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# Интеграция технологий информационного моделирования зданий (BIM) и виртуальной реальности для повышения эффективности эксплуатации объектов строительства

*При назначении технических характеристик здания необходимо учитывать все этапы его жизненного цикла. Этот процесс сопряжен с необходимостью определения ключевых показателей эффективности объекта (KPI), особенно для стадии его эксплуатации. Наиболее эффективные подходы определения данных показателей связаны с применением технологий информационного моделирования зданий и виртуальной реальности. В работе проанализированы возможности совместного использования данных технологий на стадии эксплуатации здания. Предложены методы повышения ключевых показателей эффективности объекта, а также подход к динамическому анализу характеристик здания непосредственно его жителями в ходе его эксплуатации.*

***Ключевые слова:*** *BIM, информационное моделирование зданий, виртуальная реальность, ключевые показатели эффективности, жизненный цикл здания.*

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## Integration between BIM and Virtual Reality for Enhancing the Building and Occupants During the Operational Phase

The performance level of a building is a measure of its success and failure throughout its life cycle. That leads the study to investigate key performance indicators (KPIs) to be measured, evaluated, and improved, especially during the operational phase. Consequently, the research adopts BIM technology and Immersive Virtual Reality (IVR) to model and represent an actual building in a virtual model for conducting the studies and alternatives to save time, effort, and cost, also to increase confidence in the expected results. Moreover, the example of a building used IVR and examples used BIM were analyzed to demonstrate that KPIs need to integrate BIM platforms with IVR technology. Therefore, increasing the efficiency of dealing with all indicators to measure and evaluate the responses and interactions of occupants with alternatives and solutions of this virtual model to develop and improve KPIs. Eventually, deducing and formulating a framework for dynamic interaction between a building and its occupants by integrating BIM and IVR to deal with KPIs.

**Keywords:** BIM, Immersive Virtual Reality (IVR), Key Performance Indicators (KPIs), Operational; Integration.

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Success and failure of a building are measured by what it has achieved from the required performance at the design phase during the operation phase. The built environment has a critical impact on the operation and efficiency of a building. By controlling, optimizing, and modifying the built environment; it can meet the required efficiency of performance [1, 2]. Therefore, to measure the effectiveness of operating a building and achieve the highest level of required performance. It is necessary to evaluate the actual performance of a building and measure the changes in the productivity and motivations of occupants. Here, the need for indicators appears that can through to measure and evaluate the performance of a building and occupants. It is vital to identify KPIs that should not aim at reducing the operating costs, but also improving the operational efficiency [3]. These indicators need tools and means that help to measure them by representing and modeling to can present proposals and al-

ternatives in a virtual reality that is really like the actual building. This interaction depends on developments in the sensor technologies and biometric sensors that offer opportunities to gather information in a synchronized time of both the activities of the building and the behavior patterns of the occupants. This information provides the confirmed reasons behind the particular behaviors of occupants [4]. It has to be provided a framework of the dynamic interaction between a building and its occupants because there is not a correlation between information sets reflect dynamic changes inside a building and spatial behavior states of occupants. Besides, BIM studies present an environment to building managers and what can experiment of an automatic natural interaction of occupants with their building to efficiently access their required performance using the information from BIM with minimum costs [5].

**Research problem**

Problems of buildings have emerged in the operational phase and impacted performance and productivity. As well, they may affect a building life period for several reasons:

- Lack of clarity, identifying, and describing KPIs that control in operating a building and occupants' productivity;
- KPIs are not reviewed or monitored periodically to identify the causes of problems and obstacles affecting a building and its occupants;
- Lack of employing technical tools and means to monitor, control, measure, and evaluate performance periodically;
- These tools and techniques do not use to propose solutions and alternatives to raise the performance of a building and occupants and review KPIs after improving and addressing problems that emerged in reality with minimum costs;
- Lack of controlling in interactions between a building and occupants, which harm performance and productivity and absenting a framework of these interactions.

