The rise in the number of houses which are under construction will cause an increase in the housing units that are completed and available-for-sale. The increase in housing units which are available-for-sale, indicating a surplus of supply over demand, will impact prices to decrease while simultaneously reducing operating profit and subsequently reducing the number of under-construction houses. Consequently, the decrease in completed houses and the proportional decrease in supply against demand will occur. Similar to the demand response, the supply response (represented as D2 in Figure 1) seeks to balance the price through negative balancing feedback.

Figure 1. Causal Loop Diagram



Source: Sterman (2000).

Thus, the housing market creates two negative feedback loops that attempt to reach an equilibrium point through supply, demand, and price (Kapourani & Kapmeier, 2017). As seen in Figure 1, there are delays in the emergence of these loops. Changes in price have a delayed impact on demand due to low demand elasticity. When operating profit increases, similar delays set back the increase in the number of houses that are under construction due to project preparation time and the increase in the number of completed houses due to construction durations. Consequently, one delay is observed in the D1 loop and two delays in the D2 loop (Tursun, 2023).

Although balancing and feedback loops attempt to reduce differences in supply and demand quantities, delays and ongoing corrective actions trigger new corrective actions in the opposite direction. Therefore, the equilibrium state is continuously surpassed, leading to oscillatory behavior (Kapourani & Kapmeier, 2017). Instead of aiming for an ideal equilibrium point in the housing market, it is more favorable to achieve conditions with less oscillation, easier predictability for planning and investment decisions; thus, real estate markets can be considered as regulated markets with an acceptable level of control (Tursun, 2023).

3.1.3. Simulation Model

The system dynamics model created for the examination of the Ankara housing market provides a comprehensive opportunity for investigation due to its inclusion of numerous variables affecting the housing market and their interactions as well as feedback loops. Additionally, in this study, the full model has been examined in 3 separate subsections and explained in detail, describing the variables and loops. Subsequently, these explained subsections were integrated into the full model, demonstrating all variables, feedback loops, and interactions.

The initiation of the creation of the system dynamics model for the Ankara housing market began with incorporating the classic life cycle of buildings. Although the model is designed for the Ankara housing market, it can be indicated that the stock and flows (Subsection-1) in this part of the model are applicable to housing markets in general (Figure 2). Therefore, it shares similarities with system dynamics models created for various housing markets. The number of constructions permits obtained to build houses and the project preparation (planning) time determine the flow that feeds the under-construction housing stock. Specifically for the Ankara housing market, the time required to obtain all the necessary planning and legal permits for construction to start has been set at an average of 3 months. It is assumed that construction begins after an average preparation period of 3 (Tursun, 2023).

In many cities, new buildings are being added to the existing housing and other structures, while at the same time, the preservation of the existing stock is possible through demolishing existing buildings or urban renewal efforts. In the study, the rate of starting construction, which determines the flow that feeds the under-construction housing stock, is displayed using the formula below (Tursun, 2023):

$$RSC = \max(NCP/APT, 0) \quad (1)$$

$$NHUC = TNHUCIS + RSC - RCC \quad (2)$$

The notation shown above represents: RSC as the rate of starting construction, NCP as the number of constructions permits, APT as the average planning time, NHUC as the number of housing under construction, TNHUCIS as the total number of housing under construction in the stock, and RCC as the rate of completion of construction.

Housing under construction is included in the stock of houses completed at the rate of completion of construction at the end of the average construction completion period. The construction completion period has been set at an average of 21 months for the housing in Ankara and it is assumed that the housing started will be included in the stock as completed housing after 21 months (Tursun, 2023):

$$CRC = HUC/ACT \quad (3)$$

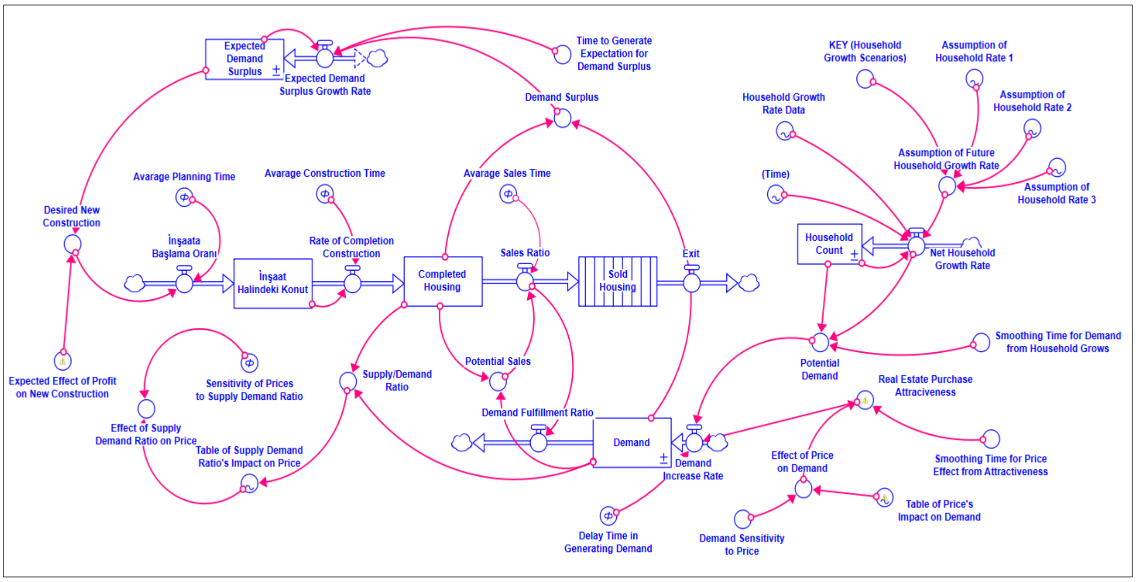
$$CHU = TNCHUIS + CRC/ACT \quad (4)$$

As shown above: CRC represents the completion rate of construction, HUC represents the housing under construction, and ACT represents the average construction time, CHU represents the completed housing units, and TNCHUIS represents the total number of completed housing units in stock.

The flow from the completed housing stock to the used housing stock is determined by the average sales period and the sales rate. The process of completed housing being sold and changing ownership requires a certain amount of time. An average sales period of 7 months has been determined for the Ankara housing market taking into account that some housing is sold before its construction is completed. It is assumed that completed housing will switch to the used housing stock 7 months after completion, depending on the sales rate (Tursun, 2023).

Housing demand is widely accepted to be determined largely by changes in the number of demolished housing units and household counts (Kapourani & Kapmeier, 2017). However, depending on the characteristics of the study area, various factors and interactions such as the number of housing units per household, delays in demand formation, attractiveness of property purchases, and potential demand can be identified. It should be noted hereby that potential demand is determined by changes in household counts. Therefore, determining housing demand necessitates the examination of changes in household counts (Tursun, 2023). In the created model, the stocks of demand and household counts, as well as the related flows and feedback loops, are detailed (Subsection-2) and illustrated in the model (Figure 3).

Figure 2. Ankara Housing Market Model (Subsection-1)



The household growth rate taken as an external variable in the model covers the period from 2013 to 2030. The household growth rate for the years 2013-2021 is calculated based on the average of the realized values. The household growth rate for the years 2022-2030 is based on the assumption of future growth rate, taking into account the average growth of past years. Thus, the net growth rate in household numbers was used to determine potential demand. The formulas used in the model for calculating the household net growth rate and potential demand are as displayed below (Tursun, 2023):

$$\text{HNGR} = \begin{cases} \text{HGR x HN}, & t < 2022 \\ \text{AFHGR x HN}, & t \geq 2022 \end{cases} \tag{5}$$

$$\text{PD} = (\text{HNGR/TSDFHG}) + (\text{DHU/NUPH}) \tag{6}$$

The terms shown above: HNGR; household net growth rate, HGR; household growth rate, AFHGR; assumption of future household growth rate, t; time, PD; potential demand, HN; household number, TSDFHG; time to smooth the demand from household growth, DHU; demolished housing units, and NUPH; number of units per household, are represented as follows.

The variable representing the adjusted effect of the interest rate on price and demand has been separately examined and integrated into the model in terms of easiness in representation. The variables determining the adjusted impact of the interest rate on sales and demand, as well as the interaction of these variables with other sub-variables, are shown in the model (Subsection 2) below (Figure 3).

$$\text{SR} = (\text{PS x AEIROS})/\text{ASP} \tag{7}$$

$$\text{AEIROS} = \text{EIROS/TIREOS} \tag{8}$$

The above-presented: SR; sales rate, AEIROS; adjusted effect of the interest rate on sales, PS; potential sales, ASP; average sales period, AEIROS; adjusted effect of the interest rate on sales, EIROS effect of the interest rate on sales, and TIREOS; timing of the interest rate's effect on sales.

The demand growth rate is determined by potential demand, real estate purchase attractiveness, housing units per household, and the delay in demand formation. Furthermore, the demand growth rate forms the flow that feeds the demand stock. The generated demand affects the supply-demand ratio and potential sales. Potential sales affect the determination of the sales rate, and the sales rate determines the demand fulfillment rate affects the reducing flow in the demand stock (Figure 3). In the model, it is assumed that there is one housing unit per household. The formula for the demand growth rate is as follows (Tursun, 2023):

$$DGR = (REPA \times PD \times UPH)/DIFD \tag{9}$$

The above shows: DGR; demand growth rate, REPA; real estate purchase attractiveness, PD potential demand, UPH; units per household, and DIFD; delay in forming demand.

