PROJECT, DESIGN AND MANAGEMENT (PDM)
https://www.mlsjournals.com/Project-Design-Management
ISSN: 2683-1597

(2025) Project, Design and Management, 7(1), 7-28. doi.org/10.35992/pdm.v7i1.2816.

IMPACT OF NATURAL DISASTERS ON HOSPITAL INFRASTRUCTURE IN GUATEMALA AND ITS MITIGATION THROUGH THE USE OF BIM

IMPACTO DE LOS DESASTRES NATURALES EN LA INFRAESTRUCTURA HOSPITALARIA EN GUATEMALA Y SU MITIGACIÓN MEDIANTE EL USO DE BIM

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Manuscript information:

Recibido/Received: 14/06/2024
Revisado/Reviewed: 22/08/2024
Aceptado/Accepted: 11/11/2024

Keywords:
hospital infrastructure, BIM methodology, natural disaster mitigation, resilience.

ABSTRACT

Guatemala is a country located in position 10 of the countries with the highest risk of natural disasters in the world. Likewise, COVID-19 highlighted the need to strengthen the resilience of hospitals in the face of health emergencies, because they simultaneously continued to provide care during outbreaks of infectious diseases, social, financial and other crises. This creates the need for buildings that have the capacity to adapt to such natural phenomena so that people can use their facilities and that they are functioning. In this sense, the use of Building Information Modeling BIM is proposed as a work methodology to design and build complex buildings and can be used for the design, construction, maintenance and demolition of hospitals. Because there are still no plans or programs for the mandatory use of BIM in Guatemala, it was decided to carry out an exploratory investigation with its primary exploration methods; through interviews and a secondary survey; collecting information from previous uses of BIM use cases, answering questions about what, why and how the development of hospital infrastructure would be carried out, the impact of natural disasters on said infrastructure and its mitigation through the uses of BIM. According to the discussions and conclusions of the results obtained in the interview, surveys and data obtained on secondary researches, it is possible to mitigate the impact of natural disasters on hospital infrastructure through the use of the BIM methodology in Guatemala.

Palabras clave:

RESUMEN

Guatemala es un país ubicado en la posición 10 de los países con mayor riesgo de desastres naturales en el mundo. Asimismo, el COVID-19 puso de manifiesto la necesidad de fortalecer la resiliencia de los hospitales frente a emergencias de salud, porque

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infraestructura hospitalaria, metodología BIM, mitigación de desastres naturales, resiliencia.	simultáneamente estos continuaron brindando atención durante brotes de enfermedades infecciosas, crisis sociales, financieras y otros. Esto crea la necesidad de construcciones que tengan la capacidad de adaptarse ante tales fenómenos naturales para que las personas puedan hacer uso de sus instalaciones y que éstas se encuentren funcionando. En ese sentido, se propone la utilización de Building Information Modeling BIM como una metodología de trabajo para diseñar y construir edificaciones complejas y puede utilizarse para el diseño, construcción, mantenimiento y demolición de hospitales. Debido a que aún no hay planes ni programas de uso obligatorio de BIM en Guatemala, se optó por realizar una investigación exploratoria con sus métodos de exploración primaria; a través de entrevistas y una encuesta y secundaria; recopilando información de casos previos de uso BIM, respondiendo las preguntas sobre qué, porque y cómo se llevaría a cabo el desarrollo de infraestructura de hospitales, el impacto de los desastres naturales en dicha infraestructura y su mitigación mediante el uso de BIM. Según las discusiones y conclusiones de los resultados de las entrevistas, encuesta y datos obtenidos y presentados en la investigación secundaria es posible mitigar el impacto de los desastres naturales en la infraestructura hospitalaria a través del uso de la metodología BIM en Guatemala.

Introduction

Due to its physiographic and geotechnical characteristics, Guatemala is prone to natural disasters such as hurricanes and tropical storms, floods, earthquakes, volcanic eruptions and landslides that have caused economic, social and welfare impacts on the Guatemalan population (Barillas, 2022). In this regard, according to the National Coordinator for Disaster Reduction (CONRED) (2021) "the Republic of Guatemala ranks 10th among the countries with the highest risk of disasters in the world".

