FUTURE CITIES AND ENVIRONMENT

A New Building Information Modeling Probabilistic Model Based On Artificial Intelligence to Optimize Residential Buildings Energy Efficiency in Jordan

TECHNICAL ARTICLE

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ABSTRACT

The demand for energy in Jordan's residential buildings is increasing, resulting in significant discrepancies between predicted and actual energy usage. Accurately predicting household energy usage is crucial for sustainable building planning and effective energy management strategies. However, traditional energy models often need to pay more attention to the complexity of occupant behavior, leading to significant differences between expected and actual energy usage.

To improve energy consumption forecast accuracy, a unique approach was proposed in this study, which combined Time-Use Survey (TUS) data with AI-driven algorithms in Building Information Modeling (BIM). The study conducted a time-use survey in 100 Irbid, Jordan residences to document detailed inhabitant behavior and daily activity patterns. The collected data was then used to train AI algorithms integrated into the BIM framework.

This integration enables the BIM model to dynamically adapt and estimate energy usage based on real-time occupant behaviors and environmental conditions instead of relying solely on static architectural and mechanical inputs. Using this BIM model with AI significantly reduced the difference between expected and actual energy usage in the analyzed houses.

The findings of this study support the usefulness of incorporating occupant behavioral data into energy prediction models. This approach provides more accurate energy consumption projections and highlights the importance of considering human aspects throughout the architectural design and energy planning stages.

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INTRODUCTION

The construction sector contributes significantly to worldwide energy consumption, with estimates ranging from 11.14% in the United States (Stein et al., 1980) to 40% in IEA member nations (Gottsche et al., 2016). The high energy consumption is related to the energy-intensive nature of building activities, particularly materials and on-site operations (Hong et al., 2016).

In 2018, Jordan imported 94% of its energy requirements, which accounted for almost 10% of its GDP (Abu-Rumman et al., 2020). There has been a rapid increase in residential energy use and government energy usage. In 2019, the number of consumers in the residential sector accounted for 86.85% of the overall consumers (NEPCO, 2019). According to JEA (Jordanian Engineering Association), the residential sector will account for 78.61% of design approval and licensing in the first half of 2022 (Dinmohammadi et al., 2023; Castelli et al., 2015; Verma et al., 2020; Mogili et al., 2022; Kim et al., 2020). These studies highlight the need for accurate estimates of household energy usage and the effectiveness of various techniques in achieving this goal.

Hasan et al. (2021) has identified a significant gap between expected and actual outcomes of energy assessments. The actual savings and cost reductions are lower than expected. Tabasi et al. (2016) used a regression model to predict energy consumption in Germany, which showed a considerable reduction in energy consumption due to the usage of renewable energy based on research by Sadorsky (2011). It has been demonstrated that the gap between predicted and actual building energy performance is often caused by occupant dissatisfaction. Accurate occupant behavior studies can reduce yearly energy usage by up to 150% (Clevenger, 2014).

Preliminary findings suggest that operational problems and occupant behavior significantly impact schools' energy efficiency and the difference between design estimates and actual energy use. There is special interest in the ability of renters to handle additional aspects in residential constructions. While operators in commercial buildings often adjust heating setpoints, residents in residential structures frequently have power over them (De Wilde, 2014).

According to research conducted by Elmualim and Gilder in 2014, electricity usage in residential buildings increases by about 3% for occupants over 50 years old, and consumption also significantly increases when children are present in the house. Karjalainen (2016) suggested that implementing resilient design solutions can significantly reduce the impact of occupant behavior on energy consumption by 75–79% among less conscientious users. This highlights the importance of considering realistic occupant behavior when developing energy-efficient buildings.

A study conducted by Far, Ahmed, and Mackee (2022) revealed that the lack of comprehensive data on occupant behavior from other research is a critical reason for the energy performance gap. The study underscores the need to gather accurate occupant behavior data to optimize thermal performance and enhance buildings' long-term sustainability and climate resilience.

Heating energy consumption varies significantly across different user scenarios, indicating that the impact on energy usage and comfort could be more consistent and dependent on the complexity and diversity of users' heating practices (Laskari et al., 2022).

Research shows that adopting energy-efficient practices may dramatically reduce building energy use (Lopes et al., 2012; Delprato, 1977; Paone et al., 2018). Implementing intelligent lighting systems, adjusting thermostat settings, and encouraging habits such as disconnecting gadgets are also effective measures (Lopes et al., 2012). Studies underline the necessity of developing knowledge about the energy consequences of activities and the advantages of energy-efficient practices (Delprato, 1977). Furthermore, eco-feedback and gamification have been presented as practical techniques to influence building occupant behavior (Paone et al., 2018).

Various studies have explored using time use surveys (TUS) to model occupant behavior. In particular, Osman (2021) has conducted a comprehensive review of TUS data, modeling techniques, and their applications in building energy research. Widén et al. (2012) and Aerts et al. (2013) have expanded TUS-based models to include occupancy, activities, and energy use. Widén has focused on deterministic and stochastic approaches, whereas Aerts has focused on discrete occupancy profiles.

González et al. (2021) conducted a study to integrate BIM and Building Energy Modeling (BEM) methodologies to optimize lighting, plug-load, and HVAC systems in energy-efficient buildings. Their experimental design provides valuable insights for decision-makers in selecting effective strategies to improve energy efficiency. In another study focused on retrofitting school buildings,] et al. (2015) demonstrated how BIM can significantly improve energy efficiency, structural integrity, documentation of completed works, and quality control. This underscores the potential of BIM to maintain and manage existing educational facilities.

Furthermore, Zhao et al. (2021) explored the application of BIM in the lifecycle management of buildings in China, emphasizing its benefits in thermal systems and HVAC design. This approach adheres to China's Green Building Design Evaluation Standards and reduces costs across design, construction, and operation, promoting optimal economic efficiency.

Researchers such as Soroush (2020) has demonstrated the usefulness of BIM in optimizing energy usage, with Soroush achieving a 58.46% reduction in energy costs by using BIM-based design and energy performance evaluation. Agostinelli et al. (2021) has taken this one step further by combining BIM, AI, and machine learning in a residential neighborhood's cyber-physical system for energy management, resulting in a virtuous energy system and highlight the importance of BIM and AI in increasing energy efficiency in residential sector.