When examining the supply-demand balance in the housing market, it is noteworthy that one of the significant factors influencing price formation is the supply-demand ratio. Considering the factors influencing price formation, it becomes necessary to determine the expected price and expected construction costs. In many system dynamics models created to study the housing market, expected price, and expected construction costs have been included as stocks (Barlas et al., 2007; Kapourani & Kapmeier, 2017; Sterman, 2000). In the developed system dynamics model in this study, expected price and expected construction costs have also been included as stocks and their interactions with other variables are detailed in the model (Sub-section 2) as shown in Figure 3.

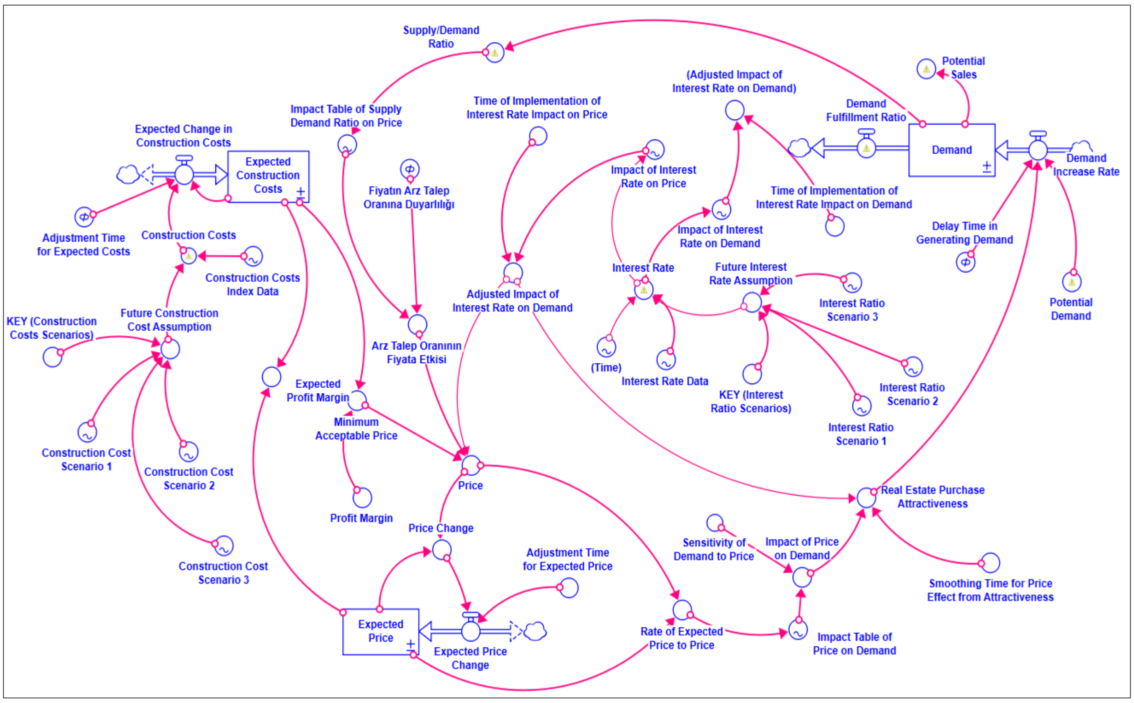
Formulas for construction costs and change expected in construction costs are shown below (Tursun, 2023):

$$CC = \begin{cases} CCID, & t < 2022 \\ FCCA, & t \geq 2022 \end{cases} \tag{10}$$

$$CECC = (CC - ECC)/ECAT \tag{11}$$

The above shown: CC; construction costs, CCID; construction cost index data, FCCA; future construction cost assumption, t; time, CECC; change expected in construction costs, ECC; expected construction costs, and ECAT; expected cost adjustment time are expressed (Tursun, 2023):

Figure 3. Ankara Housing Market Model (Subsection-2)



Housing suppliers determine the minimum accepted price for a house based on their profit margin and expected construction costs. They aim to achieve at least a 30% profit margin on this price. Therefore, a profit margin of 30% is assumed in the model. While profit margin increases on account of high interest rates as well, it decreases in economic conditions where the interest rates are low. Hence, suppliers need to consider interest rates when making investment decisions. Additionally, a higher real interest rate has a dampening effect on the profit margin. Therefore, the smoothed impact of the interest rate on the profit margin should also be taken into account (Kapourani & Kapmeier, 2017).

The minimum accepted price determined by considering the profit margin and the impact of the supply-demand ratio on the price determine the price variable. There is an inverse relationship between supply and price. When supply is low, buyers are willing to pay higher prices. Conversely, when supply is high, prices decrease. The price affecting both supply and demand is determined according to realized sales. Buyers' and sellers' perceptions and price expectations differ. There may be a difference between the realized price and the expected price. The ratio of expected price to realized price is updated based on delayed values of the realized price (Kapourani & Kapmeier, 2017). The formulas related to the ratio of expected price to realized price, effect of price on demand and the impact table of price on demand are as shown below (Tursun, 2023):

$$\text{REPRP} = \text{EP/P} \quad (12)$$

$$\text{EPD} = (\text{FTET x BFFO})^{\text{SDP}} \quad (13)$$

$$\text{TEPD} = f(x); f' \geq 0; f''_{x<x_{ref}} \geq 0; f''_{x>x_{ref}} \leq 0 \quad (14)$$

The terms shown above represent: REPRP; the ratio of expected price to realized price, EP; expected price, F; price, EPD; the effect of price on demand, SDP; the sensitivity of demand to price and TEPD; the table of the effect of price on demand.

There is an inverse relationship between demand and the supply-demand ratio. Therefore, an increase in demand reduces the supply-demand ratio, while a decrease in demand increases it. An increase in price initially decreases the ratio of expected price to price, but since the expected price will be updated with a delay relative to the price, it will gradually increase towards its previous level. The effect of price on demand is determined by the values in the table of the effect of price on demand and the sensitivity parameter. Generally, it has been determined that demand is not quite flexible in real estate markets taking into account the price elasticity of demand. Additionally, it has been considered that the effect of price on demand influences the attractiveness of real estate purchases, and the attractiveness of real estate purchases affects the rate of increase in demand (Figure 4).

In the model, the price formation in relation to operating profit, supply, and demand was examined. The expected profit margin is determined by expected unit market or selling price and expected unit construction costs. The expected profit margin affects the values in the table for the impact of profit on desired new constructions and interacts with the sensitivity of supply to price, forming the table of effects. This table of effects, along with the sensitivity of supply to price, shapes the effect of expected profit on new constructions, essentially determining the desired new constructions, or in other words, the number of building permits issued (Tursun, 2023). This, in turn, affects the rate of commencing construction, and in the subsequent loop, influences the supply-demand ratio, ultimately completing the negative feedback loop that affects price formation (Figure 4).

The formulas for expected profit margin and the impact of expected profit on new construction are as shown below.

$$\text{EPM} = (\text{EP} - \text{ECC})/\text{EP} \quad (15)$$

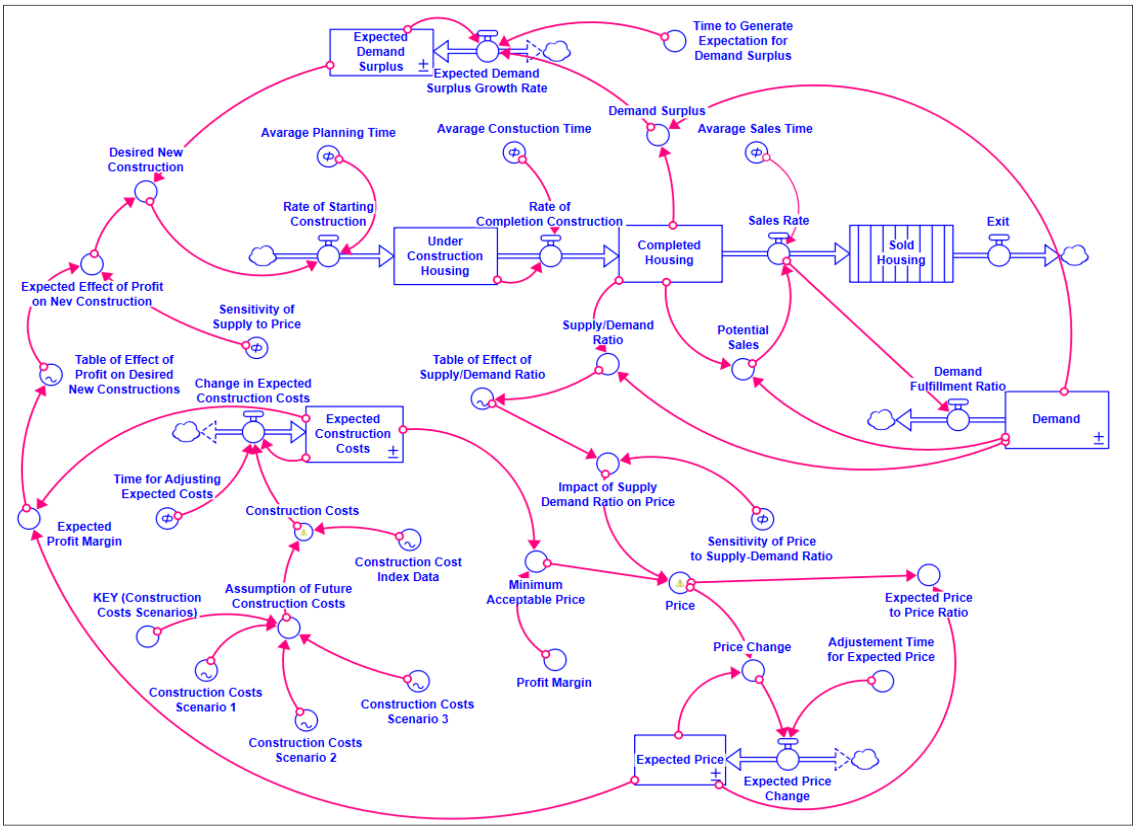
$$\text{EENCP} = \text{ETPDNC}^{\text{SSP}} \quad (16)$$

The shown notations represent: EPM; expected profit margin, EP; expected price, ECC; expected construction cost, EENCP; expected effect on new constructions from profit, ETPDNC; effect table on profit for desired new constructions and SSP; sensitivity of supply to price.