According to the Pan American Health Organization/World Health Organization PAHO/WHO (2023a) indicates that:

The COVID-19 pandemic highlighted the need to strengthen the resilience of hospitals to health emergencies and disasters, not only because they have been the backbone of the response, but also because they simultaneously continued to provide care during all types of disasters, infectious disease outbreaks, social, financial and other crises (para. 1).

In this regard, as part of the programs for the implementation of hospital infrastructure resilient to health emergencies and natural disasters in Guatemala, CONRED indicates that the Executive Secretariat of the National Coordinator for Disaster Reduction together with representatives of WHO and PAHO, as well as the Ministry of Health and Social Assistance MSPAS met to learn about the Protocol for the Application and Certification of Standards for Disaster Reduction (NRD) that establishes safety guidelines in buildings, both in new designs and remodeling or repairs of existing work in order to prevent all kinds of damage to the integrity of the people who occupy it and to the infrastructure itself and to work on a Manual or Protocol for Safe Hospitals in the country (2013, para. 1 to 4).

As a result of the above, Guatemala has addressed the issue of reducing the impact of natural disasters on hospital infrastructure by means of a manual of protocols and standards. Consequently, this research proposes the use of the Buiding Information Modeling (BIM) methodology in the design for the construction of hospitals in Guatemala. Authors such as Meléndez et al., (2019, pp. 153-157) states that:

BIM... is a working methodology that generates and manages the data of a building project from the very beginning of the design process, optimizing documentation and project management... is a data creator and manager to design and construct large building works, considering the project geometry and additional data... in a three-dimensional way and in real time... can be used to illustrate the complete building process, maintenance and even demolition.

The above is an indication that BIM methodology can be a valuable tool in hospital construction, in addition to what Bustos & Sosa (2021a, pp. 91 and 92) state:

Hospitals being built in the State of California...involve building systems and processes integrated with BIM [shaping] resilient buildings capable of remaining in operation even during an earthquake measuring 9.0 or higher on the Richter scale. [Performing] space clearance simulations... [allowing] to identify problems such as dimensions and circulation distributions, correct and then, bring them to reality. [Avoiding] tragedies. The benefits of BIM do not end with the delivery of the work, they continue during its management and even in the case of a possible remodeling or demolition... by means of the digital model and with the support of specialized software, energy analysis, natural lighting analysis, ventilation analysis, interior temperature analysis, sunlight and radiation analysis can be performed.

The previous work that can be done during the design of a construction with BIM methodology is noteworthy, since it is possible to anticipate the construction development by performing functional tests of the infrastructure to be built and observe in the BIM model created the behavior before certain events, thus saving lives and guaranteeing the resilience of the building to be developed, up to the demolition and even the reuse of recyclable materials in the mentioned infrastructure, hence the importance of the benefits of the use of BIM for hospital infrastructure design projects as mitigation against natural disasters that constantly affect Guatemala.

In this sense, a research instrument was designed which consists of a closed dichotomous survey, designed by the author of this research and once it was carried out, it was reviewed, corrected and validated in its content by two architects, the first designer, consultant and supervisor related to hospital infrastructure and the second specialist in hospital design, both with knowledge in BIM methodology.

In summary, the questions asked to the participants and contained in the aforementioned research instrument are as follows: 1. Do you develop hospital projects in Guatemala? 2. Do you know of any hospital construction projects using BIM methodology in Guatemala? 3. Do you know of any BIM implementation plan or program for infrastructure development in the country? Do you consider it possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction using BIM methodology? 5. Do you consider it important to implement the BIM methodology in the construction of hospitals in Guatemala?

Method

Design

Since there are still no mandatory programs for the implementation of the BIM methodology for hospital design in Guatemala, an exploratory research was conducted with its primary and secondary exploration methods answering the questions of what is needed, why it is needed and how the development of hospital infrastructure using the BIM methodology would be carried out locally. Is BIM methodology being implemented in hospital design and construction in Guatemala? Are there institutions that offer technical and professional training based on formal education on BIM methodology in the country? Is it possible to develop design and construction projects, as well as to give continuity to hospital infrastructure already built with BIM methodology in Guatemala?