**Research aim and objectives**

The study aim is to evaluate and improve KPIs of the built environment in the operational phase by a comprehensive framework of the dynamic interaction between a building and occupants to control and enhance those indicators by integrating BIM with IVR. The objectives of this study:

- To collect and define the KPIs of a building and its occupants;
- To profit from BIM potentials through representing, modeling buildings, and helping to measure and apply KPIs on a virtual model to save time, effort, and money. Therefore, it can be developed the actual building by solutions and proposals are provided in this virtual model;
- To profit from IVR potentials by linking and integrating with BIM, which helps users to interact with this virtual model and evaluate it;
- To formulate a framework to control the dynamic interaction between a building and its occupants that controls in KPIs through measuring, evaluating, and improving by BIM linked to IVR.

**Research methodology**

The theoretical approach depended on summarizing, identifying, and classifying KPIs based on the literature survey. The analytical approach addressed the applying challenges of KPIs. Moreover, which means will be used to review and observe periodically to recognize problems and obstacles affecting the performance of a building and occupants. The practical-analytical approach to utilizing and employing BIM as a technical tool and a mean for modeling a building to control, measure, and evaluate KPIs periodically and the synchronized way after linking to IVR as an immersive interactive environment. Besides an applied example of using IVR was analyzed and how to employ and benefit from it to measure and evaluate built environment components and humanitarian aspects. Then the paper will study and analyze case studies have applied BIM to evaluate their buildings after operating to determine any KPIs was evaluated and can in which degree to enhance and raise the efficiency of KPIs. The inductive approach proposed a dynamic interaction framework between the building performance and its occupants, which controls in KPIs to be measured, evaluated, and improved by BIM linked to IVR.

**Key performance indicators (KPIs)**

The performance measurements have not to focus primarily on financial issues, current measurement practices and emphasize aspects like the commercial, work goals, motivate, comfort, and satisfaction [6]. The mutual metrics reveal the performance level of a building like those are correlating to aspects of financial and the built space, but do not indicate presented contribution to strategic results of an enterprise [7, 8]. The performance indicators always need to deal with and control that represent core requirements and limitations in operating a building like communication; emergencies preparedness and business continuity; environmental management and sustainability finance and business; human factors; leadership and strategy operations and maintenance project management; quality; real estate and property management; and, technology [9]. KPIs are as a type of metrics to measure the degree of performance of systems, processes, or services inside a building. The pur-

pose of gathering information and calculating KPIs is to analyze the effectiveness and efficiency of measures, which have been taken to improve planning and service processes [10, 11]. Therefore, those KPIs need to meet basic requirements and needs:

- The experimental and operational goal: KPIs must reflect the overall project's aims and be able to measure meeting occupants' needs, also all costs and effort;
- Precision and inclusive: Describing and estimating of KPIs must not neglect any scope for argument or manipulation;
- Controllability: KPIs should be the cause of intelligent decisions as new variables can be controlled by these adequate decisions. Therefore, KPIs demand to be recognized as external variables for planning the performance and services; and
- Measurability: KPIs should be identified clearly and measured quantitatively without any extreme costs. In addition, it should provide the required data.

Hence, the study has followed the classification of indicators in four categories as physical, financial, functional, and survey-based, which depended on the previous studies in Table 1. It should emphasize that the indicators were improved through other studies and are introduced to use in most cases [2, 10]. These KPIs have been classified as unquantifiable or depend on subjective, inherent opinions or self-estimation as "survey-based" KPIs [8]. Major thirty-five indicators were defined by the previous studies to establish sets of KPIs. The introduced list of indicators reflects researchers' views and perception. In a survey study was conducted on the industry representatives' opinions were obtained by the brief of eleven the building management professionals who were involved in the building management services and consultancy [1].

