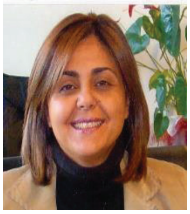
Analyzing the Residential Energy Efficiency Concept through Systemic Feedback Approach



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Abstract: *Construction projects include several dynamic features consisting feedback structures, time lag and nonlinearity in cause-effect relationships among project fundamentals. These aspects cause projects to act in complex conditions, which are incomprehensible, unforeseen and difficult to manage. Therefore, during project processes, development of project performance acquires creating mental models and decision heuristics. This article seeks to develop our knowledge capacity about relationships of project parameters in the context of building energy efficiency concept. The objective of the study is to provide a feedback mechanism based on building structure, retrofitting action and also end-user behavior. At the end of the paper, suggested feedback model is analyzed and general behavior of the system is evaluated.*

Keywords: *System dynamics*, *systemic feedback approach, residential energy efficiency*

Konut Enerji Verimliliği Kavramının Sistemik Geribildirim Yaklaşımıyla İncelenmesi

Özet: *Yapım projelerinin temelinde, geri bildirim mekanizmaları, zaman gecikmeleri ve sebep-sonuç ilişkilerinde lineer olmayan çeşitli dinamik yapılar yer almaktadır. Bu yapılar, projelerin anlaşılmaz, öngörülemeyen, yönetilmesi güç, karmaşık bir hal almasına neden olur. Bu sebeple, proje performansının geliştirilmesi için proje süresince, zihinsel modeller ve karar verme mekanizmaları buluşsal yöntemlerle desteklenmektedir. Bu çalışma, bina enerji verimliliği kavramını temel alarak proje değişkenlerinin ilişkilerindeki bilgi kapasitesini geliştirmeyi amaçlamaktadır. Çalışmada aynı zamanda, bina yapısına, yenileme faaliyetine ve nihai kullanıcı davranışına dayalı bir geri bildirim mekanizması oluşturulmaktadır. Araştırmanın sonucunda, önerilen geribildirim modeli incelenmekte ve sistemin genel davranışı değerlendirilmektedir.*

Anahtar Kelimeler: *Sistem dinamikleri, sistemik geribildirim yaklaşımı, konut enerji verimliliği*

1. INTRODUCTION

Construction projects require overall planning, organization and control of the works from beginning to completion. Demands and complexity increase in both big and small scaled building projects. In the long run, these issues cause some changes on time, scope and the goal, which are the keystones of a project, furthermore it brings back the alterations of project performance and cost. For instance; in any process of a project, demands of the client regarding the design of the project create delays besides budget exceeding.

Over the years, need and desire find themselves a place in a sustainable context and its sophistication in construction industry. With sustainability approach and energy efficiency concepts, construction industry has faced with the different dimensions of the building sector. Due to the two main considerations, sustainability is strongly connected to the construction sector. First one, building trade is more effective on the environment when compared to the other human actions; building and construction sector uses the 25-40% of the total energy in OECD (Organization for Economic Cooperation and Development) countries and also 'built environment' leads to 40% of the world greenhouse emissions [1]. Second consideration is the leaning of people to transform their houses to more comfortable and healthy places. However, arising complexity and need to construct new sustainable buildings or to convert the old buildings to new ones started to bring risks, disturbances, changes, excessive energy consumption, delays and cost overruns in tow.

Retrofitting is a crucial part of both meeting emission decrease purpose and replying the user's need. It also supports the energy use in a more effective way and generates sustainable lifestyles [2]. As in all construction projects, in retrofitting ones; feedback, time delays and nonlinear relations affect the project performance in a reducing way and complicate the management of the project [3]. Moreover, the prediction of future energy concept and cost savings become difficult.

Construction projects include several dynamic features such as feedback structures, time lag and nonlinearity in cause-effect relationships among project fundamentals. These aspects cause projects to act in complex conditions, which are incomprehensible, unforeseen and difficult to manage [4] .

The effects of dynamic project characteristics can't be understood and run efficiently by managers. So, during project processes, the development of project performance acquires creating mental models and decision heuristics.

This research seeks to develop the understanding of our knowledge capacity about the relationships of project parameters within the frame of building energy efficiency. In the study, system dynamics (SD) modeling technique supporting a holistic view of arrangement is applied for the understanding [5] of a residential building construction project.

2. LITERATURE REVIEW

2.1. New Building Construction and Retrofitting Project Characteristics

Budget and time define the main characteristics of construction projects. These interdependent components in fact affect each other during project processes. For example, a decrease in budget causes the slowdown of project completion [6].

In the literature study of Favié and Maas [7] the characteristics of building projects were defined and some of the most common characteristics of the projects were determined respectively, to be: Project complexity, size (floor area, number of stories, etc.), type (residential, office, public building, building retrofitting, etc.), political, legal and economic conditions, completion time of the project, contract form and liability division, project location and environmental concerns, technological improvement level, lifespan of project, project value and quality etc.

Since new building construction projects have more economic and environmental restraints, retrofitting projects has become crucial. Quality increase and cost decrease, replying environmental requirements and integration of new technology with old structure are some of the retrofit projects justifications.