Participants

Primary research was carried out through interviews with a first group of eight expert designers of hospital infrastructure in the areas of architecture, civil and mechanical engineering, electrical and plumbing (MEP) to extract information on the use of BIM in the design and construction of healthcare infrastructure and its positive impact on natural disasters and general recommendations that the experts could provide.

In the second group, seven experts in general infrastructure design were interviewed in order to determine the development and use of BIM models in Guatemala, team or collaborative work with this methodology and its results, as well as the implementation of BIM in the country and the use of simulation programs by specialty associated with this methodology, among others.

On the other hand, with a third group, a closed dichotomous survey was conducted with modelers, designers and executors of infrastructure in general and of health care centers to answer questions about the use of BIM, whether or not they consider it

important to develop construction projects in general using the aforementioned methodology and whether they have or are developing hospital infrastructure projects with BIM.

Finally, as secondary research, information was collected from previous cases in Guatemala on the use of BIM in the design and construction of hospitals or infrastructure in general in the country.

Research Instrument

A research instrument was designed consisting of a closed dichotomous survey for which 15 people were selected from a population of 50 BIM modelers, students, teachers, developers and/or designers, design and construction project managers in general and hospital project managers. However, it is important to mention that a pilot test of the survey, test or questionnaire was carried out, in order to subsequently carry out the final test.

To define and validate the population and the sample, we approached representatives of companies and educational entities, both related to design and construction, as well as BIM knowledge. Those involved in the survey were given a written informed consent document, indicating that the data and opinions obtained will be kept confidential and strictly confidential, and will not be associated with any particular opinion.

Validity and Reliability

The research instrument was designed by the author of this research and once it was completed it was reviewed, corrected and validated in its content by two architects, the first a designer, consultant and supervisor related to hospital infrastructure and the second a specialist in hospital design, both with knowledge in BIM methodology. These experts have given their opinion on the objectivity of these questions and have validated their understanding of the formulation of the questions or queries and their delimitation in terms of critical aspects for the data analysis procedure and, therefore, the results of the same.

Research Development Process

Four steps were developed for the development of the research process of this work, as shown in Figure 1 below.