Several research have examined Dynamo BIM AI's capabilities in various disciplines. Kadcha et al. (2022) pioneered an integrated method of BIM data extraction and visualization using Dynamo and Power BI, focusing on cost analysis, clash detection, change tracking, and plan extraction. Hu (2024) developed a system for converting GIS-based roadway models into multidimensional BIM platforms utilizing Dynamo, boosting project complexities and traffic insights. Kopka (2016) investigated the modeling and analysis of spatial structures based on free-form surfaces with BIM and Dynamo. These collaborative studies demonstrate Dynamo BIM AI's potential for improving data extraction, visualization, and design support in the AEC sector.

This study proposes a new way to improve the accuracy of predicting household energy consumption in Jordan. The approach involves using Time-Use Survey (TUS) data with AI algorithms in Building Information Modeling (BIM). By analyzing the daily activities and behaviors of residents in Irbid through TUS, the research trains AI algorithms that enable the BIM framework to predict energy use based on real-time occupant behavior and environmental conditions. This method significantly reduces the gap between predicted and actual energy usage, making energy models for residential building planning and management more reliable.

METHODS

The study utilized a mixed methods research approach that combined qualitative and quantitative methodologies to gain a better understanding of tenant behavior in the residential sector. An innovative approach has been developed to improve residential structures' energy efficiency and occupant comfort. This approach involves the integration of Time-Use survey (TUS) and Artificial Intelligence (AI) algorithms with the Building Information Modeling (BIM) framework. The methodological integration presented in the study combines qualitative insights with quantitative investigation and subsequent AI modeling. This approach increases the reliability of the study findings and enhances the practical value of BIM systems for forecasting and reacting to real-world usage.

The research comprehensively explained how residents interact with their living environments. Qualitative data was gathered through interviews and focus groups, while quantitative data was collected through extensive Time-Use surveys. This data formed the foundation for creating complex AI models that could anticipate and replicate BIM system behavior.

METHODOLOGY PHASES

The study was divided into two main phases: Theory Setup and Practical Setup.

Theory Setup

To research theoretical setups and uncertainties using the Time-Use Data (TUS) survey technique, follow these two key steps:

1. **Design the Survey to use as main source of data and as main input in AI algorithm:** Create a survey with TUS, which gives a structure that aims to capture a comprehensive dataset that covers personal backgrounds, daily activities, and technological influences and use Key human activities affecting energy use that have affected house design and other factors that have been found in the previous researches as below table:

   The survey covered 25 questions demographics (8 questions), occupant behavior patterns (15 questions), and the impact of technology on energy consumption (2 questions).

2. **Analyze Results by Employ Interpretivism:** Analyze the responses to identify patterns and correlations between demographics, daily behaviors, and technology use. This analysis will help pinpoint critical factors affecting energy consumption and occupant behavior, facilitating future targeted interventions or studies and Utilize an interpretive approach to analyze the collected data, focusing on the subjective meanings and social circumstances

VARIABLE	RELATED TO	SOURCE
Window opening	Privacy	Nazer, H. (2019).
Heating and cooling	Privacy	Nazer, H. (2019).
Demographic (age, family size etc…)	Religion	Nazer, H. (2019).
Lighting	Privacy	Jordan Green Building Council, 2019
Closing Curtin	Culture	(Safa, Ahmad and Yamen. 2018)
Using Islamic technique	Culture	(Safa, Ahmad and Yamen. 2018)

Table 1 Variable to be used in survey (Privacy and culture aspects).

that influence human behavior. This will allow a deeper understanding of how individuals perceive and interact with their environments.

Practical Setup

To research practical setups and, follow these two key steps:

1. **Data Preparation:** The first step involved a comprehensive cleaning of the data collected from surveys. This data was carefully organized and then entered an Excel file, which served as the primary database for all the inputs required for the study. This step was crucial to ensure the accuracy and reliability of the data that fed into the subsequent modeling processes.
2. **Using Revit and AI-Enhanced Scripting:** Autodesk Revit was selected as the primary software for Building Information Modeling (BIM) due to its robust capabilities in accurate modeling and extensive support for architectural design Several studies have investigated the use of Building Information Modeling (BIM) software in the construction industry. Meouche et al. (2013) conducted a comprehensive review of the capabilities of BIM software, with a focus on Autodesk Revit 2012 Babatunde et al. (2019) both highlight the potential of BIM to enhance efficiency and cost estimation in the industry, with Babatunde specifically identifying its use in quantity surveying practices. Noor et al. (2018) expands the discussion to the application of BIM in

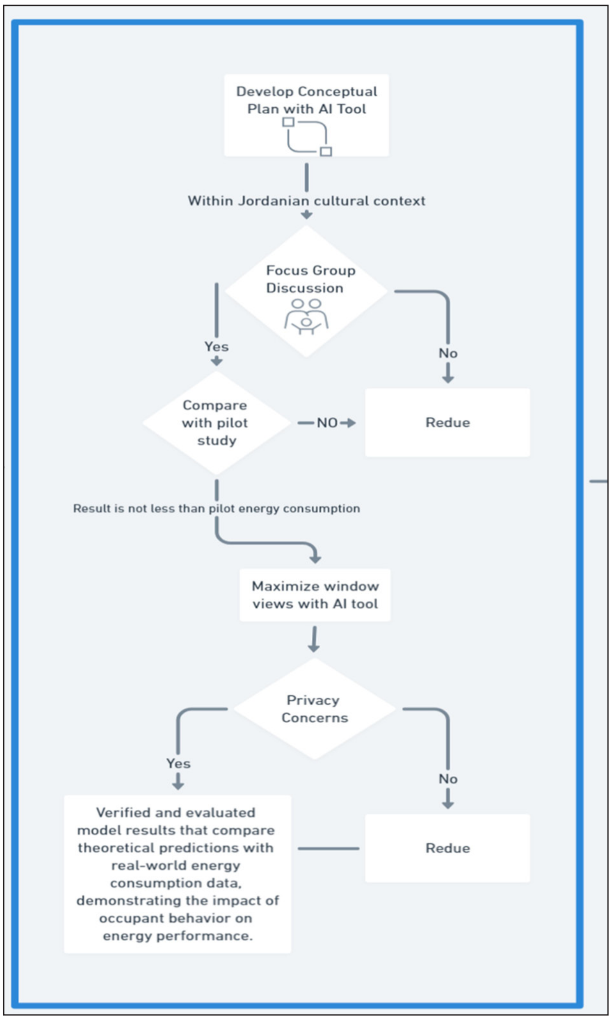

Figure 2 Process.