According to Sanvido and Riggs [8]: “A retrofit project is the modification or conversion (not a complete replacement) of an existing process, facility, or structure. Such modification may involve additions, deletions, rearrangements or not-in-kind replacements of one or more parts of the facility.”

The retrofit projects have many limitations for stakeholders as different from grass roots projects. Owners, constructors, operators and designers are not free to realize whatever they want to do. However, good management strategies can overcome the possible budget, schedule, mitigation problems and such. Below, the constraints are explained in terms of retrofit projects.

Information is limited in retrofit projects. Buildings can be old and also scope of project, used materials and drawings cannot be clear.

Time is another constrain that becomes restricted until a plant is shut down. Since the time is affected by all factors, it is a crucial parameter that should be managed carefully.

Space is the necessary area for operations in retrofit projects, so it is one of the most important constraints. In an existing structure, while retrofitting implementations, laydown areas, narrow accesses and area for the equipment and rigging can cause problems.

Environment is constrained; because air temperature, working with risky materials, elevated noise and vibration affects retrofitting project process and completion [8].

2.2. Building Energy Efficiency Concept

Building energy efficiency is the scope that the energy use per square meter of floor area of the building meets the established energy consumption criterions for that specific building type under identified climatic conditions. Building energy consumption benchmarks are seen as symbolic values for common building forms against that an actual performance of the building can be analyzed.

Building energy consumption standards are obtained from the analyses of different building types within a certain country. Median level of performance which is taken from all buildings in specific category is accepted as typical benchmark. The benchmarks differentiate according to country and building type. They are used in HVAC applications, lighting and electrical implementations. Heat loss measure called “U-Value” is also one of the ways to define the building energy performance. U-Value is defined as the transfer rate of heat (thermal transmittance) through one side to another which becomes temperature difference. The measurement unit of U-Value is W/m^2K. The lower the U-Value is, the better the energy efficiency becomes. Since the openings in a structure gain or lose heat, the amount of required energy increases for heating and cooling. Therefore, most building codes arrange minimum standards for the energy efficiency of doors, windows, walls and skylights.

In countries, the demand for energy services is increasing day by day, so the governments are in cooperation with end-users to meet growing demand and to extend the generation capacity. With energy efficiency investments, lots of benefits are provided in buildings. For example; energy use is reduced by balancing space heating/cooling and water heating activities; household appliances, office machinery and lighting tools are adapted for effective electricity use; the value of property increases, required capital outlay and stand-by systems' costs decrease; depending on all of these benefits, end-user comfort rises considerably [9].

Looking at the building as a whole, the architectural and energy design of the building must be considered together. Hence, the requirements for lighting loads and interior improvement can be met by minimizing the capacity of mechanical and electrical systems and by architectural design solutions [10].

The holistic structure approach can be implemented effectively through simulation software, especially at the planning stages. Thus design objectives can be controlled and design changes can be re-assessed before implementation. In the study, the system dynamics approach is used to evaluate the energy efficiency status of a building, by determining impact parameters, and by analyzing the relationships of variables with a holistic approach.

2.3. System Dynamics Approach

SD approach rejects traditional methods requiring detailed component models in projects, and it focuses on behavioral modes and feedback relations of dynamics [11]. Feedback perspective is the main concept of the system dynamics. The behaviors of complex systems can be easily understood, explained and arranged with systemic feedback approach. Defining the possible project risks is very important to get a timely intervention; so that the risks don't comprise of individual factors. It is necessary to manage and look at the whole system to determine the risks and its effects [12].

Regarding the history of System Dynamics (SD), SD is a way of going beyond traditional realm of systems approach towards a wide-ranging complicated engineering problems. SD takes an interest with internal relation of different factors of a system on schedule. In addition, SD takes the dynamic quality by integrating such concepts as stock, flows, feedback and delays. Accordingly, SD sheds light on the dynamic behavior of system in time. SD is a knowledge domain and therefore it can be considered as a logical extension of systems engineering (SE) and systems analysis (SA). SD explicitly checks out the dynamic behavior that develops because of delays and feedbacks in the system. Jay W. Forrester, who is the management professor at the MIT/Sloan School, is seen as the founder of this novel method to comprehend and figure out the problems in the business and social science domains. SD had a significant intellectual effect across the world. Very notable and disputable applications of SD are the growth of world models, World2 and World3, which were put out in World Dynamics (1971) and in The Limits to Growth (1972) chronologically. Despite using system dynamics, the world models were in the line of fire from a very wide range of disciplines, government and academia, they accomplished to bring some of the very important difficulties and troubles that humankind is facing today to the front row of academic and political thought process. As a method, system dynamics has been successfully used in a broad array of business and socio-economic areas to comprehend the troubles and find out different policy interventions. It is believed that SD is such a substantial tool that it could be utilized successfully for a wide range of problems, but for the growth of SD, it needs a leap to go beyond where it is today [13].

SD field appeared in the late 1950s under the leadership of Jay W. Forrester. A novel discipline came into existence, called Industrial Dynamics and it was first implemented in the area of the strategy management of industrial obstacles [14]. Industrial problems took on a different perspective and were named “System Dynamics” following the book “Urban Dynamics”. Being the second field, “World Dynamics (and Limits to Growth)” which was on the growth of population and financial development policies came into being during the late 1970s. Since then SD has spread out to a lot of various areas such as project management, economy, education, energy, politics, psychology and health. [14].