Figure 1
Steps for the development of this research

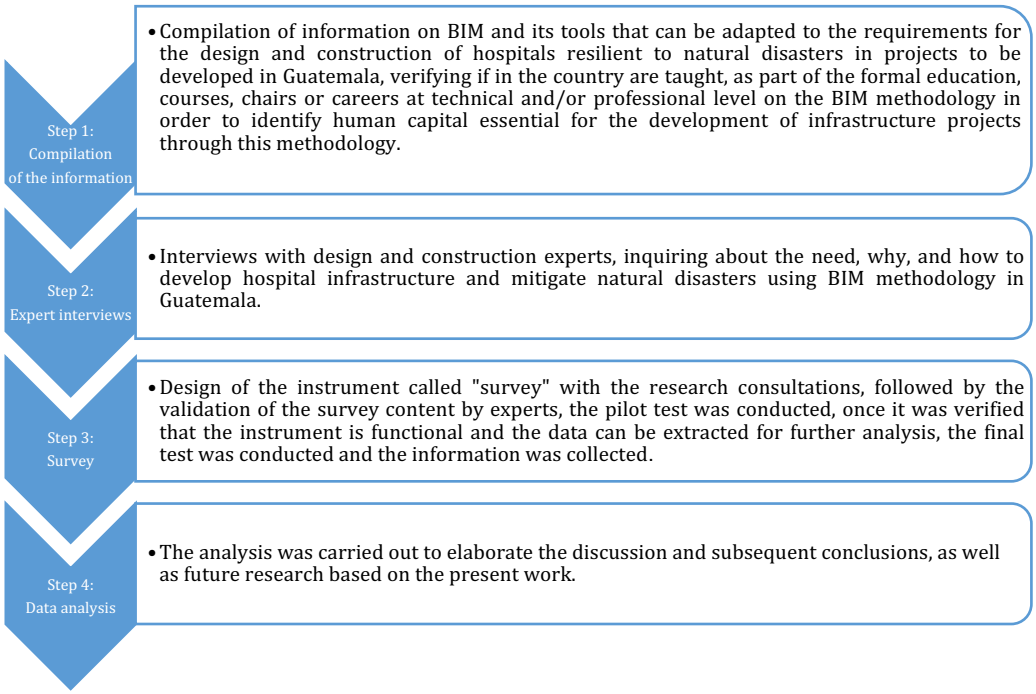


Figure No. 1 shows the work in interviews with professionals in the area and the design of the instrument called "survey", in the interviews the experience of working on projects with the BIM methodology and/or with programs aimed at making hospitals resilient to natural disasters and the results that they have obtained, the survey is oriented to closed dichotomous answers on the knowledge of the methodology and/or the aforementioned programs developed in Guatemala.

Procedure and Data Analysis

In accordance with the approaches taken and with the information gathered, it is possible to answer these questions, which are as follows:

1. Why implement design projects for the construction of disaster resilient hospitals in Guatemala using BIM methodology?

To that end, WHO/PAHO (2023b) states:

The growing need for Resilient Hospitals in the face of health emergencies and disasters in the Region of the Americas is also based on scientific evidence that demonstrates the importance of these hospitals being resilient, sustainable (SMART), inclusive, flexible and adaptable, in order to learn from experiences and recover in a timely and efficient manner (para. 2).

In fact, health care centers in the regional area are affected by natural disasters, requiring buildings that can withstand and provide services to the population in need and according to Bolaños (2020a), Guatemala was affected in November 2020 by tropical depression ETA, reporting 21 deaths, 103 missing persons, 3,125 people at risk, and 27,129 evacuations. Hurricane Mitch hit in 1998, catalogued by the Hurricane Center of Miami, USA as one of the worst hurricanes in the last quarter century, with official figures of 268 deaths and an economic impact of 1,061.4 million US dollars in losses. In 2005, as a result of tropical storm Stan, a landslide caused the disappearance of the community of Panabaj (para. 1-12).

As a result, the country has suffered great devastation from tropical depressions. Regarding disasters caused by volcanic eruptions in Guatemala, Bolaños (2020b) mentions that in 2010 the Pacaya volcano made a strong eruption and at the same time tropical storm Agatha made landfall on the Atlantic coast of the country, between both events the primary population affected was 104,052 people affected, 159,882 evacuated, 110 missing, 92 injured and 193 dead, as well as 74,214 sheltered. In 2018 the Volcán de Fuego erupted leaving 201 people dead and 229 missing (para. 19-22, 35-39).

Also, in addition to natural disasters caused by volcanoes and storms, there has been damage caused by earthquakes in the country, according to Bolaños (2020c), the population of San Marcos recorded two earthquakes, the first in 2012 and the other in 2014, causing losses of about 128.5 million US dollars, reporting for the second earthquake about 50 deaths and multiple damaged houses and buildings. In 2017 an earthquake was recorded causing damage in San Marcos, Huehuetenango, Quiche, Quetzaltenango, Totonicapán and Suchitepéquez, reporting 3,518 people affected, 81 victims, 4 injured, as well as 81 houses affected, 5 buildings, 3 roads and 1 bridge damaged (para. 26-29, 33-34). Note the series of catastrophes of different kinds suffered by the Guatemalan population.

In this sense, natural disasters have impacted the infrastructure of hospitals in Guatemala and to mitigate such impact, the use of BIM is proposed for the hospital construction process, taking into account, when designing, functionality tests of alternative areas to attend massively affected patients, as happened with COVID 19, the reduction of costs of services such as electricity, reduction of greenhouse gas emissions, better access to drinking water and other benefits offered by the design for the construction of hospitals through BIM, i.e., an integral design is proposed until the end of the life cycle and the recycling of materials used in the construction of hospital infrastructure.

2. What is needed to implement design projects for the construction of disaster resilient hospitals in Guatemala using BIM methodology?