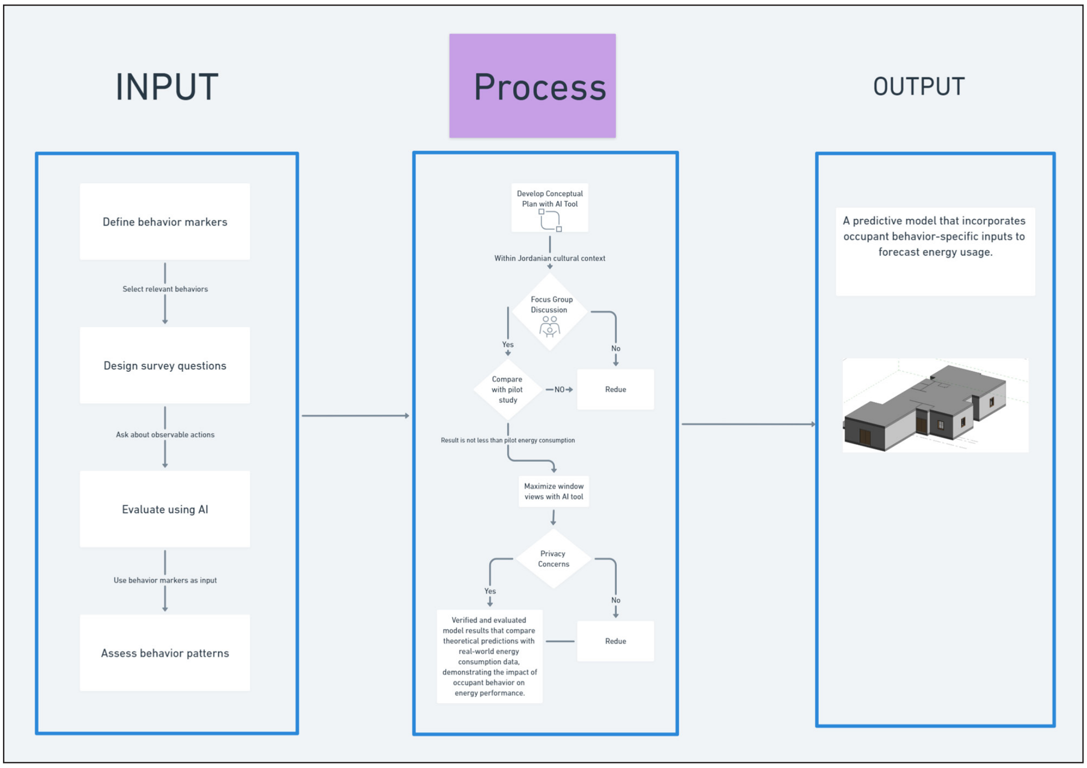

Figure 1 Work-Flow.

civil engineering projects, emphasizing the need for more research in this field. Together, these studies demonstrate the significant contribution of BIM software to the construction industry, particularly in terms of efficiency, cost estimation, and data management. The BIM environment was improved with the use of artificial intelligence through Dynamo, a scripting tool that integrates with Revit. Dynamo scripts were developed to automate tasks, analyze data, and facilitate the integration of AI algorithms with the BIM model.

3. **Model Validation:** Rigorous validation procedures were implemented to ensure the BIM probabilistic model's reliability and accuracy. This involved comparing the model's predictions with actual data and performance metrics from similar buildings or validated energy models. This step confirmed that the model could replicate real-world conditions and produce valid results. Validating the model tested its predictive accuracy and enhanced the credibility of the simulation outcomes, providing a solid foundation for recommending energy efficiency strategies.

PARTICIPANTS

Targeting residents of Irbid, Jordan's second-largest city and a place renowned for its dense population.

The poll ensured a representative and varied sample while taking participant privacy concerns very seriously. In order to provide a more thorough knowledge of participants' everyday activities, time use surveys (TUS) were explicitly added.

Numerous research have employed the time-use survey (TUS) survey approach to examine the behavior of homeowners in various nations. Nevertheless, no prior study has employed the TUS approach to forecast time consumption while taking into account the social elements (privacy and culture) that influence Jordanian homeowners' behavior. Because of this, the data structure used in this study was designed to serve as a database for future researchers to contribute further data to anticipate how much time certain space-type constructions in Saudi homes will be used. Future researchers will be able to enhance the model by gathering additional data for other domains that were not addressed in this work, including huge houses or homes with several family.

IRBID	DATA
Total Area	1,572 km² (607 sq mi)
Total Population (2015)	1,770,158
Density	1,126/km² (2,920/sq mi)

Table 2 Basic data About Irbid – Jordan.

Administer the Survey: Distribute the survey across a targeted demographic to collect qualitative and quantitative data. Ensure the survey reaches a diverse group to obtain varied insights into occupant behavior. research.

Table 4 presents the demographic distribution of participants, grouping them according to different criteria. Out of the 100 participants in the research, there are 33 men and 57 women, representing a balanced representation of the sexes. The age range is wide, with 24 people under 25, 28 between 25 and 34, 31 between 35 and 44, 13 between 45 and 54, and 4 beyond the age of 55.

There are two types of residential accommodations: villas and apartments. Of the participants, 32 live in villas and 68 in flats. Students (n = 21), workers in the private sector (n = 33), workers in the public sector (n = 28), and jobless people (n = 18) are the occupation groups. In addition, participants in the poll live in houses of different sizes: 42 live in houses between 150 and 185 square meters, 33 live in houses between 190 and 220 square meters, and 25 live in houses between 225 and 250 square meters.