The objective of those creating the supply in the housing market is to produce enough housing to meet the demand since they are aware that an excess of demand in housing will lead to difficulties in selling and a decrease in prices, which will ultimately reduce their profit. A surplus of demand, which implies a high proportion of unsold housing units, can put housing suppliers in a challenging situation and even lead to bankruptcies. Therefore, accurately identifying the surplus of demand is of vital for housing suppliers (Tursun, 2023). The interaction of the surplus of demand with other variables is detailed in the developed system dynamics model (Subsection-3) and shown in Figure 4.

Special emphasis is placed on analyzing the effects of expectations on demand and new project development (supply side), particularly in commodity markets and especially in long-lived goods markets. In local and regional real estate markets, especially in housing markets, determining data related to the expected demand quantity, existing inventory, new project capacity, and consequently the expected surplus or shortage will enable a rational analysis of the real estate market through a dynamic approach.

Figure 4. Ankara Housing Market Model (Subsection-3)



The quantity of expected surplus demand in housing influences the construction initiation rate by affecting the desired new constructions. Having an excessive number of new constructions compared to what is necessary eventually increases the number of completed and available housing units. In a similar way, completed housing units and the determined surplus demand quantity result in an increase in the expected surplus demand in housing. The formulas related to surplus demand and the expected surplus demand growth rate are shown below (Tursun, 2023):

SD = max ((DQ – TK), 0) (17)

ESDGR = (SD-ESD)/TSDCE (18)

In equations (17) and (18): SD; surplus demand, D; demand quantity, ESDGR stands for expected surplus demand growth rate, ESD represents expected surplus demand and TSDCE represents the time when surplus demand creates expectations.

The complete model of the Ankara housing market system dynamics, which is divided into three separate sub-sections as explained above (Figure 2-4), and the relationship between the elements of the sub-sections are provided in Appendix 2 as the Ankara Housing Market System Dynamics Model (full model). The list of all equations used in the created model is also presented in the appendix (Appendix 3). With the addition of new variables to the variables used in the analysis of the housing market system dynamics in the selected city, it will also be possible to conduct a market analysis or conduct studies other settlements.

3.2. Model Testing

3.2.1. Structural Tests

System dynamics models represent a simplified representation of real systems. In this respect, no model can be an exact replica of the real system and match all the details identically. Testing system dynamics models is considered a crucial stage in the modeling process. The model should possess a level of sensitivity that can serve the purpose of the research. In other words, when evaluating the validity of the model, the primary focus should be on the research objectives. The fact that system dynamics models can be used with confidence indicates their validity. Therefore, structural, and behavioral tests are applied to increase confidence in the model (Sterman, 2000). Boundary adequacy test, structural evaluation test, dimensional consistency test, and parameter evaluation test fall under the category of structural tests, while outlier test, partial test, and behavioral replication test belong to the category of behavioral tests (Kapourani & Kapmeier, 2017).

The structure of system dynamics models also constitutes the basis of model behavior. Therefore, it is important to determine that the model structure is consistent with the system's structure. All elements presented in the model must also exist in the system, and all significant factors present in the system must be incorporated into the model (Shreckengost, 1985).

Structure Evaluation Test: It is the evaluation of whether the model has been prepared in a consistent manner with the real system according to the working purpose of the model. All factors presented in the model must also exist in the real system; in other words, an element that does not exist in the real system should not be included in the model. Additionally, important elements presented in the real system must be included in the model (Senge & Forrester, 1980). The relationships between elements presented in the real system and included in the model must be defined realistically. In the Ankara housing market system dynamics model, important elements present in the real system have been included. Furthermore, when defining the relationships between the included elements, information obtained from real estate market stakeholders was utilized, and efforts were made to ensure that these definitions align with previous academic studies (Tursun, 2023).

Boundary Adequacy Test: For the validity of the model, the boundaries of the model must be appropriately and sufficiently defined. In this study, all factors affecting the housing market that can be identified were considered and internal factors, external factors, and excluded factors were determined to establish the model. Data specific to the Ankara housing market were used, in line with the study's objectives. In other words, the quantitative and qualitative data used are specific to the Ankara province. Generalizations of the model results cannot be made applied for other locations with different development characteristics or for other types of real estate such as commercial properties, offices, hotels, etc. The model's boundaries must be meticulously redefined to evaluate other types of real estate besides residential properties in Ankara (Tursun, 2023).

Dimensional Consistency Test: It can be defined as the consistency of all used variables in terms of units of measurement and the compatibility of the interaction of variables during the formulation process (Martinez-Moyano & Richardson, 2013). During the process of creating a system dynamics model, attention has been paid to dimensional consistency and appropriate transitions between units. For instance, as shown below, in the equation for the rate of starting construction, the units on both sides of the equation are the same, representing a proportional magnitude (Tursun, 2023).

Starting Construction Rate = max (Construction Permit Count / Average Planning Time, 0)

Appropriate transitions between units have been ensured in all formulas used for transitions between variables and calculations (Appendix-2).

Parameter Evaluation Test: It can be described as checking the compatibility of all data related to variables used in the model with the real system (Shreckengost, 1985). The quantitative data used in the Ankara housing market system dynamics model (population and household numbers, construction permit counts, mortgage interest rates, housing price index (HPI), construction cost index (CCI), domestic producer price index (D-PPI), sold primary housing unit counts) reflect the historical data of the Ankara housing market. In addition, qualitative data based on the opinions of market actors and obtained through literature studies have also been used in the model. The compatibility of these data, which were incorporated into the model, with the real system has been verified (Tursun, 2023).

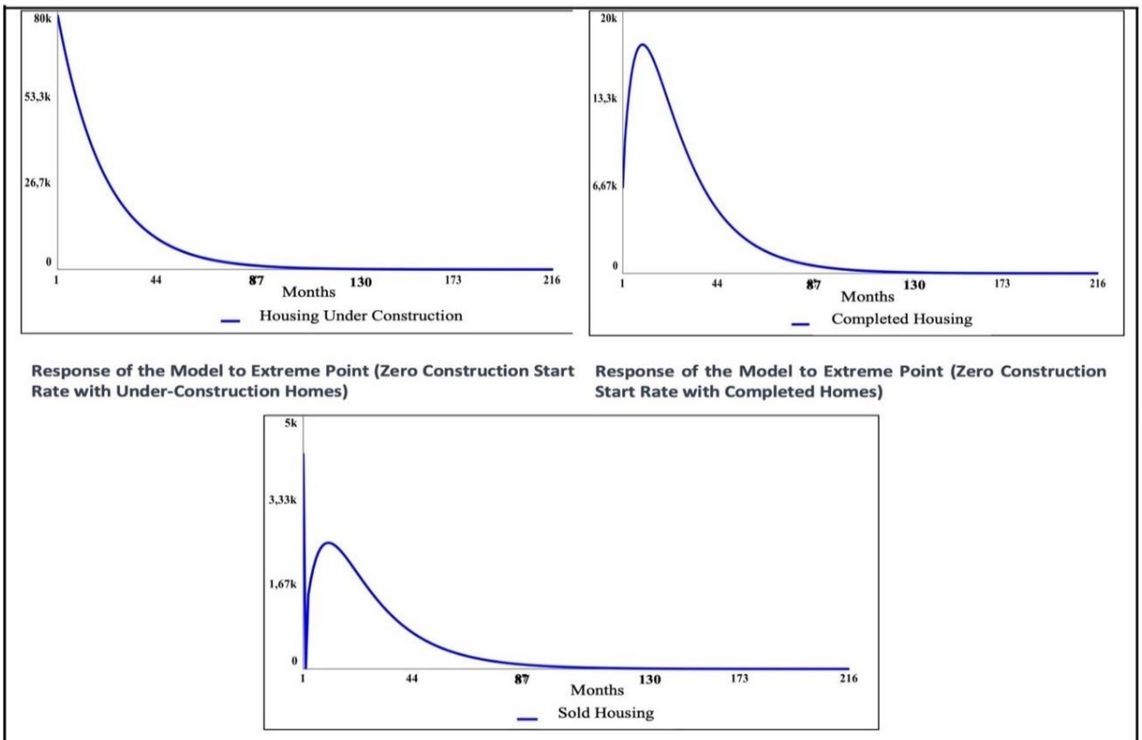
3.2.2. Behavioral Tests

Unlike standard statistical tests, in system dynamics models, assumptions such as normality, independence, and stationarity are not sought to test behavioral validity. Therefore, standard hypothesis tests like t-tests, F-tests, and χ^2 tests are not used (Söyler, 2006). Due to the dynamic nature of simulation, tests in system dynamics models differ from classical statistical methods. For instance, the limited usefulness and sometimes misleading nature of t-tests in such studies have been demonstrated in many works (Mass & Senge, 1978; Shreckengost, 1985). On the other hand, statistical tools such as comparing simulated and actual values in terms of mean, standard deviation, and trends can be employed in system dynamics models. While behavior-related tests are less technical, they tend to increase confidence in the model more for many users compared to structural tests (Shreckengost, 1985). The Ankara housing market system dynamics model has been behaviorally tested through outlier tests, partial tests, and behavior repetition tests (Tursun, 2023).