On the subject, WHO/PAHO (2010, p. 1 and 2) that; in Guatemala, the project "Strengthening communities through safer health facilities in Central America: Safe Hospital Program with a local perspective" ...to evaluate the safety of health facilities through the training of professionals...related to the topic of disaster risk management; also, the application of the Hospital Safety Index (ISH) in selected health facilities, the evaluation and analysis of results, and...the implementation of some improvement actions in the evaluated facilities. [The] project started on October 1, 2008 and ended on February 28, 2010.

To this effect, the Ministry of Public Health and Social Assistance MSPAS (2022) points out that an evaluation program was carried out using the ISH of Safe Hospitals from 2015 to 2022 in 45 hospitals of the network evidencing these 2 hospitals in category A (Have little threat and adequate security), 33 hospitals in category B (Has threats and medium security) and 10 hospitals in category C (Has many threats and little security), the evaluators were accredited by the Risk Management Unit, General Coordinator of IGSS Hospitals, DECAP, Guatemalan Red Cross and PAHO, creating short and medium term improvement plans, presenting the results to Ministerial authorities and authorities of the evaluated hospitals (pp. 4, 5, 16 y 17).

In addition to describing, the experts interviewed point out that from the history of evaluations and recommendations to the current hospital infrastructure, it is necessary to implement the design methodology through BIM for the design and construction of health care centers, since with this it is possible to apply tests and verify results by

observing the behavior in the generated 3D model, from the terrain for construction, performance tests in natural disasters such as earthquakes, landslides, mudslides, simulations of use, to the behavior of the infrastructure over the years, being possible to determine the optimal use of such facilities and their maintenance until their demolition and recycling of its elements.

In this regard, the experts also point out that COVID-19 forced them to improvise the use of certain areas of hospitals for the care of affected patients, being able to foresee from the design stage the change in the use of these areas, something that would be possible with the use of BIM in this process.

3. Is BIM methodology being implemented in hospital design and construction in Guatemala?

The interviews with the experts also revealed that they have no knowledge of hospital infrastructure development programs using BIM in Guatemala, although they mentioned that some companies dedicated to infrastructure development have begun the transition to BIM design and modeling on their own. Two experts mention that they are collaborating with a hospital design through the methodology, but that although it is Guatemalan, it is not being designed in the country.

4. Are there institutions that offer technical and professional training based on formal education on BIM methodology in the country? On this matter, the Technical Institute of Training and Productivity INTECAP indicates on its official web page https://www.intecap.edu.gt/centros/ that it is a national reference institution with 33 study centers in five national regions and within its training offer announced in https://intecap.edu.gt/ctms/tecnico-en-modelado-y-administracion-de-proyectos-bim/ it offers the BIM Modeling and Project Management Technician course.

Similarly, only in the curriculum of Architectural Civil Engineering of the Universidad del Valle de Guatemala UVG of the year 2024 is the BIM Project Management Course and it can be consulted in its official website https://www.uvg.edu.gt/carreras/civil-arquitectonica/ in addition, some national universities offer BIM master's degrees, such is the case of the Universidad del Istmo de Guatemala UNIS, in its official web page https://unis.edu.gt/facultad-de-arquitectura-y-diseno/maestria-en-building-information-modeling-bim/ offers the Master in Building Information Modeling (BIM) and likewise the UVG offers in its official website https://www.uvg.edu.gt/uvgmaster/posgrado-en-modelado-bim/ a postgraduate degree in BIM modeling.

Indeed, according to interviews with experts in BIM technical and professional training programs, there has been a low influx of students and this may be due to many causes, mainly to the lack of BIM implementation policies at the national level.

5 Is it possible to develop design and construction projects, as well as to give continuity to hospital infrastructure already built with the BIM methodology in Guatemala?

Linked to the concept, the experts interviewed indicate that it is possible to give continuity to hospitals designed and built with the methodology through the BIM Dimensions and by giving continuity to the 3D model of the infrastructure in reference to the changes made in the infrastructure being transferred to the BIM model mentioned. Regarding hospitals already built, they indicate that it is not possible to design a BIM model of an existing infrastructure because the design collisions and their resolution would be unknown, therefore, it would not be a model designed with the methodology as such and the analysis would not be accurate.