When combined with time use surveys (TUS), this comprehensive analysis provides insightful information on the wide range of demographic characteristics among research participants. It improves comprehension of the ways in which different elements, such as routine activities, may affect their viewpoints and reactions.

CATEGORY	SUBCATEGORY	NUMBER	NUMBER OF PARTICIPANTS
Respondent Gender	Female	57	N = 100
	Male	33	
Respondent Age	Under 25	24	N = 100
	25–34	28	
	35–44	31	
	45–54	13	
	55 and over	4	
Residential type	Villa	32	N = 100
	Apartment	68	
Occupation work	Student	21	N = 100
	Private Sector	33	
	Public Sector	28	
	Unemployment	18	
House area	150–185	42	N = 100
	190–220	33	
	225–250	25	

Table 3 Basic data of Survey for participants.

BUILDING CRITERIA	
Number of floors 1	1
Area of house 150–250	150–250
Skelton (Wall exterior finishing) Stone	Skelton (Wall exterior finishing) Stone
Insulation	25–30%
HVAC Mechanical ventilation (split unit)	(split unit)

Table 4 The building character sampling.

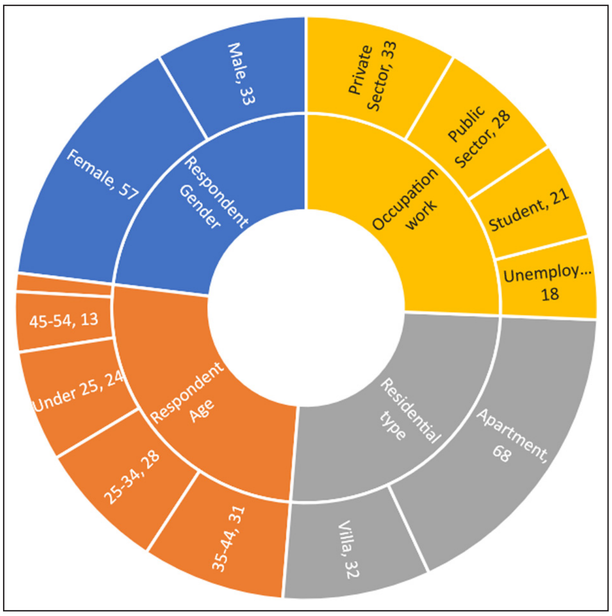

Figure 3 Survey Data visualization.

ASPECT	PERCENTAGE
1. Privacy Concerns in Home Design	
1.1 Privacy considered	40.2%
1.2 Privacy not effectively handled	59.8%
2. Cultural Considerations in Architectural Practices	
2.1 Customs and traditions not appropriately recognized	80.4%
3. Skepticism Towards Islamic Designs for Privacy	
3.1 Feel Islamic designs may improve privacy	12.1%
4. Smart Home Technology: Adoption and Resistance	
4.1 Prefer using IoT for house control	34.1%
4.2 Do not prefer using IoT	65.9%
5. Technical Solutions for Enhanced Home Privacy	
5.1 Feel certain approaches contribute to enhanced privacy	23.9%
6. Curtain Use for Privacy and Light Control	
6.1 Occasionally close windows with curtains	64.5%
7. Influence of Privacy on House Design	
7.1 Feel that privacy influences house design	78.7%
8. Variability in Lighting Control and Preferences	
8.1 Had some control over lighting	50.5%
9. Energy Efficiency in Lighting Choices	
9.1 Favor energy-saving light types	84%
10. Daylight Occupancy and Lighting Patterns	
10.1 Prefer to leave lights off throughout the day	54.3%
11. Technological Influence on Privacy and Comfort	
11.1 Acknowledge technological advancements contribute	65.5%
12. Seasonal Adjustments in Home Temperature Settings	

(Contd.)

Table 5 Survey result with percentage for the human activities, culture and privacy.

RESULTS

The survey's findings indicate a significant impact of human behavior on design and daily activities, as well as certain habits, culture, and privacy within Jordanian culture that create a disparity between actual and predictable energy consumption. The survey results as below Tables.

RESULT AS INPUTS FOR THE ARTIFICIAL INTELLIGENCE

Normally, all the setpoints in Jordan designers used the global standard, which may vary for the Jordanian people; Domi (2022) found significant spatiotemporal differences in climatic comfort levels, indicating that a uniform strategy may not be appropriate.

ANALYSIS THE DATA AND RESULT

Based on data survey and the result, the percentage of total area and the size in square meters for each room based on survey in table.

ASPECT	NUMERIC VALUE/ DESCRIPTION
- Average hours of stay at home per day	8–16 hours
- Most occupied space	Living Room
- Most frequent occupants	Students
- Winter temperature set point	30 degrees
- Summer temperature set point	20 degrees

Table 6 Survey result with Numeric value/Description.

AREA	PERCENTAGE OF HOW SPENT PEOPLE TIME ON IT FREQUENTLY PER YEAR FROM TUS SURVEY	SPACE ALLOCATION (m^2)
Kitchen	27.85%	42
Dining Area	15.18%	32
Living Room/Bedroom	20.74%	57
Guest Room	15.18%	23

Table 7 Survey result for the area needed in house 150 m^2.

VARIABLE	DESCRIPTION	DYNAMO SCRIPT/AI ALGORITHM	OUTPUT
Human Behavior	The Relation between each function According to user culture	Generate Floor plan DYN	A Different Layout of Apartment plan (Zoning stage)
Building Massing Study	Choosing the right massing to decrees the energy coast	Building Masser-2programs.dyn	Building mass (Conceptual massing stage)
Solar Radiation	Calculate the solar	SolarRadiation_1.2.dyn	The Energy efficiency for the sum in heating and cooling
Windows	Size of the windows for privacy	Create study	The needed for lighting and privacy (More detailed 3d modeling)

Table 8 Survey result for the area needed in house 150 m^2.