Outlier test: Ensuring that the model works smoothly at extreme values (outliers) increases the confidence level for the model. Tests conducted at outliers can also reveal structural issues with the model and incorrect parameters (Shreckengost, 1985). The ability of the model to function at outliers reflects both the validity of behavior and the significance of equations at extreme points (Sterman, 2000). In the developed Ankara housing market system dynamics model, outlier points have been tested, and it has been determined that the model's behavior exhibits the expected response at outliers. For instance, the scenario of an inactivity rate of zero has been tested, and the behavior of the "under construction housing" variable has been controlled. When the extreme point for starting construction rate is set to zero, the model's response has been tested in terms of completed and sold housing units, and the expected response has been observed (Figure 5).

Similarly, the extreme points of other variables in the model were tested, and the model's responses were examined. It was observed that the model's behavior exhibited the expected response at all extreme points. Thus, it can be concluded that the extreme value test for behavior was successfully conducted for the developed Ankara housing market system dynamics model (Tursun, 2023).

Figure 5. Example of an Outlier Test



Response of the Model to Extreme Point (Zero Construction Start Rate with Under-Construction Homes)

Response of the Model to Extreme Point (Zero Construction Start Rate with Completed Homes)

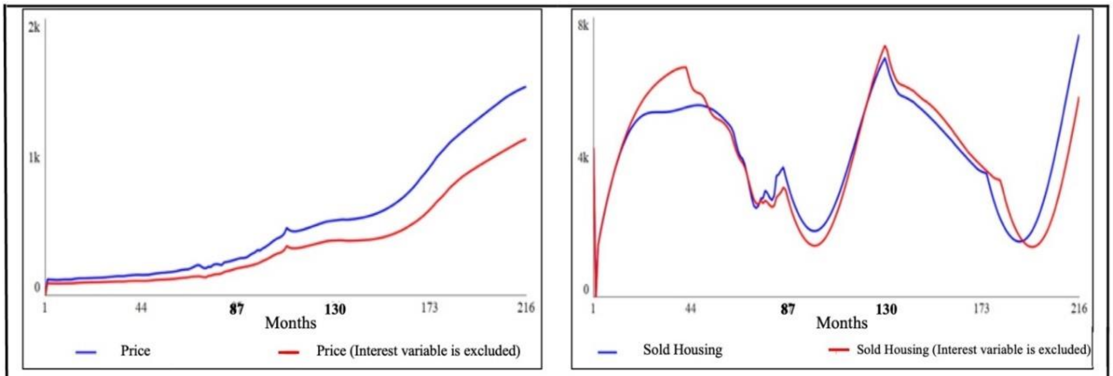
Response of the Model to Extreme Point (Zero Construction Start Rate with Sold Homes)

Source: Tursun (2023).

Partial Test: Partial testing refers to the examination of specific portions of the developed system dynamics model by considering only certain aspects of the system. Partial testing can involve the interruption of certain feedback loops or the exclusion of specific variables from the model. The aim of partial testing is to prevent confusion and improve the comprehension of the model's behavior by disregarding the other parts of the model (Kapourani & Kapmeier, 2017). In the developed Ankara housing market system dynamics model, various partial tests were performed to assess the behavior of the model. For instance, different scenarios were tested by removing interest-related data and loops from the model section, and the behavior of the price variable was examined for both cases (Tursun, 2023). Despite being an external input, it was observed that interest has a significant impact on the price variable (Figure 6). In general, it was observed that in both scenarios, the price exhibited an increasing trend.

The behavior of the remaining portion of the model concerning the variable "number of sold houses" was examined by removing all data related to interest rates. It was observed that when the interest variable was excluded from the model, the behavior of the "number of sold houses" variable exhibited a similar pattern to a large extent. However, it was also evident that the interest variable affects the model's behavior and should not be excluded from the variables considered (Figure 6). Considering the impact of the interest variable on the price, it can be inferred that interest is generally an influential factor in the housing market. It can be concluded in general that interest is an influential variable on the housing market, considering the effect of the interest variable on the price. By applying partial tests to various components of the system dynamics model created for the Ankara housing market, the behavior of the model was examined, and the confidence in the model was reinforced through these partial tests (Tursun, 2023).

Figure 6. Example of Partial Test



Model partial test (price and interest variable)

Model partial test (sold housing and interest variable)

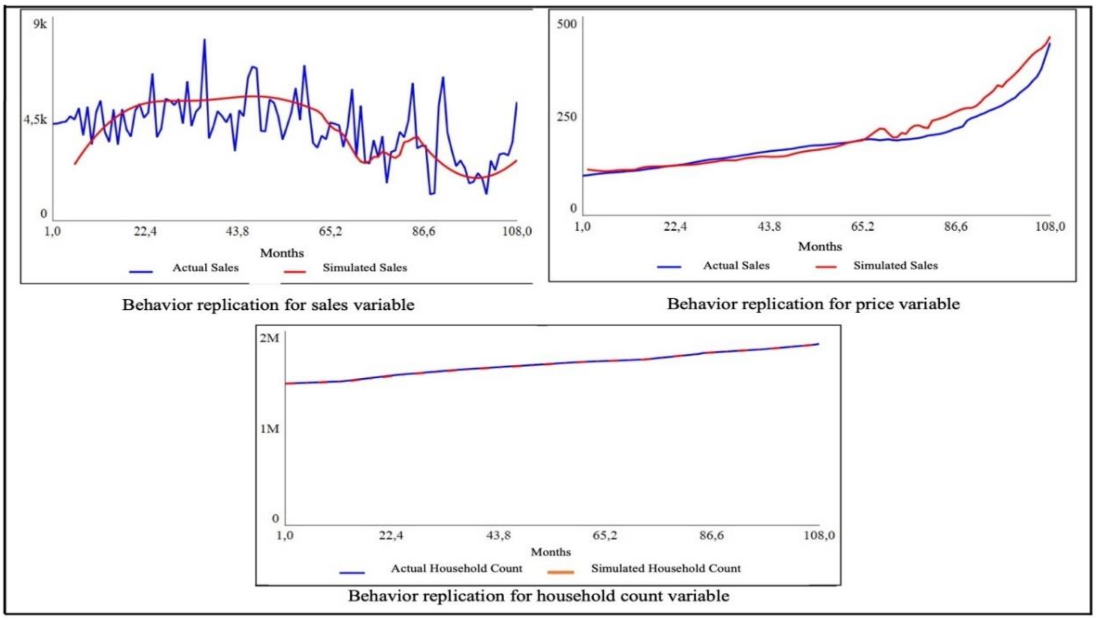
Source: Tursun (2023).

Behavior Replication Test: It involves comparing the simulation data generated by the created system dynamics model with the observed values to check whether the model reproduces the observed behavior. The alignment between the generated simulation data and the observed data is considered a crucial step in verifying that the model accurately predicts the relationships between variables and realistically depicts market data (Kapourani & Kapmeier, 2017).

The behavior of the data generated by the Ankara housing market system dynamics model, which is based on the number of newly sold residential properties within the boundaries of Ankara province between 2013 and 2021, was compared with the simulated data generated by the model for the same period (Figure 7). When the historical data is analyzed, it is seen that the highest and lowest number of house sales on a monthly basis was 8031 and 1156 units, respectively, with an arithmetic average of 4110. On the other hand, when the number of house sales in the same time interval is predicted by the system dynamics model, it is determined that the highest monthly sales were 5497 units and the lowest 1888 units and the arithmetic average was 4031. In the comparison, it was observed that the model's behavior intersected with historical data at many points, exhibited oscillation within the range of observed values during the specified period, and thus demonstrated a consistent behavior with past data. Behavior replication tests can be conducted whenever historical time series data is used in the model. In the Ankara housing market system dynamics model, behavior replication tests were conducted not only for the sales variable but also for the price and household count variables, and the simulated data was compared with historical data. It was observed that the price variable exhibited a behavior consistent with the historical data. The household count variable's historical data appeared to follow an almost linear trend (Tursun, 2023). It was determined that the data obtained through model simulation closely overlapped historical data and exhibited consistent behavior (Figure 7).

When evaluating the alignment of the values generated by the model with historical data in the behavior replication test, the purpose of the study should always be taken into consideration. It should be noted that historical data may not always exhibit perfect development according to certain rules. Therefore, the degree of alignment, parallelism, or compatibility between the simulated results generated by the model and historical data should be assessed based on the goals of the study (Tursun, 2023).