In that sense, they mentioned that the programs for simulation of construction processes by specialty, especially the pay-per-use ones, are already linked to BIM, but that

because this methodology is not yet widespread in the country and is not commonly used, they have rarely or never used the software links in question. It is important to note what the experts indicated, there are pay-per-use and free-to-use software in the BIM methodology.

6. How would the development of designs for the construction of hospital infrastructure be carried out using the BIM methodology in Guatemala?

Within this framework, according to the experts, the benefits of the use and implementation of the BIM methodology should be made known at the national level by creating dissemination policies, implementing rules and regulations for its use and encouraging the institutions in charge of the design, development and maintenance of this type of infrastructure to have the profiles required by the methodology through the Guatemalan authorities who are in charge of the decision to act and implement programs of this type.

A structural engineer mentions that for him the most important thing when using BIM in hospital designs is to be able to simulate the behavior of the structure in the 3D model with all its specialties in the face of certain natural phenomena such as floods and earthquakes, which makes it possible to detect the behavior of concurrent piping from different engineering fields such as plumbing, medical gases, electricity, weak signals, among others, avoiding collapses, since with the traditional method of 2D plans it is impossible to observe and anticipate failures or collisions between the elements described.

As a complement, since it is necessary that the centers dedicated to the health of the population are resilient to the aforementioned disasters so that people can go and make emergency use of these facilities and that these are in good condition, the tools of this methodology should be analyzed and among them are the BIM dimensions and according to what was stated by Estruga (2021) and Vitorino (2021) the following compilation was made:

Table 1
BIM dimensions as an adjuvant for resilient infrastructure development

BIM DIMENSION	PRODUCT OR DEVELOPMENT
First dimension or 1D	Concept or definition of the idea or origin of the project; includes location, initial infrastructure conditions, feasibility studies, estimates, analysis of applicable laws and standards to assess the feasibility of the project.
Second dimension or 2D	Vectorization of the project plan or sketch; it may include the development of a two-dimensional plan elaborated in CAD or computer aided design, it must be the basis for the following dimensions working with a software compatible with BIM modeling, it includes contract issues, definition of collaborative scope and sustainability schemes of the project object.
Third dimension or 3D	Three-dimensional modeling or object-oriented model; represents geometric information of the project in an integrated manner including parameterization of the components, mainly the architectural design and each of the engineering required for the development of the project, which will allow updating the model in three dimensions during the life cycle of the project, making the coordination of the disciplines of architecture, structures and facilities or MEP Mechanical, electrical and plumbing.
Fourth dimension or 4D	Planning or timing; achieved by integrating the schedule of activities and work into the developed model
Fifth dimension or 5D	Cost; includes the determination of the budget, cost control and cost estimation, all oriented to improve the profitability of the project, associated to input quantities, including materials, equipment and personnel. Additionally, organize and budget operating costs for the use and maintenance phase, which may include costs and quantities of inputs such as purchases, orders, salaries, administrative and general expenses, among others. It must be linked to the three-dimensional model developed in 3D by means of variables that allow the construction of the budget so that it can be considered in this fifth BIM dimension.
Sixth dimension or 6D	Energy sustainability or Green BIM; this includes simulations that allow energy sustainability analysis in order to visualize the energy performance of the project before important decisions are made and the construction of the project starts in order to optimize processes in real time such as future inspections, remodeling, among others. This dimension deals with the sustainable design of the project and the concept of Value Engineering, which consists of optimizing the construction systems and installations, so that by making strategic modifications, costs are significantly reduced in the construction phase and future operations without the project losing its essence.
Seventh dimension or 7D	Monitoring and maintenance or management of the project life cycle; This dimension or phase involves the use of models to foresee or carry out maintenance and operation activities of the project life cycle through its management, as well as associated services, adding the logistic and operational control of the project during the use and maintenance of the useful life, optimizing processes such as inspection, repair, maintenance, among others. By correctly applying this dimension it is possible to apply Asset Management, which corresponds to the management of assets based on principles such as knowledge, planning, organization and integrated management contained in ISO 55000 and ISO 55000-1, optimizing the performance of these assets, minimizing costs and improving the service offered, referencing the analysis of strategies during the life cycle of the building, as well as the future reforms of the construction from the 3D model made, this model is useful for the visualization and simulation of the operation and maintenance of the asset, with this it is possible to establish the objective of knowing what, when and how much.