The founder of system dynamics, Jay W. Forrester became a part of MIT as a graduate student in the Electrical engineering department, and Gordon S. Brown employed him as research assistant in the new servomechanisms laboratory in 1940. In 1956, Forrester participated in the MIT Sloan School of management and he formed the system dynamics basis there, a way to comprehend the dynamic face of varied business related matters and troubles. He made a larger use of system dynamics in business management area and officially mentioned the SD methodology in his book *Industrial Dynamics* that was printed in 1961. The fact that he met and discussed with former Boston mayor and then visited professor at the MIT caused spreading of the SD method to make out the urban housing problem in the Boston Metro area, which resulted with the publication of *Urban Dynamics,* his next book, employing system dynamics methodology in the field of social sciences [13].

2.3.1. Systemic Feedback Approach

The word dynamic has a meaning of “change” with the effect of time factor. In dynamic behavior, variables are active and have systemic feedback sense. Population growth, inflation rates, supply chains, etc. are some of the dynamic events and their dynamic acts should be conducted, changed or sometimes cancelled.

In a dynamic system, variables should be described internally. This approach creates an endogenous perspective for a system. It doesn’t mean there are no external forces affecting the system. The main point is that external effects can't be controllable and manageable whereas feedback problems need to be managed and controlled continually. Feedback problems also require observation, assessment of impacts and getting different solutions.

2.3.1.1 Main Concepts of System Dynamics

To mention System Dynamics, a “system” phenomenon is thought firstly. Basically, “**a system**” occurs from elements coming together with each other in a significant way. It is probable to give body system, trading system, legal system, health system and etc. as examples to the systems.

When system yields problems, complexity increases; and to explore problems and to find possible solutions, “**modeling**” concept exist. Problems are searched specifically, so models are set on particular issues; in other words, the whole system isn't modeled. According to the problem, model can be in practical or theoretical way, but only in case of a matter and objective existence.

System structure is formed with the whole relations of system variables [14]. Depending on structure, dynamic behaviors exist. Dynamic behavior types are; constant, growth, decline, growth and decline, decline and growth and oscillatory as represented in Figure 1.

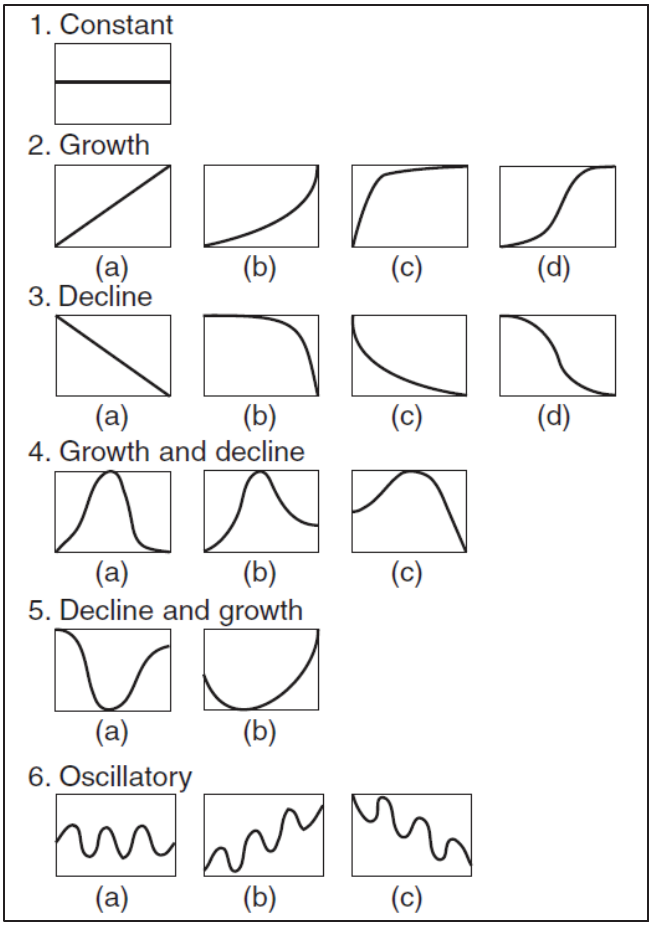


Figure 1. Detailed display of dynamic behavior graphs [14]

Based on the System Dynamics objective, it is possible to define some rules respectively for systemic feedback;

- Causal relations should be established instead of simple correlations. Simple correlations don't give us an idea about the causes of dynamics. In causal relations, input affects output and the replies of "why" are clear.
- Causal relation should be set in circular way overtime (feedback). By virtue of feedback logic and dynamic behavior, output can also influence the input as a result of input influencing output. In this situation, it is crucial to take into account that the casual relations are in a direct way.
- "Dynamic behavior patterns" should be adjusted instead of "event-orientation". Dynamic model can't be developed by considering the events in an isolated way. To create an accurate model, it is needed to investigate the underlying historical and structural causes of the events. With dynamic behavior diagrams, the causes of the problem can be more obvious, and depending on this, more appropriate policy analysis can be generated.
- An internal structure (endogenous perspective) should be generated in order to obtain dynamic behavior.