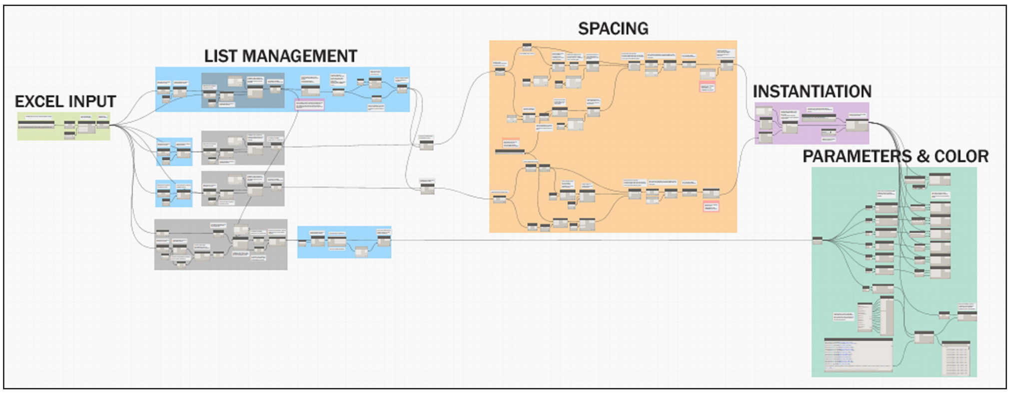

Figure 4 Space Planning Goals (Generate Floor plan DYN) by Auto-desk.

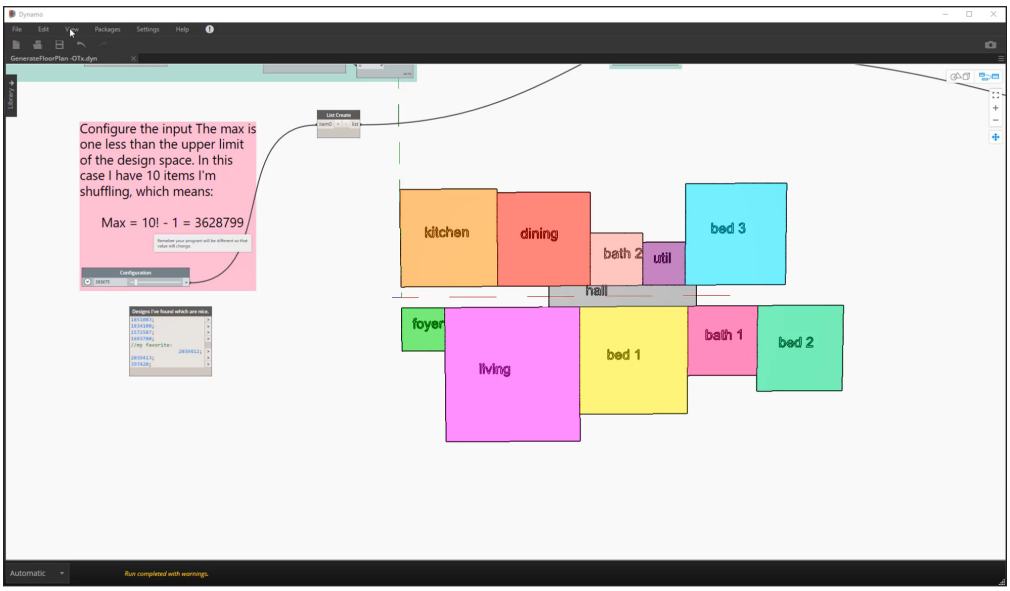

Figure 5 Plan Generator Result by author.

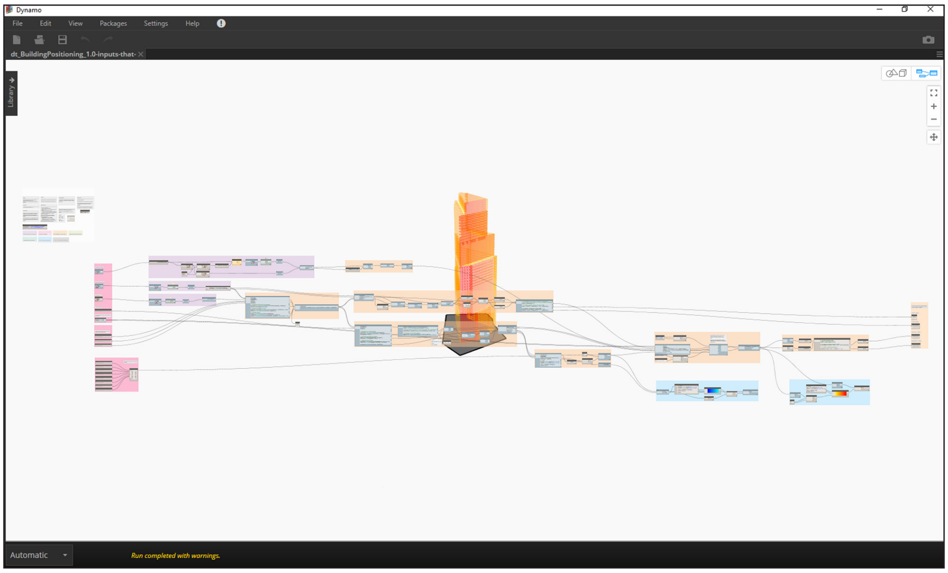

Figure 6 Solar radiation DYN by Autodesk.