Figure 7. Behavior Replication Test



Source: Tursun (2023).

Structural and behavioral validity must be ensured in order to use the model created to examine the real system with confidence. The compatibility of the model structure with the real system structure is referred to as structural validity, and the model's production of acceptable behavioral outputs is referred to as behavioral validity. As a result of structural and behavioral tests, it was observed that the system dynamics model created for the examination of the Ankara housing market adequately described the real system. Moreover, it was revealed that all factors presented in the model were also present in the actual system, the defined variables were dimensionally consistent and quantitative data were obtained from official institutions, and qualitative data were grounded in expert opinions and literature. The model exhibited expected responses at extreme points (outliers), partial tests were conducted before running the model as a whole to conduct examinations and comparisons, and finally, the behavior of the model was compared with historical data from the specified time period. The alignment of behavior was confirmed to be achieved pursuant to the purpose of the study. Through these structural and behavioral tests, it was concluded that the system dynamics model adequately represents the Ankara housing market and can be confidently used (Tursun, 2023).

3.3. Model Results of Housing Market System Dynamics

The validity of the system dynamics model created for the examination of the Ankara housing market has been tested through structural and behavioral tests and it has been determined that the model adequately represents the real system, and as a result, it can be confidently utilized for the conducted research (Tursun, 2023).

3.3.1. Running the Model in Baseline Scenario

Potential developments for the period 2022 - 2030 have been determined for household count, construction cost index (CCI), and mortgage interest rate (MIR) in the created Ankara housing market system dynamics model. After analyzing the changes in historical data for the period 2013 - 2021, assuming that the same trend will continue, suitable functions have been determined to estimate the potential developments related to the data. For instance, when examining the growth rate of household count from historical data, a decrease in the growth rate over the years is observed (Figure 8). Therefore, it is assumed that the trend that emerged in the past years will continue between 2022 and 2030, and the points that make up the historical data graph were fitted with the least squares method (LSM) and using excel as follows:

$$f(x) = -0.000006x + 0.0024$$

With this equation, the data for the period 2022 - 2030 has been calculated (Tursun, 2023).

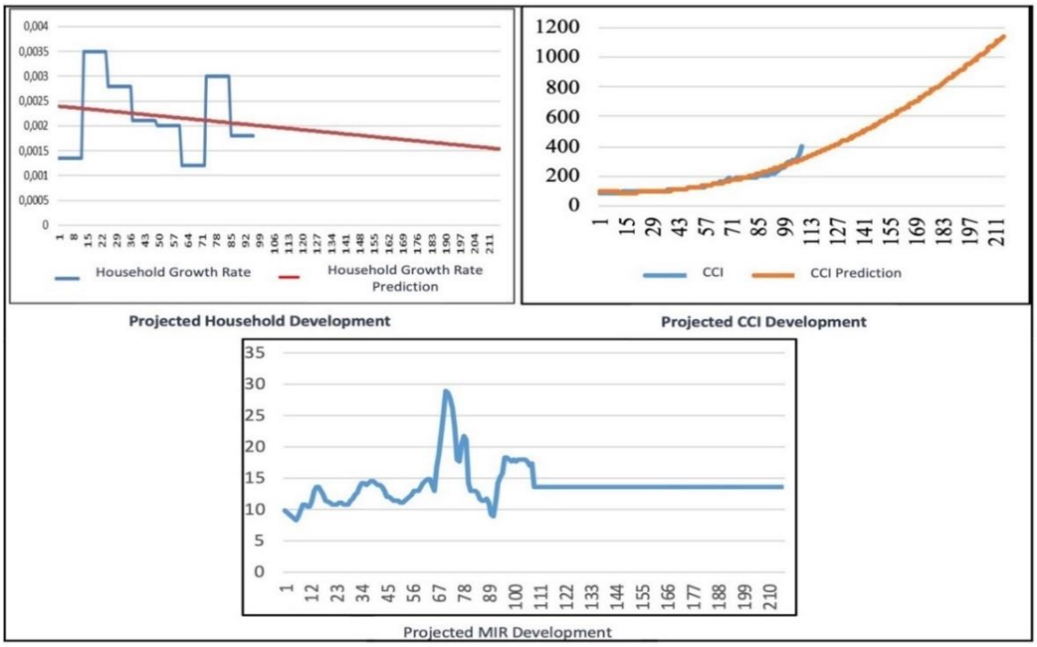
When the data for the period 2013-2021 for the construction cost index (CCI) are analyzed, it is determined with the help of trend analysis and excel that the historical data of the CCI can be represented by a polynomial equation. The polynomial equation calculated using the least squares method is as follows:

$$(x) = 0.0265\,x^2 + 0.8494\,x + 96.481$$

The change in CCI for the period of 2022-2030 has been predicted by using this equation (Figure 8). It is projected that CCI will experience a parabolic increase and reach levels around 1,150 by the year 2030 (Tursun, 2023).

The data for the period of 2013-2021 regarding mortgage interest rate (MIR) has been examined, and it was evident that the historical data exhibited highly fluctuating and irregular patterns. Approximating these data using exponential, logarithmic, or polynomial equations does not seem feasible. Furthermore, due to the nature of MIR, the determining dynamics could be more related to the country's economy and MIR policies rather than the behavior pattern of historical data. For instance, the policies of public banks, such as providing housing loans at lower rates than the normal market level, can restrict the influence of other economic indicators to some extent. Therefore, the data for the period of 2013-2021 has been analyzed, and its average has been calculated as $\bar{X}$ = 13.62%. It is expected that MIR will oscillate around the level of 13.62% during the period of 2022-2030 (Tursun, 2023). Accordingly, for the potential scenario, MIR is considered to be taken as 13.62% (Figure 8).

Figure 8. Projected Development of Variables

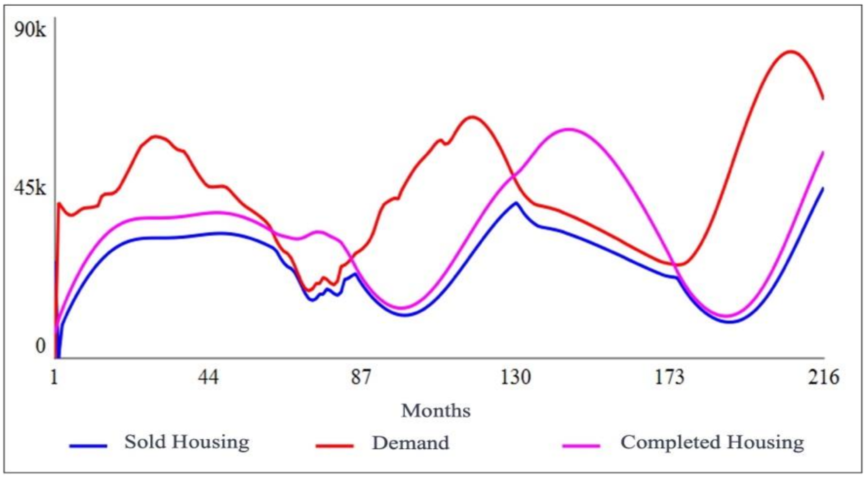


Source: Tursun (2023).

Running the model in the base state reflects the behaviors of variables over the examined time period. Once the base state is established, different scenarios can be simulated and analyzed based on the changes made. The simulations of the dependent variable and some independent variables for the 2013-2030 period in the base model are shown in Figure 9.

The number of newly sold residential properties is projected to increase from 2022 to the 10th month of 2023, reaching monthly sales levels of 6,854 units and after this year, it is expected to decrease again and reach a level of 1,589 units in the 9th month of 2028. By the end of 2030, it is projected to rise again to monthly sales levels of 7,500 units (Tursun, 2023). According to the simulation results, the behaviors of certain independent variables over the examined time period have been compared.

Figure 9. Changes in Certain Variables in Base State



Source: Tursun (2023).

The variables of demand, sold properties, and completed properties exhibit behavior that aligns with theoretical expectations and displays consistent patterns throughout the analyzed time period. Notably, the behavior of completed and sold property variables were in line with increasing or decreasing tendencies in demand for most of the examined period. Moreover, it is observed that completed and sold property numbers follow changes in demand with a certain delay and after an increase in demand, both completed and sold properties show an uptrend, and a decrease in demand is reflected in completed and sold property numbers with a few periods of lag in a similar way (Figure 9). These findings obtained in relation to the dynamics in the housing market and the interplay between these dynamics are consistent with previous academic studies (Öztürk, 2020; Sönmezer & Aytüre, 2019; Tursun, 2023).

3.3.2. Scenario Analysis

In similar research conducted with system dynamics, sensitivity analysis is often carried out before scenario analysis to determine how sensitive the model is to specific parameters and the scenarios are then created based on these findings. The sensitivity analyses of the variables in the system dynamics model of the Ankara housing market were conducted to examine their impact on the number of first-hand houses sold. It is determined that construction cost index and mortgage interest rates are the two parameters with the highest sensitivity, while the number of households is the variable with the highest sensitivity after these two parameters. It can be said that the number of first-hand houses sold is also sensitive to other parameters to a certain extent, but this effect is relatively limited (Tursun, 2022). However, our study focuses on the assumption of shortened construction periods based on the advancements in construction technologies and how housing markets might be affected by this assumption. Therefore, scenarios are directly shaped by variations in construction completion times.