A forementioned dynamic behavior formation depends on structure. For structure representation, casual links and loops are created between elements. When the variables affect a dynamic behavior externally, it can only obtain an idea about the reasons underlying the behavior shown in the example in Figure 2.

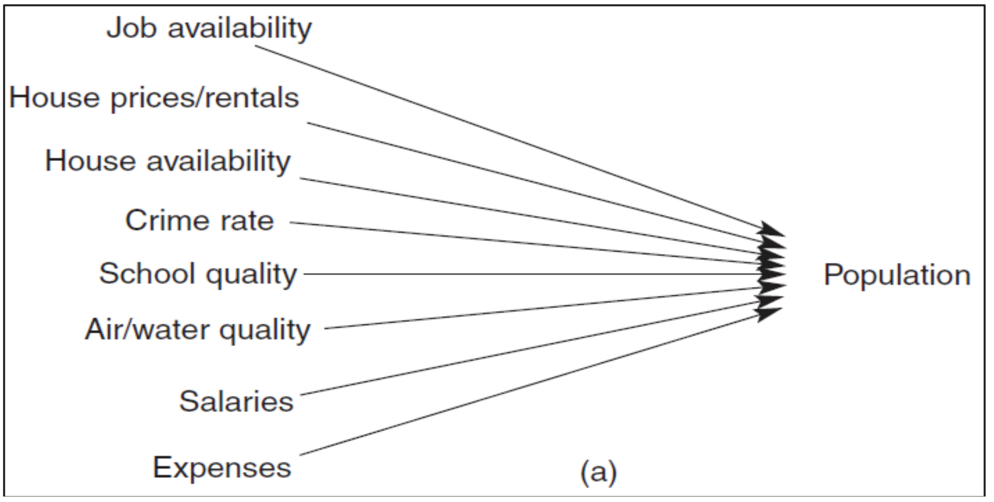


Figure 2. An exogenous model of city population [14]

However, to understand the main causes and produce possible policies about dynamic behavior, the variables of the structure should be related internally. Feedback approach is provided with internal structure displayed in Figure 3.

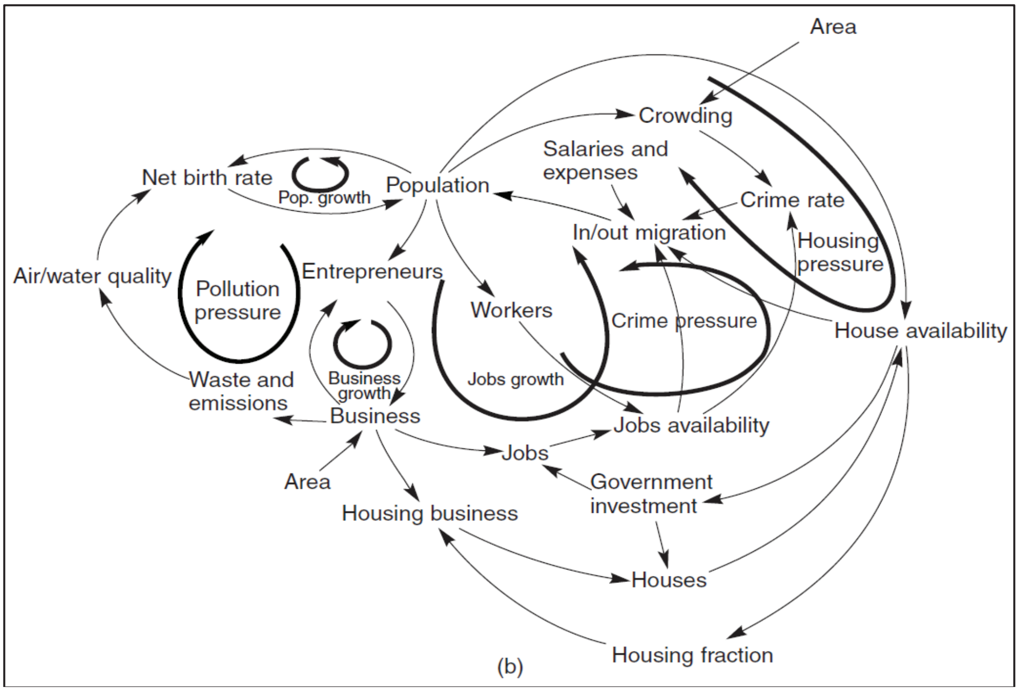


Figure 3. An endogenous model of city population [14]

- Systems approach should be properly defined
  In systemic perspective, it is important to make the distinction between endogenous and exogenous structure well. External factors affecting the system can't be handled and it is difficult to define a boundary then. On the other hand, internal dynamics identifies the model boundary and the boundary is required to be established greatly. While determining the boundary, it is needed to recognize relations and interactions of internal variables with each other and also with external elements. Another issue to be noticed for systems perspective is the modeler's ability that decides the boundary of the model.

2.3.1.2. Positive and Negative Feedback Loops & Causal Loop Diagramming
Based on the relation of X ⟶ Y causality (x is an input and y is an output), while X is increasing, Y is also growing. This effect has a positive meaning. If X increases and then Y decreases, this becomes a negative influence; Figure 4 shows negative and positive loop examples.