Eighth dimension or 8D	Construction Safety; safety related information is added to the geometric model, by adding this information to the model it is possible to predict the risks in the construction process by identifying the activities that when applied will improve safety at work and prevent accidents.
Ninth dimension or 9D	Lossless construction; in this dimension it is oriented to optimize and speed up all the steps of the construction phase of a project, through the digitalization of the processes
Tenth dimension or 10D	Industrialization of construction, aims to industrialize and make the construction sector more productive by implementing technology and integrating physical, commercial and environmental data, among others.

In this sense, the designed facilities built, based on the BIM Dimensions are generated in a three-dimensional model in which a series of tests and solutions between concurrent architectural and engineering specialties have been performed to it (third BIM dimension), perform energy sustainability analysis to the construction (sixth BIM dimension) and even being able to continue the BIM work on the infrastructure through the maintenance of the same (seventh BIM dimension), meanwhile, states WHO/PAHO (2018 p. 113):

The Health Facilities Initiative...based on the ISH...bridges the gap between environmental performance, climate resilience, hazard resilience and disaster risk reduction in health facilities. (A higher standard will be set in design and construction, as well as in energy and water use and service provision to help withstand expected climate variability and change). The expected impact of the Smart Health Facilities Initiative is to build or remodel facilities to be climate adapted and resilient to disasters affecting the Caribbean.

It is noteworthy that WHO/PAHO has indicated the construction of health facilities that have the capacity to adapt to the climate and are resilient to natural disasters with flexibility in terms of infrastructure performance testing

Linked to the concept, another important tool is the "Level Of Development LOD" which defines the level of development or maturity of information that an element, construction system or infrastructure assembly has within the BIM methodology and according to the BIMnD Team (2013), Imasgal (2022) and Sanchez (2016) the following compilation was made:

Table 2
LOD Development Level used for modeling according to BIM methodology

LOD	DESCRIPTION
LOD 100 Symbolic representation	It is the elementary model of the project; it is represented graphically with a symbol or other generic and schematic representation.
LOD 200 Generic System	The element is represented graphically within the model as a generic object with an approximate quantity, size, shape, position and orientation.
LOD 300 Specific System	The element is represented graphically within the model as a specific system, in which the object has specific quantity, dimension, shape, position and orientation. Geometric elements are also linked to non-graphic information, which is more detailed than that possessed by the previous level.
LOD 350 Interference detection	LOD 350 is equivalent to LOD 300 but includes the detection and solution of interferences between different elements, referred to projects involving several disciplines or specific project disaggregation. It affects the analysis, programming and coordination of the project. Sometimes the cost per item and as a whole,
LOD 400 Manufacturing	The element is graphically represented within the model as a specific system, in which the object has specific dimensions, position, shape and spatial orientation with details for its fabrication and installation. Geometric elements are linked to non-graphic information that is more detailed than that presented in the previous level.
LOD 500 Verified on-site representation	The model element is a site-verified representation, in terms of size, shape, quantity, position and orientation, the final graphic information is linked to the geometric elements of the system.
LOD 600	The G202 document of the American Institute of Architects AIA indicates the possibility of creating new LOD levels, among them the LOD 600, the object does not have a detailed geometric definition, but it does have conditions of recycling, material properties, toxicity, useful life, basic manufacturing properties, distance to the point of manufacture/recycling, weight, volume, ways of transportation and disassembly, among others. It has non-graphical information linked to the element.

Consequently, the use of LOD 350 in infrastructure developments is important, as it enables the detection and solution of interferences between concurrent specialties, especially and according to experts, in hospital facilities, in addition to architecture, structural, sanitary, mechanical, electrical, electronic and computer engineering, among others, are involved. With respect to hospitals and their contribution to the environment when designing health center infrastructure, the provisions of the LOD 600 on recycling of materials once the life cycle of the project has been completed should be taken into account. According to the research, it is possible to develop design projects for the construction of hospitals using the BIM methodology and its tools as an alternative to mitigate the natural disasters that affect Guatemala.