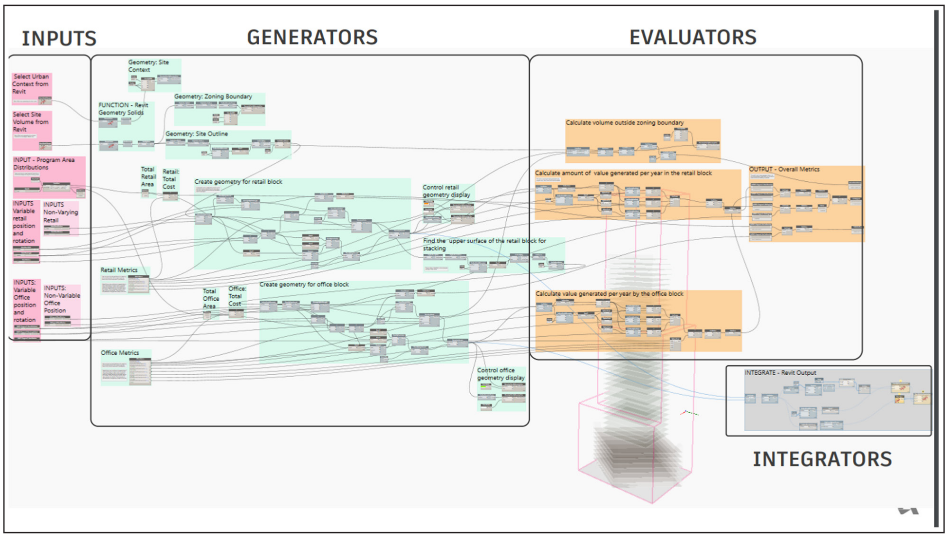

Figure 7 Building Masser DYN by Autodesk.

After using all the above Dynamo script and run it all based on the survey inputs for related data below results have been found.

Table 9 Consumption (KW) the predicted energy usage from the BIM model pilot research utilizing AI Dynamo scripts.

	TIME (M)	CONSUMPTION PRED. (KW)
Months	1	487
	2	570
	3	483
	4	588
	5	515
	6	475
	7	625
	8	595
	9	465
	10	396
	11	372
	12	385
Avg		496.32
System capacity (KW)		3.81

Table 9 Table shows the Consumption predictable in traditional simulation technique without BIM.

VALIDATE BIM-AI MODEL THROUGH REAL-WORLD SIMULATIONS

A preliminary survey of existing residential buildings in Jordan, to identify discrepancies between the predicted energy consumption generated by BIM-AI model and the actual energy usage observed. This process will ensure model›s accuracy and reliability by grounding its predictions in real-world conditions.

A case study technique was employed to refine survey questions assessing the impact of culture on occupant behavior and energy simulation results. Attention was directed towards a conventional house constructed in Irbid in 2020. This one-story residence, covering an area of 150 square meters, featured double-glazed windows, 30 cm-thick concrete exterior walls, and 8 cm of insulation. The ground floor of the dwelling was divided into three zones, as illustrated in Figure 7.

The chosen one-story residence exemplified a typical multifamily residential floorplan and geometric design in Jordan, with heating and cooling systems appropriate to the country's hot, humid, and cold conditions.

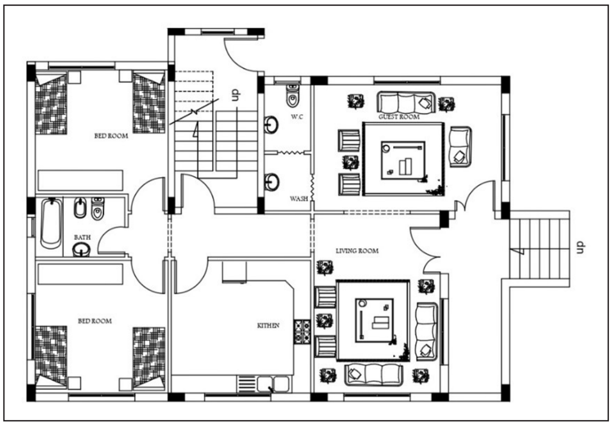

Figure 8 Typical House Plan (Mohammad Alrafai house) by author.

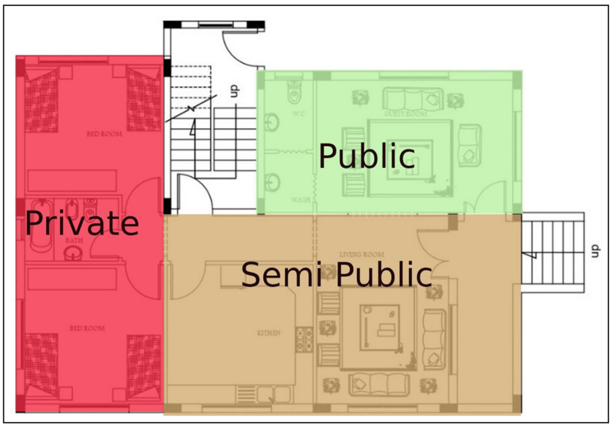

Figure 9 Zones in typical Jordanian house by author.

	TIME (M)	CONSUMPTION ACT. (KW)	CONSUMPTION PRED. (KW)
Months	1	467	500
	2	565	600
	3	470	500
	4	561	610
	5	507	550
	6	463	490
	7	601	650
	8	589	600
	9	448	471
	10	393	401
	11	351	400
	12	379	400
Avg		482.83	514.33
System capacity (KW)		3.71	3.96

(Contd.)

Table 10 The consumption Act and consumption Pred without human behavior and based on the traditional y to calculate.

	TIME (M)	CONSUMPTION ACT. (KW)	CONSUMPTION PRED. (KW)
Months	1	467	487
	2	565	570
	3	470	483
	4	561	588
	5	507	515
	6	463	475
	7	601	625
	8	589	595
	9	448	465
	10	393	396
	11	351	372
	12	379	385
Avg		482.83	496.32
System capacity (KW)		3.71	3.81

Table 11 The consumption Act and consumption Pred with human behavior and based on AI to calculate.

According to the base case has been analyzed there is a gap between the actual and predictable energy consumption in the typical house Jordanian design there is about a 31.5 kw. this gap led to miss understanding for the real energy consumption.

The below table for the Consumption Act from previous pilot house that have been chosen and Consumption predictable that from the BIM with AI created.