Causal loop diagrams (CLD) are formed with positive and negative feedback progresses. Cause and effect relations are identified with CLDs. CLDs don't include stocks and flows, they explicitly contain the stock and flow structure.

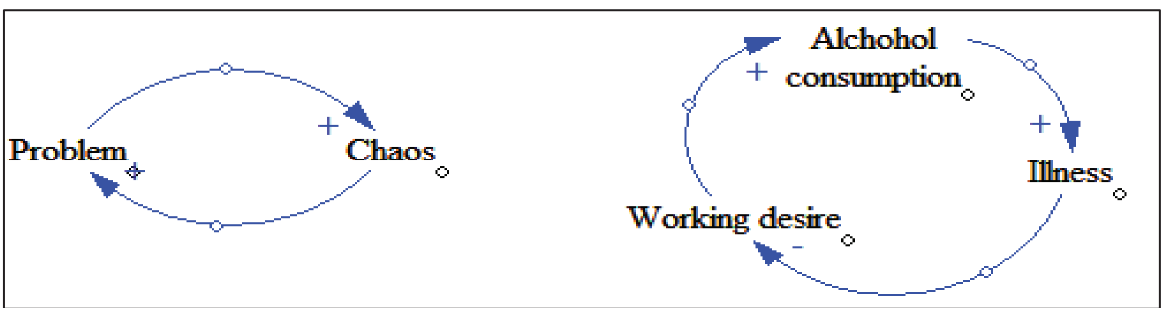
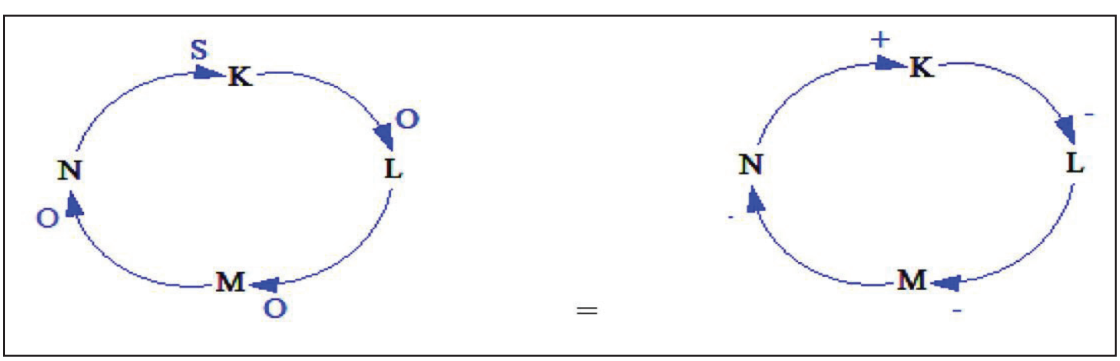


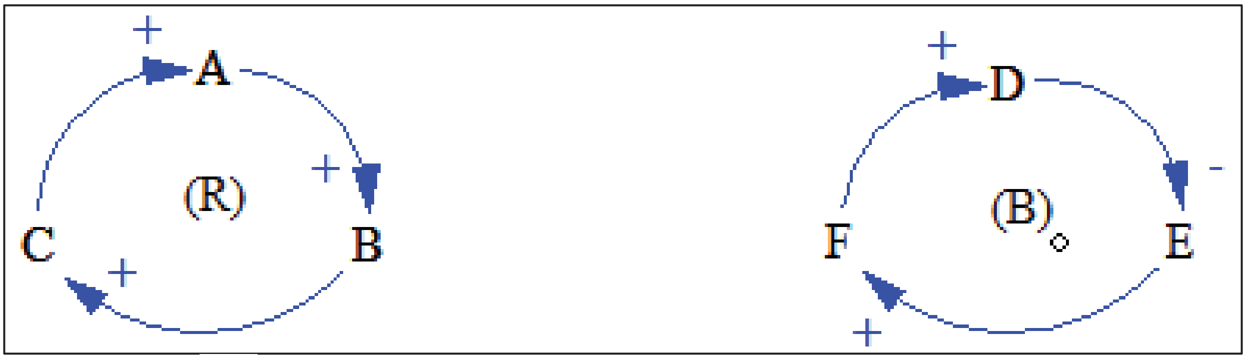
Figure 4. Positive and negative loops

Causal diagrams have some general symbols (letters) to indicate system's situation. (Figure 5 a and Figure 5 b).



S: Same direction (plus (+) sign)
O: Opposite direction (minus (-) sign)

Figure 5a. Signals of causal loops



R (Reinforcing):  Snowball rolling down icon

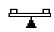
B (Balancing) = C (Counteracting):  Teeter-totter icon

Figure 5b. Signals of causal loops

2.3.2. System Dynamics Application Areas

Sterman [15] declares how widely practicable of SD is: "System dynamics has been applied to issues ranging from corporate strategy to the dynamics of diabetes, from the cold war arms race between the US and USSR to the combat between HIV and the human immune system. System dynamics can be applied to any dynamic system, with any time and spatial scale. In the world of business and public policy, system dynamics has been applied to industries from aircraft to zinc and issues from AIDS to welfare reform."

SD modeling technique is specifically used in medicine, law, urban studies, global studies, environmental studies, information science, literature, history, economics, finance, chemistry, physics, etc. [15].