- ***Physical Indicators:*** the appropriateness and efficiency have been required to achieve functions, space quality, accessibility, and resource consumption.
- ***Financial Indicators:*** Those all correlate to cost are collected to show costs and payment. They provide an immediate evaluation can be utilized to make decisions.
- ***Functional Indicators:*** organizational or business mission, employees, and other support aspects in terms of adequacy of occupants and productivity. Hence, they will reveal the state of spaces, productivity, and change rates, which measure occupants' satisfaction.
- ***Survey-Based Indicators:*** They cannot quantify or are collected by meeting occupants. Surveys use a questionnaire typically in which the questions depend on the type of study like permanent or temporary occupants, and any other that the study needs. They can be useful to measure the environmental and psychological aspects where the highest importance is given based on reactions and opinions.

**Challenges and obestacls in measuring KPIs**

Through the previous presentation of the key performance indicators and their classification. The study has taken into consideration the challenges to apply and utilize KPIs [2, 13]: choosing the related KPIs; documenting KPIs clearly and accurately; collecting data on KPIs; analyzing the origin causes of low performance and coming up with recommendations; making decisions based on KPIs results; dealing with indicators by: A – periodic follow-up, B – make decisions continuous of improvement (Resources), and C – engage stakeholders.

**BIM as a technical tool for dealing with KPIs**

Needing for Building Information Modeling (BIM) has lately increased as much international company and government taking the initiative to support BIM in a building life cycle. Moreover, BIM ensures to benefit from efficient information in building management [14]. There will be an improvement of the life quality in the workplace because BIM encompasses multiple disciplines to ensure the highest functionality and productivity of the built environment by integrating occupants, place, processes, and technology [9, 15]. The BIM application platforms like (Revit-ArchiCAD-Bentley); BIM project management and coordinating like (Tekla-Vico-Bentley-ProjectWise); and, BIM energy study tools like (Green Building Studio – Energy Plus – Integrated Environmental Solutions) [16]. Therefore, employing BIM for building management at the occupancy and operational phase can benefit from BIM not only for 3D visualization purposes, but also for controlling, measuring, and evaluating KPIs, space planning, renovation, or maintenance by modeling and representing a building, elements, and systems that always contributes in operating to support KPIs synchronized periodically [5, 17]. An integrated BIM system is capable of supporting operations of the building management comprehensively. Motivating possibilities for partners to adopt BIM during operating the building in cases of evaluating the design, The potentialities of partners are being motivated to adopt BIM during operating a building and evaluating design cases, infrastructure complexity, sustainability, cost, reliability, and management [18]. In addition to BIM will help: to efficiently perform a building permit; to use visual and intelligent metrics to rapidly evaluate the retrofit impact and maintenance; to quickly gather and edit building operations databases; and, to manage built environment from Mechanical, Electrical, and Plumbing (MEP) systems with BIM asset operating tools. The advantages of integrating BIM at the operational phase: the cost of effective operation; shorter time for making decisions; resource for making decisions;

***Рис. 1.*** *Показывает среду без погружения (слева) и среду погружения – стереоскопическая визуализация (справа)*
***Fig. 1.*** *Shows the non-immersive environment (left) and the immersive environment (right) [21]*

better way for documentation systems; flexible collaboration and work; updated information; and, conflicts discovery [9]. Building management practices contribute 5–10% of the gross national product of some countries, and the full costs during the building life cycle may be seven times higher than the initial costs [19]. A key set of activities during operation related to maintenance and repair and some unnecessary costs happen while performing them. In another study, BIM could be implemented and benefited for different application areas of the building operations such as: locating building elements; facilitating real-time data access; 3D visualization; checking; maintainability; marketing; creating and updating digital data; space supervision; risk management; planning and feasibility studies for non-capital construction; managing and monitoring energy; and, self-education and improvement [14, 17]. Five main challenges must be overcome to promote suitable BIM models for managing sustainable operational: identifying critical required information to inform operational decisions; the high level of effort to create new or modified existing BIM models for the buildings; information transfer is managing between actual time operations, control systems, and BIM model; dealing with uncertainty based on incomplete documents of a building; and, the behavior of dealing with spaces, the building elements, and occupants' productivity [18, 20].