DISCUSSION

The survey findings highlight numerous key issues to consider while designing a home. These include the efficacy of resolving privacy issues, cultural factors in architectural practices, skepticism of specific design techniques such as Islamic designs for privacy, and acceptance and opposition to smart home technologies. Furthermore, the table emphasizes the significance of technological solutions for improved home privacy, the usage of curtains for privacy and light management,

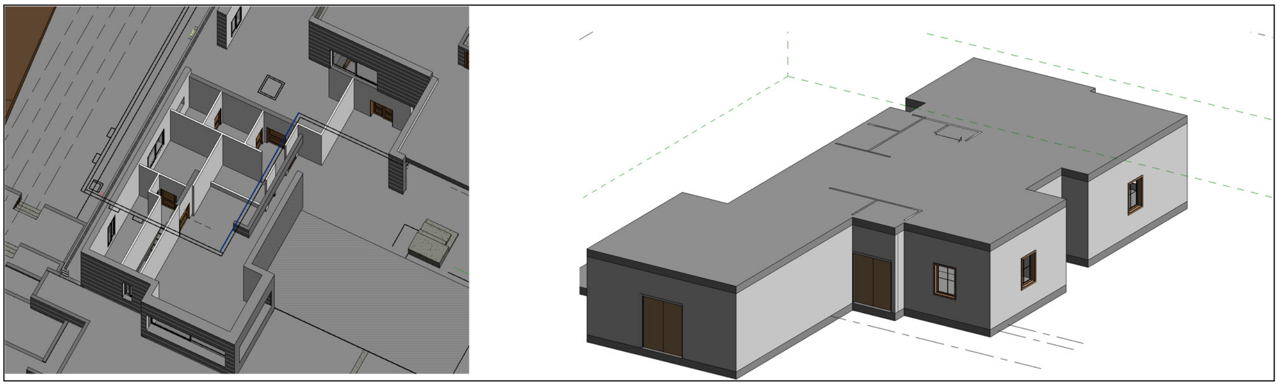

Figure 10 BIM probabilistic mode (Internal) by author. BIM probabilistic mode (External) by author.

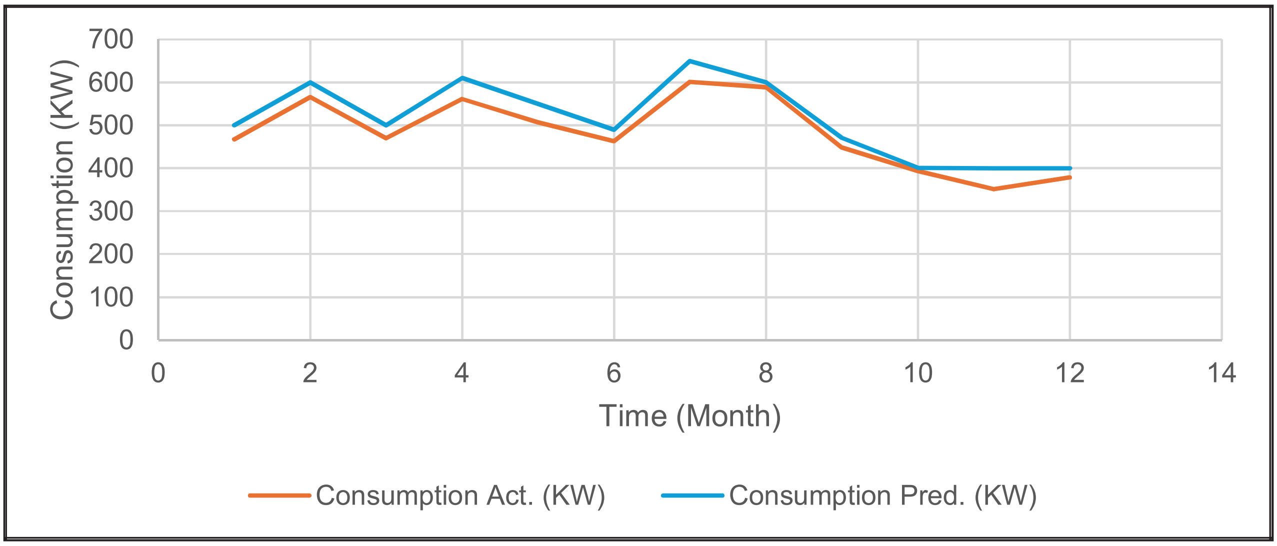

Figure 11 Actual and predictable energy consumption for one year Mohammad Alrafai house).

and the impact of privacy on overall house design. Furthermore, it highlights diversity in lighting control and preferences, the importance of energy economy in lighting decisions, and the influence of daylight occupancy and lighting patterns, Finally, it highlights the impact of technology on privacy and comfort, as well as the need of making seasonal adjustments to house temperature settings.

The decrease in average energy consumption from 514.33 KW to 496.32 KW demonstrates the effectiveness of the AI-enhanced Building Information Modeling (BIM) system in improving the accuracy of energy demand forecasts. Additionally, the investigation into "Predicted System Capacity" in a secondary dataset reflects the model's aim to apply artificial intelligence for the inclusion of predictive analytics, providing deeper understanding of a building's energy capacity potential.

This comprehensive strategy is in line with the fundamental goal of sustainable architectural design, emphasizing the importance of ongoing evaluation and enhancement for achieving maximum energy efficiency. The findings from this comparative study lay a strong foundation for the development of the BIM probabilistic model, offering insightful guidance for the refinement of predictive analytics, enhancement of energy efficiency, and furthering sustainable construction methodologies in Jordan. Incorporating these results into the model presents an opportunity to push the boundaries in optimizing energy use in residential buildings and enriches the discussion on intelligent decision-making in sustainable architecture.

JOB	NUMBER
Junior architects	5
Senior architects	2
BIM modeler	3
draft persons	4

Table 12 Table of focus group members.

FOCUS GROUP DISCUSSION ON THE RESULT SESSION ON THE OUTCOME AND CONCEPT

The model Have been presented to the Group of Junior architects, Senior architects, BIM modeler draft persons as below table.

A- Junior Architects' Perspectives on Improvement

"As young architects, we are inspired by the AI-integrated BIM model's promise to change sustainable design, but we also see room for improvement. To properly use this technology, we recommend making user interfaces more intuitive for individuals starting out in their professions. Furthermore, including additional instructional materials into the model may shorten our learning curve, allowing us to contribute more effectively to sustainable design projects. Tailoring the model to include local architectural styles and materials common in Jordan might increase its relevance and efficacy in our unique design context."