In the construction industry, SD usage has been increased in the context of managerial and improvement problems analysis [16]. In the field of construction management, system dynamics (SD) modeling techniques are often applied based on time and cost variables. Yaghootkar and Gil [17] searched the impact and significance of project management within the context of schedule-driven and capacity of resources. Nasirzadeh and Nojedehi [18] examined the labor productivity and its effects on project performance through the SD-based modeling approach. Xu et al. [19] studied "Public-Private-Partnership" (PPP) being one of the preferential procurement methods of highway projects. White [20] evaluated the minimization of SD models of projects in terms of variable numbers and non-linearity. Laslo and Goldberg [21] handled organizational conflict problem based on matrix structure, similar skilled group of people coming together for work practice in a multi-project environment. Eden et al. [22] compared the two approaches of litigation; system dynamics modeling technique and measured mile analysis. Nasirzadeh et al. [23] studied on construction risk allocation which was the important problem between contractors and owners. Titus et al. [24] searched the problems of construction industry in Kenya, depending on the fluctuations in construction activities and slow growth. Cui et al. [25] wrote about the effect of SD on cash flow management strategies on construction projects. Nasirzadeh et al. [26] handled the risk management problem of construction projects. Tang and Ogunlana [27] studied on dynamic performance of local construction organizations in Malaysia affected from Asian financial crisis. Tang and Ogunlana [28] addressed the changing activities of Asian construction sector with the effect of globalization. Love et al. [29] and Li et al. [30] focused on the construction rework impacts on projects. Lé and Law [31] analyzed the complex learning system in an architecture, engineering and construction organization (AEC) industry. Chen and Fong [32] discussed the knowledge management capability (KMC) evolution and knowledge processes in construction firms in accordance with supplying the needs of changing market environment, conducting and controlling the challenges, and also estimating performance outputs based upon time factor. Tatari et al. [33] studied on enterprise resource planning systems (ERP) in construction industry which its proper management enables financiers or stakeholders to make successful investment and get accurate information flow about construction processes. Hwang et al. [34] addressed the problem of imbalance between supply and demand in Korean housing market.

The energy efficiency based on the residential building structure and the interior systems has been examined thoroughly in the built environment studies in the literature. In the case of studies other than the general one, the problem of CO_2 emissions in the urban context has been scrutinized. Onat et al. [35] addressed the U.S. residential buildings in order to find out the possible policies for decreasing or stabilizing the Greenhouse Gas (GHG) emissions in their research. Mid and long term policy effects of green buildings were studied with stock-flow diagram. Armenia et al. [1] mentioned that the energy saving was an important issue in recent years. The paper analyzed socio-technical factors to provide energy efficiency and technological improvement. Authors studied the relationship between building's technical performance and occupant's feelings about it. Blumberga et al. [36] examined that if First National Energy Efficiency Action Plan (EEAP) of Latvia was sufficient in its own context, it was due to the fact that Latvia had the big potential in energy savings with renovated apartment buildings, however planning processes were weak. Fong et al. [37] considered system dynamics model (SD) in an urban context. Main theme was to estimate the status of CO_2 emissions that are growing in Malaysia -especially Iskandar Development Region (IDR) and Johor Bahru city as urban conurbation- in the future. Thompson and Bank [38] applied System Dynamics (SD) modeling technique as a proof-of-concept approach. An air system model and infection sub-model was created and the impact of the bio-terrorist attack was examined. Dyner et al. [39] addressed the energy efficiency scenarios based on household appliances in residential buildings with system dynamics (SD) modeling technique. Xing et al. [2] assessed the retrofitting action of building with the combination of system dynamics (SD) modeling technique and SAP tool –building physics model- and they called this model as 'SdSAP'. Oladokun et al. [40] studied household energy consumption and CO_2 emission (HECCE) reduction system.

3. METHODOLOGY

Lots of models adopting the system dynamics approach [5] include the dynamic aspects into models of project improvement. The project dynamic behavior hypotheses of the modeler are represented by feedback structure and a framework is created on the modeler's researches of the project behavior. In the paper, retrofitting construction project management is considered, depending on the concept, building energy parameters are identified as the dynamics, which can affect the project's performance throughout retrofitting process of the project. Further, SD model is used to evaluate the energy efficiency situation of a building by determining the impact parameters and analyzing their relationship in a holistic approach.

3.1. Identification of Building Energy Efficiency Dynamics

Considering the building retrofitting projects, the parameters of building energy efficiency can be taken as project dynamics, such as climate data, shading barrier, CO_2 emission, building zone, building material, used appliances, lighting, ventilation, heating-cooling, water heating, building location and form [41]. The parameters that complicate the projects and affect the project performance are briefly described below.

Climate Data: One of the important factors defining the building energy performance. It also affects the environmental performance and it is a determinant for the results of energy efficiency simulations.

Shading Barrier: It is defined as "surrounding buildings" that block the sun light of main building. Distance to the building, effect sizes and impact surface are the important parameters of shading barrier.

CO_2 Emission: It is the result parameter coming from the simulation of building energy performance. When it is thought that CO_2 emission is caused by buildings, it becomes an impact parameter in energy effectiveness.

Building Zone: Refers to the independent interior spaces of the building due to air-conditioning, heating and cooling systems. Units which have similar ingrains can be taken as separately or in common zones in a simulation program. Zoning facilitates the calculation of the energy performance.