The fact that construction completion times are currently 21 months and that this period is expected to shorten in the future as a result of the development of construction technologies requires alternative scenarios to take shorter periods into consideration. Since the created housing market system dynamics model allows to quickly simulate different values of the variables, many different levels of construction completion times were easily simulated. Considering the volatility of the number of first-hand houses sold as a result of the simulation and the purpose of the study, it was deemed sufficient to compare only three different scenarios. For the first scenario, the baseline level (Currently, the construction completion period is 21 months) of the model was taken while in the second scenario, construction completion times were set at 9 months, and in the third scenario, they were set at 3.5 months. In order to determine these scenarios, the status of the sold housing variable was analyzed according to all levels of the construction completion time variable while the model was in the base case. In order to make a comparison, the two most stable and partially stable states of the sold housing variable were identified and the scenarios were created by determining the corresponding durations. Under these three defined scenarios, simulation results for the sold first-hand property numbers were compared and evaluated. It is essential to note that in all three scenarios used in the study, all variables related to the housing market were taken according to the likely scenario (Scenario-1) and only the construction completion times were modified to define the other two scenarios.

3.3.3. Examination of Model Outputs

In a study conducted with the anticipation that technological advancements in the construction sector would significantly reduce construction completion times, the research focused on the assumption that housing project completion times are currently around 21 months, and this time frame was set as the baseline (base) condition of the model, also referred to as Scenario-1. In scenario-2 and Scenario-3 on the other hand, the case where the construction completion times were 9 months and 3.5 months respectively had been examined, provided that all other variables kept at the baseline condition. The simulation results for the sold first-hand housing units in the Ankara housing market for the period 2022-2030 were obtained for each of these scenarios. The comparative results of all three scenarios are presented in Figure 10, Table 1, and detailed monthly housing sales estimates can be found in Appendix-1.

Table 1. Monthly Sold Housing Units Estimates by Scenarios

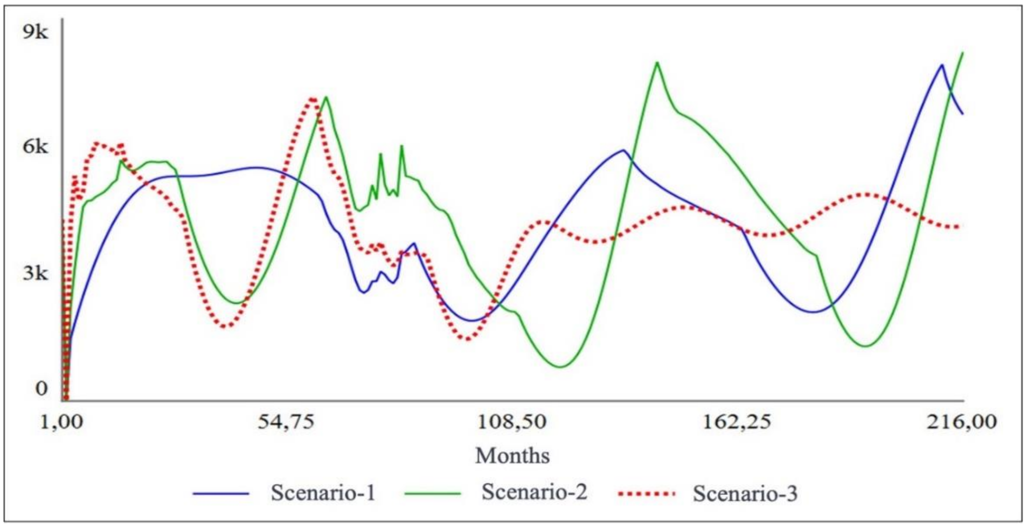
Months	Scenario-1	Scenario-2	Scenario-3
December, 2022	4413	796	4054
December, 2023	5758	3443	3820
December, 2024	5032	7691	4453
December, 2025	4413	6225	4396
December, 2026	3132	4743	3910
December, 2027	2090	3471	4309
December, 2028	3305	1290	4863
December, 2029	6382	3577	4433
December, 2030	6748	8224	4130

When examining the monthly housing unit sales estimates (Appendix-1), it is observed that for Scenario-1, between 2090 and 7929 housing units are predicted to be sold in the Ankara housing market for the period 2022-2030. Under Scenario-1, it was observed that there are significant fluctuations within a wide range of sales numbers based on the estimates of monthly housing unit sales, the range of variation in housing unit sales is 5839 units, with a standard deviation of approximately 1507. Taking into account the assumption of reducing construction completion times to 9 months for Scenario-2, it is estimated that between 796 and 8224 housing units will be sold on a monthly basis. Under Scenario-2, similar to Scenario-1, there is a wide range of fluctuations in housing unit sales, with a variation range of 7427 units and a standard deviation of approximately 2222.

Under Scenario-3, which includes the assumption of reducing construction completion times to 3.5 months, it was observed that the monthly housing unit sales numbers for the period 2022-2030 are observed to vary between 3052 and 4863 units and the range of variation in housing unit sales is 1361 units accordingly, with a standard deviation of 323.5. In comparison to the other two scenarios, Scenario-3 exhibits narrower fluctuations in monthly housing unit sales, with the sales numbers centered around 4246 units, indicating a more predictable housing market situation (Figure 10).

In the study by Özbaş et al. (2014), using a system dynamics approach and Istanbul housing market data, they concluded that reducing construction times and considering the number of housing units under construction when initiating new projects significantly reduced-price fluctuations in the housing market. A similar result is obtained in this study which exhibits that reducing construction completion times can lead to decreased fluctuations in the number of newly sold housing units and result in a more stable and predictable market condition in terms of sales numbers. Therefore, it can be indicated that the findings of this study align with previous academic research.

Figure 10. Comparison of Sold Housing Numbers According to Scenarios



4. Conclusion

Technological advancements that are experienced in various aspects of life and almost shape people's lifestyles are bound to have effects on real estate markets as well. Especially in the construction sector, it is evident that technological developments will lead to shortened construction completion times. In the conducted study, the potential impacts of the reduction in construction completion times based on technological advancements on the real estate sector have been revealed.

In the system dynamics model of the Ankara housing market created within the scope of the study and focusing on construction completion times, three different scenarios were considered, each assuming that housing construction could be completed in 21 months, 9 months, and 3.5 months. Under Scenario-3, which includes the assumption of reducing construction completion times to 3.5 months, it was determined that the range of variation in housing unit sales is 1361 units, with a standard deviation of 323.5. In comparison to the other two scenarios, when construction completion times are reduced to 3.5 months, it was found that fluctuations in monthly housing unit sales would occur within a much narrower range, approximately around 4246 units per month.

As can be seen in the case of the research on the Ankara housing market, the system dynamics method provides the opportunity to look at the subject under investigation from a broad perspective and to conduct research with a holistic approach. The system dynamics model provides research opportunities such as comparing many different alternative situations, determining the policies necessary to achieve the desired market conditions, or which dynamics should be intervened in and how. System dynamics models, which are based on system thinking, emphasize that data alone cannot be sufficient to make sense in complex systems and that processes, not numbers, should be the focus of research in order to address problems from a broad perspective. The system dynamics approach provides support for decision-makers' decisions in a cost-effective and risk-free manner and fulfills the function of a decision support system in this respect.

In order to implement housing projects in real estate investments successfully, the housing market must be predictable. Moreover, predictable market conditions are of great importance for all stakeholders in the housing sector, including construction companies, developers, buyers in the housing market, financiers, infrastructure providers, as well as municipalities and the overall national economy. The ability to build houses in shorter periods of time, even down to as little as 3.5 months due to advances in construction technologies, offers an alternative to policies that usually rely on highly sensitive variables such as construction costs, loan interest rates, and population to achieve predictable market conditions. The predictability of the market allows public institutions to plan infrastructure and superstructure services such as roads, water, sewerage, electricity, natural gas, communication, transportation, procurement of necessary urban land and zoning applications to be carried out successfully. It will also reduce the investment risk of contractors and construction firms that constitute the supply side of the housing market. When the supply and demand ratios in the housing market approach an equilibrium point, this will contribute to the number of houses sold and price stability, and reduce the uncertainties affecting the purchasing decisions of house buyers. Nevertheless, as the housing market represents a complex system, employing the system dynamics approach - an effective method for analyzing complex systems - can enable the development of policies for achieving predictable market conditions using various housing market variables.