**Integration immersive virtual reality (IVR) with BIM**

Automatic natural interactions between the occupants, an environment, and a building can be controlled and monitored to observe reactions [21]. Therefore, evaluating those reactions and the spatial perception of a user for doing efficient procedures to access their required performance by linking BIM with IVR as the immersive environment to represent occupants' behaviors within an environment was built by BIM. Thus, it will help to save time and costs, also access to decisions that help to develop performance as soon as possible. Virtual Reality (VR) is described as a reality and immersive simulation of a 3D environment that was created using interactive software and hardware experienced and controlled by body movement [22, 23]. Adopting the building representation is near to the human experiment in the reality that will promote the development of buildings correspond with actual users. The differences between non-immersive and immersive virtual reality is accurately the degree of presence or engagement where the immersive sample strives to improve by utilizing stereoscopic visualization and other means as Fig. 1. As the perception process continues to enter via various sensory stations, so the immersive preparation gives the more interfaces, the more likely it is to facilitate extraordinary levels of attendance [21, 24].

In immersive environments; stereoscopes; widely view fields; and, high interaction that are critical elements for reaching the highest presence levels. The presence affected by environmental factors and personal tendencies. For example, one's ability to do selective attention (concentrating on virtual motives and ignoring motives from the physical environment) be relevant to experience powerful presence degrees [24]. Due to the level of spatial perception solely; it cannot forecast the degree of attendance and the quality of design proposals [22]. Thus, the lack of attendance is the reason for low spatial perception [25].

**Investigating and analyzing an applied example of IVR to evaluate KPIs**

Explaining how to use and benefit from IVR to measure and evaluate built environment components and humanitarian aspects. Another study executed an experiment at the entrance hall of the architecture school building

in Brazil was selected as a physical environment can be modeled as in Fig. 2 by these procedures [21].

First, the choice guidelines were to obtain the required data for making the two 3D models; the physical space; the adequate level of complexity; the variety (Proportions-Structure elements-Shapes); and, physical nearness to the laboratory for the immersive environment to be established. Second, the two virtual models optimized concerning each platform. The first virtual model produced by AutoCAD utilizing Sketch Up platform is non-stereo to experiments in a non-IVR environment. The second model using the Unity platform that allowed for converting the regular 3D model into a stereoscopic model to examine inside the immersive environment. Consequently, the second model is a stereoscopic version of the first: the same design of the floor surface, material, and illumination. Both simulations could be categorized as a modest exploratory virtual reality (Revit as a BIM platform could use to represent or model that model). The exploratory virtual reality is where a user able to investigate the environment by identifying a person's path, pausing at aimed locations, and concentrating on specific elements. The term modesty is relevant to the level of reality of a 3D model that has low-resolution render influences like (Illumination-Shade-Shadow-Material). Both models operate on the same workstation and utilize the same interaction devices. Third, preparing the three-difierent questionnaires for each environment: (the non-immersive; immersive; and, physical). Required questions are arranged to motivate the respondent perception of space elements. Fourth, a preliminary experiment was conducted to test the equipment and perform final adjustments. From fifth to eighth are procedures for gathering data and were executed in this order, with one respondent at a time. Respondents interacted with the non-immersive, immersive, and physical environment. In the ninth step, the responses in three environments were compared. The

***Рис. 2.*** *Представление и модель IVR холла Школы архитектуры и дизайна, UFMG, Бразилия [21]*
***Fig. 2.*** *Shows the representation and model of IVR of the Entrance Hall of Architecture and Design School, UFMG, Brazil [21].*