Building Material: It describes any of the material constituting the building. While entering the data to the simulation program, columns, beams, walls, ceilings, slabs, building envelope, doors, windows etc. are considered as direct elements relating to the building performance. Especially building envelope is crucial factor for thermal insulation of buildings.

The Appliances Used in the Building: All kinds of electronic devices (computer, heater, kitchen equipment etc.) that are used for the furnishing of the building affect energy performance and efficiency.

Lighting System: Interior and exterior lighting elements and natural lighting factors support minimum energy consumption and provide energy efficiency.

Ventilation System: The model and capacity, type, power and age of the ventilation system are necessary variables for energy performance assessment and simulation modeling.
Heating and Cooling Systems: These systems are integrated to each other. Heat gains and losses, coefficients, temperature differences, material characteristics and impact values are considered as main determinants of the systems, and are entered in the simulation program separately for each element. Heating and cooling parameters are the most important factors that influence the building in energy efficiency context.

Hot Water System: Similar to the ventilation system, the capacity, power, type and age of the system define the hot water system parameters. This factor is seen as energy consumption data in simulation.

The Location of the Building: The topography of the building, distance between adjacent buildings, utilization time from the sun, direction of the facades are the main factors that designates the building location.

Form of the Building: The geometric structure, the size and number of doors and windows, roof details, number of the story, building and story height, building surface area, the location and size of the opaque and transparent components are crucial determinants for calculation of building energy efficiency [42].

These parameters affect the building's energy needs and performance when combined with the time factor, thus it is difficult to estimate and control the dynamic parameters. With system dynamics approach, the interrelations of the impact parameters are emphasized to provide right control of the systemic behavior and risks. Based on the parameters mentioned above, a feedback model is established for energy efficiency extent. In the development of the general feedback model, while some parameters are added directly to the loop, some parameters are not included.

3.1.1. Framework of the System Dynamics Model (Qualitative Model)

The study suggests a qualitative feedback model that provides information between project parameters in limited time and space. Model framework is generally based on residential energy demand (RED), residential energy consumption (REC) and heating and cooling energy efficiency (HCE) parameters which are acquired from the literature reviews and these variables are integrated to each other (Figure 6).

The causal map is created by "Vensim" software and the cycle descriptions are expressed in the following order; Loop 1 is residential energy consumption one and this loop is formed as REC→ Comfort level→ Quality of life→ Size and Number of House→ REC. Here, the parameters affect each other in a positive way, so this loop is called reinforcing or positive loop (R1). Loop 2 defines heating and cooling efficiency as Heating & Cooling Efficiency→ REC → CO_2 Emission→ Climatic Impact→ HCE and it is a reinforcing loop again. When loop 2 and loop 1 are connected via comfort level factor, new cycle becomes balancing (B3) and it is shown as HCE→ Comfort Level→ Quality of life→ Size and Number of House→ REC→ CO_2 Emission→ Climatic Impact→ HCE. It means that an increase in HCE balances REC via comfort level. Loop 4 includes RED→ Use of Installed Capacity→ Energy Cost→ RED and the loop becomes reinforcing (R4). Loop 5 creates people satisfaction cycle based on energy cost such as; RED→ Use of Installed Capacity→ Energy Cost→ People Satisfaction→ RED and it is identified as positive loop (R5). Further, RED has a few different loops in itself consisting of energy price; another one of them is Loop 6 which is described as RED→ Energy Capacity Depletion (ECD) → Energy Cost→ RED. This loop is balancing (B6) because of the aim being to balance the demand. Loop 7 shows the relation of energy supply and demand. It is formed as RED→ ECD→ Investment Incentives→ Energy Supply→ Energy Cost→ RED and this loop is balancing again (B7). Loop 8 is based on energy alternatives parameter and this relation is displayed as in RED→ECD→ Energy Alternatives→ Energy Cost→ RED and this eighth cycle is reinforcing (R8). In loop 9, when conservation increases, energy demand decreases. Here, the loop becomes like RED→ ECD→ Conservation→ RED and it is assigned as balancing loop (B9).