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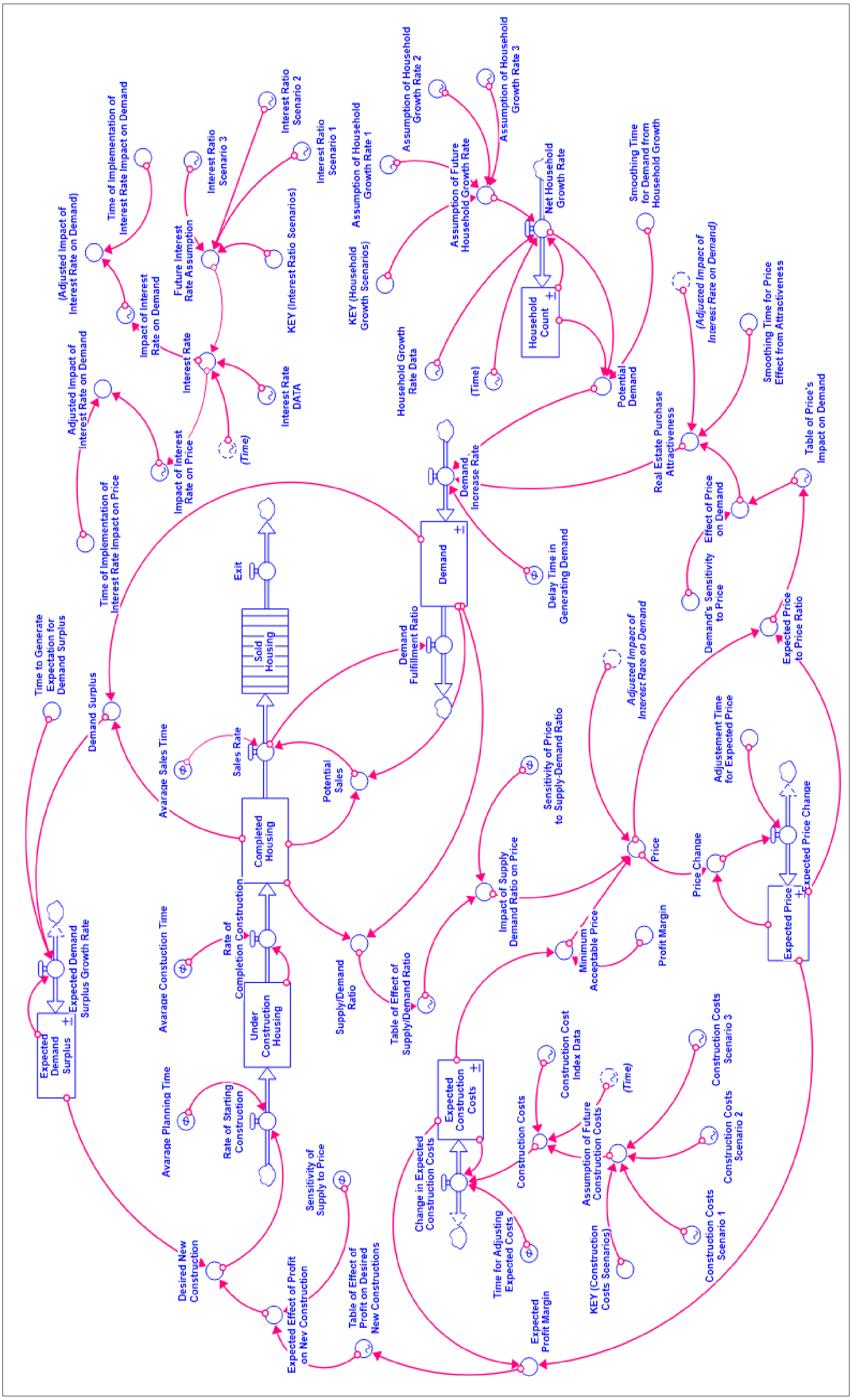
Appendixes

Appendix 1: Monthly Home Sales Forecasts According to Scenarios

Month/Year	Scenario-1	Scenario-2	Scenario-3	Month/Year	Scenario-1	Scenario-2	Scenario-3
Jan.2022	2754	2101	3502	Jul-2026	4070	5412	4051
Feb-2022	2902	2004	3695	Aug-2026	3888	5280	4011
Mar-2022	3054	1776	3863	Sep-2026	3677	5143	3976
Apr-2022	3210	1576	4001	Oct-2026	3481	5005	3947
May-2022	3367	1400	4107	Nov-2026	3300	4867	3925
Jun-2022	3523	1246	4178	Dec-2026	3132	4743	3910
Jul-2022	3678	1112	4214	Jan.2027	2976	4621	3903
Aug-2022	3831	1000	4220	Feb-2027	2832	4500	3904
Sep-2022	3981	910	4201	Mar-2027	2700	4380	3913
Oct-2022	4128	845	4163	Apr-2027	2580	4263	3931
Nov-2022	4272	806	4112	May-2027	2472	4148	3956
Dec-2022	4413	796	4054	Jun-2027	2376	4037	3989
Jan.2023	4552	819	3995	Jul-2027	2293	3929	4029
Feb-2023	4687	875	3937	Aug-2027	2223	3824	4075
Mar-2023	4819	967	3883	Sep-2027	2168	3722	4127
Apr-2023	4947	1097	3837	Oct-2027	2126	3612	4184
May-2023	5071	1265	3799	Nov-2027	2100	3530	4245
Jun-2023	5190	1472	3771	Dec-2027	2090	3471	4309
Jul-2023	5303	1716	3754	Jan.2028	2095	3422	4375
Aug-2023	5410	1997	3747	Feb-2028	2118	3076	4441
Sep-2023	5510	2314	3750	Mar-2028	2158	2751	4506
Oct-2023	5602	2662	3764	Apr-2028	2215	2464	4569
Nov-2023	5685	3040	3788	May-2028	2290	2211	4628
Dec-2023	5758	3443	3820	Jun-2028	2383	1988	4683
Jan.2024	5820	3867	3860	Jul-2028	2493	1796	4732
Feb-2024	5872	4307	3907	Aug-2028	2622	1633	4774
Mar.24	5911	4757	3959	Sep-2028	2768	1501	4809
Apr-2024	5808	5211	4015	Oct-2028	2931	1399	4835
May.24	5654	5664	4073	Nov-2028	3110	1328	4853
Jun-2024	5524	6109	4133	Dec-2028	3305	1290	4863
Jul-2024	5416	6539	4193	Jan.2029	3515	1287	4863
Aug-2024	5323	6948	4252	Feb-2029	3739	1318	4856
Sep-2024	5242	7329	4309	Mar-2029	3975	1385	4839
Oct-2024	5171	7677	4362	Apr-2029	4222	1488	4815
Nov-2024	5106	7986	4410	May-2029	4478	1629	4784
Dec-2024	5032	7691	4453	Jun-2029	4743	1806	4746
Jan.2025	4967	7366	4490	Jul-2029	5013	2020	4703
Feb-2025	4908	7114	4520	Aug-2029	5288	2269	4654
Mar-2025	4853	6915	4542	Sep-2029	5564	2552	4602
Apr-2025	4800	6796	4557	Oct-2029	5840	2866	4547
May-2025	4748	6744	4564	Nov-2029	6113	3208	4490
Jun-2025	4700	6697	4562	Dec-2029	6382	3577	4433
Jul-2025	4652	6642	4552	Jan.2030	6643	3967	4377
Aug-2025	4602	6577	4534	Feb-2030	6895	4374	4323
Sep-2025	4553	6501	4509	Mar-2030	7134	4794	4273
Oct-2025	4506	6417	4477	Apr-2030	7360	5221	4227
Nov-2025	4459	6324	4439	May-2030	7569	5651	4187
Dec-2025	4413	6225	4396	Jun-2030	7760	6076	4154
Jan.2026	4366	6119	4349	Jul-2030	7929	6493	4128
Feb-2026	4321	6009	4299	Aug-2030	7575	6893	4111
Mar-2026	4275	5901	4248	Sep-2030	7294	7272	4102
Apr-2026	4230	5797	4196	Oct-2030	7070	7624	4102
May-2026	4173	5663	4145	Nov-2030	6892	7943	4112
Jun-2026	4120	5544	4097	Dec-2030	6748	8224	4130

Appendix 2: Ankara Housing Market System Dynamics Model (Full Model) (Tursun, 2022)



Appendix 3: Equations Used in the Model

No	Type	Variables	Equation	Properties	Units	Annotation
(1)		Rate_of_Starting_Construction	MAX((Desired_New_Construction/Avarage_Planning_Time); 0)		House/Month	UNIFLOW
(2)		Under_Construction_Housing (t)	Under_Construction_Housing(t - dt) + (Rate_of_Starting_Construction - Rate_of_Completion_Construction) * dt	INITUnder_Construction_Housing = 79092	House	NON-NEGATIVE
(3)		Rate_of_Completion_Construction	Under_Construction_Housing/Avarage_Constuction_Time		House/Month	UNIFLOW
(4)		Completed_Housing(t)	Completed_Housing(t - dt) + (Rate_of_Completion_Construction - Sales_Rate) * dt	INIT Completed_Housing = 6525	House	NON-NEGATIVE
(5)		Sales_Rate	Potential_Sales/Avarage_Sales_Time		House/Month	UNIFLOW
(6)		"(Adjusted_Impact_of_Interest_Rate_on_Demand)"	Impact_of_Interest_Rate_on_Demand/Time_of_Implementation_of_Interest_Rate_Impact_on_Demand			
(7)		Net_Household_Growth_Rate	IF "(Time)"<109 THEN (Household_Growth_Rate_Data*Household_Count) ELSE (Assumption_of_Future_Household_Growth_Rate*Household_Count)		Household/ Month	UNIFLOW
(8)		Potential_Demand	(Net_Household_Growth_Rate/Smoothing_Time_for_Demand_from_Household_Growth)+((Household_Count/100)/12)			
(9)		Demand_Increase_Rate	(Real_Estate_Purchase_Attractiveness*Potential_Demand)/Delay_Time_in_Generating_Demand			UNIFLOW
(10)		Construction_Costs	IF "(Time)"<109 THEN Construction_Cost_Index_Data ELSE Assumption_of_Future_Construction_Costs			
(11)		Change_in_Expected_Construction_Costs	(Construction_Costs-Expected_Construction_Costs)/Time_for_Adjusting_Expected_Costs			
(12)		Expected_Price_to_Price_Ratio	Expected_Price/Price			
(13)		Effect_of_Price_on_Demand	(Table_of_Price's_Impact_on_Demand)^Demand's_Sensitivity_to_Price			
(14)		Table_of_Price's_Impact_on_Demand	GRAPH(Expected_Price_to_Price_Ratio) Points: (0,030, 0,0431849163208), ...**(*)**			
(15)		Expected_Profit_Margin	((Expected_Price-Expected_Construction_Costs)/Expected_Price			
(16)		Expected_Effect_of_Profit_on_Nev_Construction	(Table_of_Effect_of_Profit_on_Desired_New_Constructions)^Sensitivity_of_Supply_to_Price			
(17)		Demand_Surplus	MAX((Demand-Completed_Housing); 0)			
(18)		Expected_Demand_Surplus_Growth_Rate	(Demand_Surplus-Expected_Demand_Surplus)/Time_to_Generate_Expectation_for_Demand_Surplus		House/Month	
(19)		Expected_Price(t)	Expected_Price(t - dt) + (Expected_Price_Change) * dt	INIT Expected_Price = 111		

(*) All of the data used for this variable are shown in referance (Tursun, 2022).