**Таблица 1**
**Table 1**

**Четыре категории KPI** [1–3, 6–8, 10–12]
**Shows the four categories of KPIs** [1–3, 6–8, 10–12]

| Physical | Financial | Functional | Survey-based |
|---|---|---|---|
| The building state (quantitative): Building Performance Index (BPI) | Operating costs. | Productivity | Users' satisfaction with services |
| The building state (qualitative): maintenance; physical state; sanitary; plumbing; mechanical services; lighting; electrical | Occupancy costs | Parking | Community satisfaction and participation |
| Property and real estate | Capital costs | Employee or occupant's turnover rate | The learning environment, its appropriateness (building-functions) |
| Waste | Utility costs | Mission Dependency Index (MDI) and vision | Appearance |
| Safety and health | Building maintenance cost | Occupant's satisfaction with function or service | |
| Indoor environmental quality (IEQ) | Grounds-keeping costs | Adequacy of space | |
| Accessibility for handicapped | Guarding Cost | The learning environment and functional suitability | |
| Energy resource consumption: use net annual energy; natural gas; electric | Current replacement value (CRV) | Community satisfaction and participation | |
| Resource consumption – water | Deferred maintenance, and deferred maintenance backlog | Appearance | |
| Resource consumption – materials | Capital renewal | Space utilization | |
| Security | Maintenance efficiency Indicators (MEI) | | |
| Site and location | Building condition index (FCI) | | |
| | Movement costs | | |

respondent was not expected to be accurate in perceiving the immersive environment exactly as the physical environment, despite the perception decreased inside the non-immersive environment. Finally, these comparisons will show the perception of maintenance indexes, which will serve for all subsequent analysis and enhancements from KPIs as in Table 1.

Therefore, from the mentioned case study; these motivating alternatives and application fields will play a very significant role during using BIM in a building. BIM will integrate with new programs to capture information as IVR through it can operate a building in an easy way. Hence, IVR will support interaction with the required BIM information in a studied building and take into account human aspects and productivity. BIM and IVR are used, employed and integrated into the building management operations are still new, and there is little practical data on these issues. The studies have used ways like online-surveys and scenarios to examine the use and integration of BIM and IVR for operating and occupying a building ideally and efficiently. IVR as apart from the mixed intelligent reality is a progression of conventional virtual reality environments and the most hopeful expression of ambient intelligence. IVR provides a user to see the real world, with virtual objects overlapped or composited with the real world. Therefore, IVR adds reality, rather than completely replacing it. That makes IVR is a good choice to manage a building and traditional tasks based on the live show of spaces that can integrate into databases and they need all in one interface. The study of IVR helps to solve real-world problems because there is no need for a distracting switch domain. Furthermore, since building managers are continually moving through spaces, having a portable to a computer or a mobile device will be beneficial if they were to employ IVR in their responsibilities [22]. Having a sophisticated and comprehensive BIM model includes the required information. Besides a 3D model of all elements and systems in a building can be used as a database that can be integrated with IVR to provide an intelligent environment for building managers to examine the level of processes of operating and maintenance [26].

### Analyzing the applied examples of BIM to evaluate KPIs

In this section, the study will investigate and analyze case studies have applied BIM to evaluate their buildings after operating to determine any KPIs were evaluated to can develop, enhance, and increase the efficiency their KPIs as in Table 2, these cases:

1. The first: a parking garage project its structure made of the precast concrete [27].
2. The second: a sports complex, including a baseball stadium and clubhouse [27].