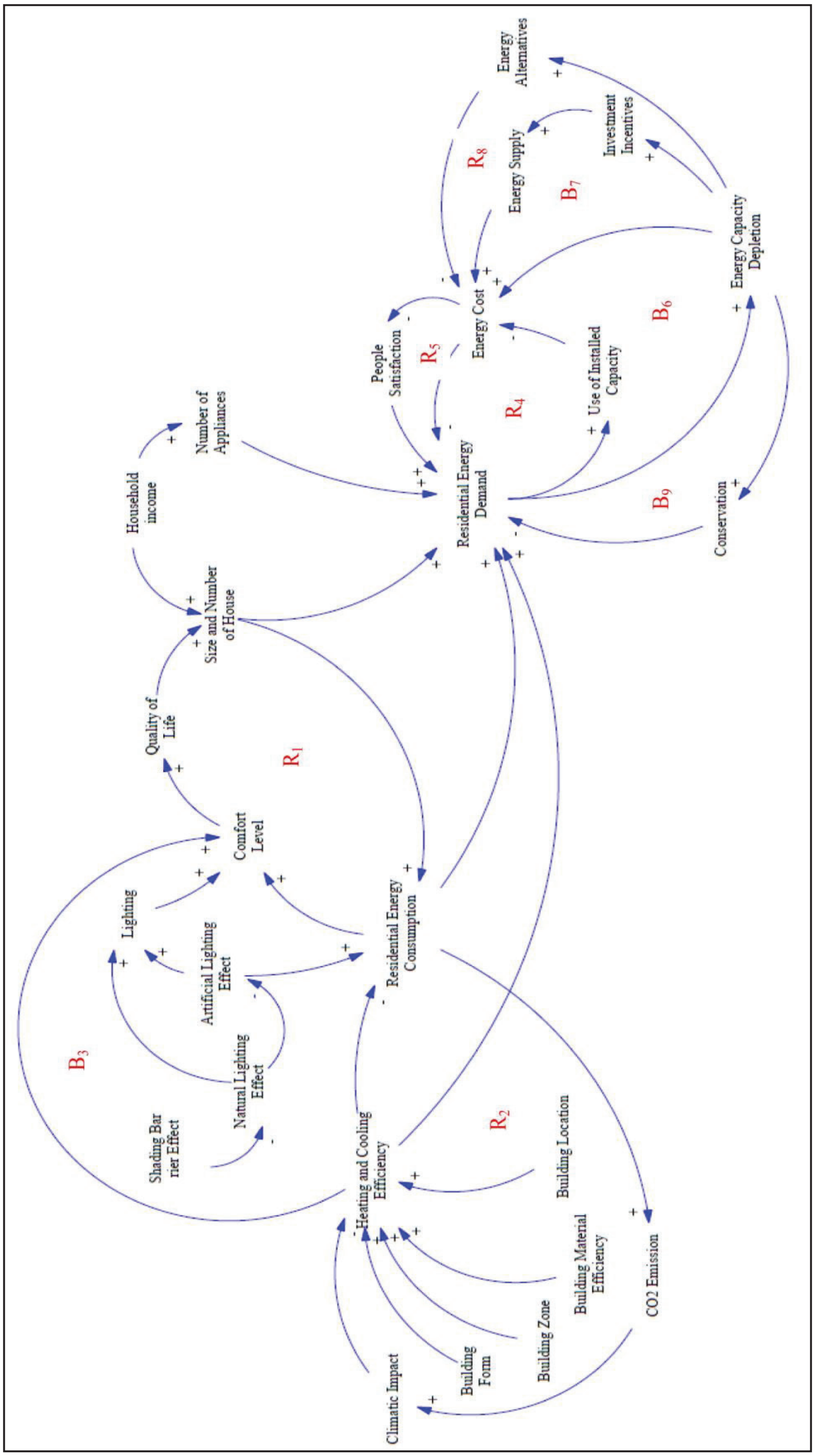


Figure 6. General qualitative display of residential building energy efficiency [1, 2, 36, 39].

4. CONCLUSION

In the study, the effect of building variables on the energy efficiency was analyzed by feedback cycles. Residential energy efficiency feedback loop shows the relations of impact parameters and their effects on each other. In the model, comfort level is kept balanced by increasing heating-cooling efficiency and decreasing energy consumption. Moreover, people satisfaction loop is a reinforcing one and its escalation depends on energy demand, installed capacity usage and energy expense.

In the causal map, the parameters don't affect each other alone, and so it is not true to think that only one parameter changes the system's behavior; the system's behavior depends on the loops including all variables' relation. The resulting causal maps do not have the same strength, while some cycles are dominant in the system, some cycles may be weaker. There should be a control mechanism for this and thus feedback is the mechanism that controls this. To enlighten the subject with an example; when a house wall is destroyed, it is not easy to suppose status and effects of such parameters like the cost of demolishing a wall, the time spent in demolition, the arrangement to be done after demolition, etc. By creating a feedback model, the wall demolition/renewal system can be kept under control, the probabilities and the effects can be estimated to a certain extent and decision making process accelerates. Besides these, while setting a feedback model, it should be noted that making good adjustments such as which loop is to be balancing and which loop is to be reinforcing, directs the whole system.

Furthermore, starting from the change in home heat setting, the energy efficiency of public buildings such as office buildings; public offices can be assessed with system dynamics approach and the designs can be formed accordingly. The dynamic variables can be intervened before implementation, by planning energy efficiency applications practically and cost-effectively. In the planning phase, the possible effect of an unapplied element can be analyzed because it is not considered necessary in the design of the building. Also, the reasons of dynamics having bad effects on the system are defined, and it is intended to eradicate or minimize them by improving new and powerful policies.

4.1. Limitation and Future Directions

This paper is a part of an ongoing thesis study. The feedback diagram emphasized in the article is not enough on its own in the decision-making process. Although it is possible to see the interrelationships of parameters in these cycles, the model must be digitized with mathematical equations in order to develop effective decision-making mechanisms. In the following section, qualitative feedback model will be transformed to a formal structure. This formal-quantitative model will be integrated to the simulation program. After the simulation of dynamic parameters, different scenarios will be held and assessed based on a case study. Thus, more accurate estimates can be obtained about the system hence more effective scenarios can be produced and the applicability of these scenarios can be evaluated.

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