B- Senior Architects' Perspectives on Refinement

"As senior architects, we believe the AI-based BIM probabilistic model is a critical tool for promoting energy-efficient design. However, in order to be really transformational, the model must interface smoothly with existing project management and architectural design tools. Improving interoperability will guarantee that the shift to implementing this paradigm into our operations goes smoothly and efficiently. Furthermore, extending the model to enable more granular control over energy efficiency characteristics would allow us to better customize solutions to customer demands and environmental goals. Emphasizing customization and adaptability will be critical to the model's effect."

C- BIM Modelers' Request for Enhancements

"As a BIM modeler, the use of AI brings up intriguing potential for enhancing building energy efficiency. However, in order for the model to fully realize its potential, we call for improvements in data handling skills, particularly the capacity to filter and evaluate local climate data more efficiently. Improving the program to automatically recommend energy-efficient design changes based on real-time data analysis might greatly simplify our process. Furthermore, enabling a more collaborative environment within the model in which BIM modelers, architects, and engineers may collaborate in real time will promote a more integrated approach to sustainable design.

D- Draft Persons' Recommendations for Development

"As drafters, the prospect of an AI-based BIM probabilistic model to influence our work with an emphasis on energy saving is really promising. To fully utilize this technology, we propose creating more thorough rules and templates particular to energy-efficient construction components. This would not only increase the quality of our sketches, but would also help us comprehend the concepts of sustainable design. Furthermore, boosting the model's ability to provide precise feedback on the energy implications of draft alterations in real time might considerably improve the drafting process, making it more dynamic and informative."

LIMITATIONS AND FUTURE RECOMMENDATIONS

The study's sample population needed expansion, potentially limiting the applicability of its findings to broader Jordanian society. Contextual factors, such as cultural norms, socioeconomic statuses, and geographical variations in climate and lifestyle, required thorough addressing, thereby restricting the comprehensiveness of the study's conclusions. Additionally, reliance on self-reported data for occupant behavior introduced the possibility of biases and errors in reported energy use patterns. Furthermore, focusing on short-term observations overlooked crucial patterns and seasonal variations, emphasizing the necessity for long-term monitoring to gain a comprehensive understanding. Comparative analysis with other nations or areas with similar socioeconomic circumstances needed improvement to provide insights into personalized Building Information Modeling (BIM) adoption strategies tailored to local factors. Another constraint was the need for more evaluation of how BIM technology aligns with current systems and processes in the construction sector. Factors such as integration simplicity, compatibility with existing processes, and the learning curve associated with adopting new technology are crucial in assessing BIM's efficacy and popularity.

Recommendations for future research include:

- Increasing the sample size to improve generalizability.
- Exploring the influence of contextual elements on occupant behavior.
- Utilizing modern technologies for more accurate behavior monitoring.
- Incorporating qualitative research approaches for deeper insights into occupant behavior.
- Expanding the dataset to include a broader range and employing sophisticated methodologies or technologies for enhanced accuracy and applicability.
- Utilizing Internet of Things (IoT) techniques to investigate their effects on human behavior.

CONCLUSION

In conclusion, incorporating AI-enhanced Building Information Modeling (BIM) technologies is a big step forward in tackling the intricacies of occupant behavior within Jordanian house architecture, particularly in terms of energy efficiency. This study emphasizes the critical significance of technological improvements in closing the gap between predicted and actual energy usage by conducting a thorough investigation of energy consumption trends and forecast accuracy. The collaborative efforts of stakeholders, ranging from young architects to drafters, underscore the common goal of improving and modifying these models to fit local circumstances, assuring their relevance and effectiveness. Moving forward, implementing standardized approaches and incorporating occupant behavior data into design software are critical pillars in the development of sustainable residential settings, not only in Jordan but across the world,

The proposed framework offers a systematic approach to standardizing procedures and metrics, empowering researchers and designers to efficiently bridge the occupant behavior gap. Through this paradigm, stakeholders in the field can gain a deeper understanding of occupant behavior nuances and identify design shortcomings. The ultimate objective is to construct residential homes that are not only more efficient but also sustainable, aligning with energy efficiency goals.

The adoption of consistent methods and measurements is pivotal in closing the occupant behavior gap, leading to more precise energy consumption projections and enhanced energy efficiency outcomes. This standardized approach facilitates collaboration among academics, designers, and policymakers, fostering an environment conducive to innovation and breakthroughs in home design practices.

Addressing the occupant behavior gap lays the foundation for more sustainable communities in Jordan and beyond. The insights garnered from this research can guide future endeavors, empowering researchers to delve deeper into the factors influencing occupant behavior and refine design techniques accordingly. Ultimately, integrating occupant behavior data into design software is deemed indispensable for creating energy-efficient residential environments that not only cater to occupants' evolving needs but also contribute to reducing overall environmental impact.

The comparative analysis of energy consumption and prediction accuracy in building systems provides a foundational link to the aspirations outlined in the proposal for a new Building Information Modeling (BIM) probabilistic model based on artificial intelligence to optimize residential buildings' energy efficiency in Jordan. In examining two datasets spanning twelve months each, the study reveals a noteworthy improvement in the accuracy of consumption predictions in the second dataset, This study sets a solid framework for future research and innovation, aiming to create energy-efficient houses that meet the demands of their residents while also contributing to larger environmental sustainability goals....

COMPETING INTERESTS

In accordance with the journal's policy on competing interests, I hereby declare the following in relation to my research submission and potential role as a peer reviewer:

1. **Financial Interests:** I declare that I have not received any financial support that could be interpreted as constituting a potential conflict of interest with respect to my research submission or my duties as a reviewer. This includes the absence of any current financial arrangements with organizations that might have an interest in the published work, such as grants, consultancies, or employment.
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I understand the importance of transparency and integrity in the research and publication process and have provided this declaration to the best of my knowledge and belief. Should any potential conflicts of interest arise in the future, I commit to notifying the journal promptly.

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