**Таблица 2**
**Table 2**

**Контрольный список KPI, которые были измерены и оценены для каждого случая**
**Shows the checklist of KPIs that each case had been measured and evaluated**

| KPIs | | The case | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Physical | A physical building state (quantitative): Building Performance Index (BPI) | ✓ | ✓ | ✓ | ✓ | ✓ |
| | A physical building state (qualitative): maintenance; physical state; sanitary; plumbing; mechanical services; lighting; electrical | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Property and real estate | | | ✓ | | |
| | Waste | | | ✓ | ✓ | ✓ |
| | Safety and health | ✓ | ✓ | ✓ | ✓ | |
| | Indoor environmental quality (IEQ) | | | ✓ | ✓ | ✓ |
| | Accessibility for handicapped | | | ✓ | ✓ | ✓ |
| | Resource consumption energy: use net annual energy; consumption; natural gas; electrical | | | | ✓ | |
| | Resource consumption – water | | | | ✓ | |
| | Resource consumption – materials: material consumption | | | | ✓ | ✓ |
| | Security | | | ✓ | ✓ | |
| | Site and location | | | ✓ | | |
| Financial | Operating costs | ✓ | ✓ | ✓ | ✓ | |
| | Occupancy costs | ✓ | ✓ | | ✓ | |
| | Utility costs | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Capital costs | | | ✓ | | |
| | Building maintenance cost | ✓ | ✓ | | ✓ | |
| | Groundskeeping cost | | | | | |
| | Guarding Cost | | | | ✓ | |
| | Current replacement value (CRV) | ✓ | ✓ | ✓ | ✓ | |
| | Deferred maintenance, and deferred maintenance backlog | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Capital renewal | ✓ | ✓ | ✓ | | ✓ |
| | Maintenance efficiency Indicators (MEI) | ✓ | ✓ | | ✓ | ✓ |
| | Building condition index (FCI) | ✓ | ✓ | ✓ | ✓ | |
| | Movement costs | ✓ | ✓ | | ✓ | ✓ |
| Functional | Productivity | | | ✓ | ✓ | ✓ |
| | Parking | | | ✓ | | |
| | Employee or occupant's turnover rate | | | | | ✓ |
| | Mission Dependency Index (MDI) and vision | | | ✓ | ✓ | |
| | Customer/building occupant satisfaction with products or services | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Adequacy of space | | | ✓ | ✓ | ✓ |
| | The learning environment, educational suitability, and functional suitability | | | ✓ | ✓ | ✓ |
| | Community satisfaction and participation | | | ✓ | ✓ | ✓ |
| | Appearance | | | ✓ | ✓ | ✓ |
| | Space utilization | ✓ | ✓ | ✓ | | ✓ |
| Survey-Based | Customer or building occupants' satisfaction with products or services | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Community satisfaction and participation | | | | ✓ | ✓ |
| | Learn environment, educational suitability, and appropriateness | | | ✓ | ✓ | ✓ |
| | Appearance | | | ✓ | ✓ | ✓ |

3. The third: a municipal Centre with commercial buildings and the new Vilnius County building, in Lithuania, north-eastern Europe [28].
4. The fourth: Kerr hall east at Ryerson University in Toronto, Ontario, Canada [20].
5. The fifth: the case using IVR that previously mentioned to measure and evaluate the components of the built environment and humanitarian aspects [21].

After KPIs have been reviewed and collected as a checklist in the above table from the previous study cases was addressed in other researches. The study found the four cases focused on physical environment aspects more than behavior and performance aspects of users like productivity, users' comfort, and positive interaction with built environment elements. In addition to the study found that the fifth case used IVR technology, which focused on users' interaction with components and elements of the built environment and indicators need to be a practical survey from occupants even if only at the expense of financial indicators. Consequently, the research aim is to deal with these indicators and consider them at the operational and occupancy phase through integrating BIM and IVR for treating deficiencies and obstacles them to evaluate and improve the performance of a building and occupants. Thus, the need has emerged for a framework for dynamic interaction between a building and its occupants, which controls in KPIs to evaluate and improve them by BIM based on IVR.