No	Type	Variables	Equation	Properties	Units	Annotation
(20)		Expected_Construction_Costs(t)	Expected_Construction_Costs(t - dt) + (Change_in_Expected_Construction_Costs) * dt	INIT Expected_Construction_Costs = 71		
(21)		Expected_Demand_Surplus(t)	Beklenen_TalepExpected_Demand_Surplus(t - dt) + (Expected_Demand_Surplus_Growth_Rate) * dt	INIT Expected_Demand_Surplus = 79101-53624	House	
(22)		Household_Count(t)	Household_Count(t - dt) + (Net_Household_Growth_Rate) * dt	INITHouseholdCount=1460454	Household	
(23)		Sold_Housing(t)	Sold_Housing(t - dt) + (Sales_Rate - Exit) * dt	Init Sold_Housing = 4278 Transit Time = 1 Continuous Accept Multiple Batches	House	CONVEYOR
(24)		Demand(t)	Demand(t - dt) + (Demand_Increase_Rate - Demand_Fulfillment_Ratio) * dt	INIT Demand = 1		
(25)		Expected_Price_Change	Price_Change/Adjustement_Time_for_Expected_Price			
(26)		Exit	CONVEYOR OUTFLOW		House/Month	
(27)		Demand_Fulfillment_Ratio	SatışSales_Rate			UNIFLOW
(28)		"KEY_(Interest_Ratio_Scenarios)"	1			
(29)		"KEY_(Household_Growth_Scenarios)"	1		dmnl	
(30)		"KEY_(Interest_Ratio_Scenarios)"	1		dmnl	
(31)		Impact_of_Supply_Demand_Ratio_on_Price	"Table_of_Effect_of_Supply/Demand_Ratio"^"Sensitivity_of_Price_to_Supply-Demand_Ratio"			
(32)		"Table_of_Effect_of_Supply/Demand_Ratio"	GRAPH("Supply/Demand_Ratio") Points: (0,000, 0,993976434168), ...**(*)**			
(33)		"Supply/Demand_Ratio"	Completed_Housing/Demand			
(34)		Sensitivity_of_Supply_to_Price	0,005			
(35)		Desired_New_Construction	Expected_Effect_of_Profit_on_Nev_Construction*(Expected_Demand_Surplus)			
(36)		Minimum_Acceptable_Price	Expected_Construction_Costs*(1+Profit_Margin)			
(37)		Time_for_Adjusting_Expected_Costs	3		Month	
(38)		Adjustement_Time_for_Expected_Price	3		Month	

(*) All of the data used for this variable are shown in referance (Tursun, 2022).

No	Type	Variables	Equation	Properties	Units	Annotation
(39)	○	Interest_Rate	IF "(Time)"<109 THEN Interest_Rate_DATA ELSE Future_Interest_Rate_Assumption			
(40)	○	Interest_Rate_DATA	GRAPH(TIME) Points: (1,0, 9,775), ... **(*)**			
(41)	○	Interest_Ratio_Scenario_1	GRAPH(TIME) Points: (109,0, 13,62), ... **(*)**			
(42)	○	Interest_Ratio_Scenario_2	GRAPH(TIME) Points: (109,0, 8,3), ... **(*)**			
(43)	○	Interest_Ratio_Scenario_3	GRAPH(TIME) Points: (109,0, 28,95), ... **(*)**			
(44)	○	Impact_of_Interest_Rate_on_Price	GRAPH(Faiz_Oranı) Points: (0,00, 0,6000), ... **(*)**		dmnl	
(45)	○	Time_of_Implementation_of_Interest_Rate_Impact_on_Price	0,5			
(46)	○	Impact_of_Interest_Rate_on_Demand	GRAPH(Faiz_Oranı) Points: (0,00, 0,995315004353), ... **(*)**		dmnl	
(47)	○	"(Adjusted_Impact_of_Interest_Rate_on_Demand)"	Impact_of_Interest_Rate_on_Demand/Time_of_Implementation_of_Interest_Rate_Impact_on_Demand			
(48)	○	Time_of_Implementation_of_Interest_Rate_Impact_on_Demand	2			
(49)	○	Price	Minimum_Acceptable_Price*Impact_of_Supply_Demand_Ratio_on_Price*Adjusted_Impact_of_Interest_Rate_on_Demand			
(50)	○	Price_Change	Price-Expected_Price			
(51)	○	Smoothing_Time_for_Price_Effect_from_Attractiveness	0,1		Year	
(52)	○	"Sensitivity_of_Price_to_Supply-Demand_Ratio"	3			
(53)	○	Real_Estate_Purchase_Attractiveness	("(Adjusted_Impact_of_Interest_Rate_on_Demand)"*Effect_of_Price_on_Demand)/Smoothing_Time_for_Price_Effect_from_Attractiveness			
(54)	○	Future_Interest_Rate_Assumption	IF "Anahtar_(Faiz_Oranı_Senaryoları)"=1 THEN FOS_1 ELSE IF "Anahtar_(Faiz_Oranı_Senaryoları)"=2 THEN FOS_2 ELSE FOS_3			
(55)	○	Gelecekteki_Hane_Sayısı_Büyüme_Oranı_Varsayımı	IF "ANAHTAR_(Hane_Sayısı_Büyüme_Senaryoları)"=1 THEN HSBOV_1 ELSE IF "ANAHTAR_(Hane_Sayısı_ Büyüme_Senaryoları)"=2 THEN HSBOV_2 ELSE HSBOV_3			
(56)	○	Gelecekteki_İnşaat_Maliyeti_Varsayımı	IF "KEY_(Interest_Ratio_Scenarios)"=1 THEN Interest_Ratio_Scenario_1 ELSE IF "KEY_(Interest_Ratio_Scenarios)"=2 THEN Interest_Ratio_Scenario_2 ELSE Interest_Ratio_Scenario_3			

(*) All of the data used for this variable are shown in referance (Tursun, 2022).

No	Type	Variables	Equation	Properties	Units	Annotation
(57)	○	Household_Growth_Rate_Data	GRAPH(TIME) Points: (1,00, 0,00135), ... **(*)**		1/Year	
(58)	○	Assumption_of_Household_Growth_Rate_1	GRAPH(TIME) Points: (109,0, 0,0017), ... **(*)**		1/Year	
(59)	○	Assumption_of_Household_Growth_Rate_2	GRAPH(TIME) Points: (109, 0,002),... **(*)**		1/Year	
(60)	○	Assumption_of_Household_Growth_Rate_3	GRAPH(TIME) Points: (109, 0,002), ... **(*)**			
(61)	○	Smoothing_Time_for_Demand_from_Household_Growth	3,5		Year	
(62)	○	Construction_Cost_Index_Data	GRAPH(TIME) Points: (1,00, 67,0), ... **(*)**			
(63)	○	Construction_Costs_Scenario_1	GRAPH(TIME) Points: (109,0, 259,81), ... **(*)**			
(64)	○	Construction_Costs_Scenario_2	GRAPH(TIME) Points: (109,009345794, 330,92897011), ... **(*)**			
(65)	○	Construction_Costs_Scenario_3	GRAPH(TIME) Points: (109,009345794, 340,795234953), ... **(*)**			
(66)	○	Profit_Margin	0,30			
(67)	○	Table_of_Effect_of_Profit_on_Desired_New_Constructions	GRAPH(Expected_Profit_Margin) Points:(-0,500, 0,0133857018486), ... **(*)**			
(68)	○	Avarage_Planning_Time	3		Month	
(69)	○	Avarage_Sales_Time	7		Month	
(70)	○	Avarage_Constuction_Time	21		Month	
(71)	○	Potential_Sales	MAX(MIN((Demand); (Completed_Housing)); 0)		House	
(72)	○	Demand's_Sensitivity_to_Price	3			
(73)	○	Time_to_Generate_Expectation_for_Demand_Surplus	11		Month	
(74)	○	Delay_Time_in_Generating_Demand	1,5		Month	
(75)	○	"(Time)"	GRAPH(TIME) Points: (1,0, 1,0), ... **(*)**			

(*) All of the data used for this variable are shown in referance (Tursun, 2022).

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