## A proposed framework of a dynamic interaction between its occupants through integrating BIM with IVR

As an inductive approach; the study proposes this new comprehensive framework and modeling system supports the dynamic interaction of the building spaces and occupants to collaborate towards improving productivity (the performance of the building spaces and occupants) and the sustainability of the built environment. The proposed framework steps are: to check the building spaces and occupant conditions; to perform feedback: presenting information about each part about own condition; transparency principle: providing information about the state of a building and occupants; to represent and model the building with all components and systems using BIM; to link the BIM model with IVR; to study and analyze a building by IVR was discussed in this paper and all other available methods (questionnaires and surveys) of gathering and analyzing information to deal with all them; to establish the common working field: defining KPIs of balancing the goals and constraints of a building and occupants; to make mutual decisions by analyzing procedural alternatives of a building and occupants to achieve the common purpose; to develop the BIM model; to repeat the sixth step; to take procedure (based on KPIs by measuring and evaluating); and, to offer the proposals, solutions, and recommendations to enhance and support KPIs at the operational phase (or return to the tenth step). The framework steps represent periodic cycles of the dynamically interactive dialog between a building and its occupants to achieve the balancing sustainability of the building performance and its occupants. Supporting more holistic related data set and analytics focused on spatial, temporal, and psychophysiological states, the framework uses qualitative and quantitative tools to collect the required information types and the appropriate metrics through a virtual model of the actual building.

## Discussion

The KPIs that were studied as in Table 2 according to the individual conditions and the purpose of each project. The KPIs that were not included in the previous studies (at the first, second, third, and fourth cases) were addressed in the fifth case of IVR because either the building didn't provide other means and systems to serve all KPIs or the BIM models of those cases were not linked with IVR or another technology. In the case study of IVR was analyzed and motivated occupants' spatial perception of the following: vertical distance; area; quantifying; horizontal distance and between elements, shape; and, positioning. In addition to the BIM model can provide them to measure and evaluate, but the occupants' reaction remains the influential factor within objective questions with equivalent choices; the questions were taken to motivate the occupant's perception to evaluate the occupation efficiency. Therefore, the case study of the IVR could use the BIM platforms rather than the used software where it can benefit Interferences between different disciplines in the modeling stage, which hinder unifying the team's goal and working to make it more successful that needs much effort to resolve. The difference in results between the studied BIM model and actual reality in nature in most cases because of potentials. Researchers and users of this new method accepted and understood for measuring and evaluating performance by minimum costs throughout all phases. Methods of data gathering and survey are used to analyze, measure, evaluate occupants' interactions in the built environment, also develop interaction between them to be more positive that may impact on the result.

## Conclusions

The research has demonstrated the importance linking BIM to IVR and confirmed that through a proposed framework of interaction between a building and its occupants to measure and evaluate KPIs at the operational phase; also, controlling in the required productivity level by those KPIs. The research has addressed the KPIs were collected from previous studies and reviewed them in the cases addressed KPIs to check and evaluate in

the buildings at the operational phase. Besides, there were deficiencies and obstacles at measuring and applying KPIs because of the limited BIM model can deal with human aspects and measure KPIs associated with it. Hence, the fifth case study that based on IVR enabled from measuring, evaluating, developing, and dealing with KPIs related to the humanitarian aspects and productivity after using IVR technology as was presented in the paper. In addition to reducing differences often occurs between what specialists hoped; what is actual; and the minimum cost, effort, and time. All of these push at the end of the study to formulate a framework for managing the dynamic interaction between a building and its occupants to can apply a BIM model linking to IVR at the building in the operational and occupancy phase to deal with all KPIs. The research has presented a proposal for dealing with KPIs through technological tools to measure, evaluate all types of indicators, then support, and improve them with the maximum accuracy in the operational phase and their relationship with occupants' performance. Furthermore, there may be other methods will be presented by researches and other studies that need to be investigated and evaluated in the future. Besides, future projects can benefit from this study to apply BIM linked to IVR in their life cycle phases and introduce proposals for evaluating and improving their KPIs as the initiative to promote BIM in building life cycles.

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