Results

Results of the Interviews of the First Group of Participants

Interviews were conducted with a first group of eight expert designers of hospital infrastructure: 3 architects, 2 civil engineers, 1 electrical engineer, 1 mechanical engineer

and 1 electromechanical engineer. These were individual, personal, by telephone or by means of applications such as WhatsApp, notes were taken and, at the request of the interviewees, no recording was made of the interviews, which were conducted to extract information on the use of BIM in the design and construction of health infrastructure as a mitigation alternative to natural disasters affecting the area and general recommendations that the experts could provide.

In this sense, the interviewees indicated having knowledge of BIM, but only 2 architects, 1 civil engineer and the electrical engineer indicated having participated in at least one hospital infrastructure design and construction project developed with this methodology, indicating the difficulty of the project development, they indicate the difficulty of the project development, both for the use of software and hardware (that all of them had recent model computers with the software installed and running), the use of communication channels between all involved (definition of the software to be used and access to it) and the definition of profiles to develop the project, that the experts involved, both architects and engineers, had BIM knowledge in their areas.

With reference to this, the experts interviewed with BIM knowledge mentioned that it is possible to give continuity to hospitals designed and built with the methodology through the BIM Dimensions and giving continuity to the BIM model of the infrastructure, referring to the changes made in the infrastructure being transferred to the BIM model mentioned. Regarding hospitals already built, some of the interviewees indicated that they cannot work with the methodology because they do not know the conditions of construction and changes made to the infrastructure in question. In other words, it is not possible to design a BIM model of an infrastructure, since the design collisions and their resolution would be unknown, therefore, it would not be a model designed with the methodology as such and BIM tests could not be applied in their entirety.

Within this framework, all the interviewees indicate that they are not aware of any public or private regulation in the country, of mandatory use of the BIM methodology and that the efforts for its implementation have been individual, as for the acquisition of knowledge about BIM, some institutions have provided it to their workers, but mainly at a personal level, they have gone to educational institutions paying to obtain practice and theory of the methodology.

In addition to this situation, they mention that policies and programs should be created at the national level to disseminate the topics of "BIM methodology", "hospitals with resilience to natural disasters" and "implementation of BIM at the national level" in Guatemala, especially to institutions dedicated to the development of hospital infrastructure projects.

Likewise, it is recommended that the institutions in charge of developing such projects in their design, construction and maintenance stages, whether public or private, should ensure that their work teams are trained in BIM, since for such implementation it is recommended to have among their personnel, the different profiles that make up the working groups for the development of constructions through the methodology.

Results of the Interviews of the Second Group of Participants

In the second group, seven experts in general infrastructure design were interviewed (3 architects, 2 civil engineers, 1 engineer specializing in plumbing and 1 electrical engineer) in order to determine the development and use of BIM models in Guatemala, team or collaborative work with this methodology and its results, as well as the implementation of BIM in the country and the use of simulation programs by specialty associated with this methodology, among others.

In this sense, all the experts indicate having knowledge of the BIM methodology, indicating that they have participated in the development of infrastructure in general with this methodology in the country and, like those interviewed in the first group, they are not aware of any mandatory regulations or laws in Guatemala on the use of BIM. Regarding the development of projects with BIM, they mention that they have been developed mainly with collaborative work, people have demonstrated knowledge and practice in BIM acquired individually. Experts mention that some companies, especially foreign ones, are requesting their designs for construction with BIM.

On the other hand, the experts coincide in indicating that the simulation programs in their specialty already include a link to BIM, although their use is for a fee and not all the experts interviewed have used them. The Hydrosanitary expert interviewed indicates that he has not used simulation programs linking them with BIM, but he makes his design with simulation tests and exports it to the BIM model.

Similarly, the experts interviewed mentioned that it is possible to give continuity to hospitals designed and built with the BIM methodology through the BIM Dimensions, as well as to the changes made in the mentioned infrastructure once they are transferred to their BIM model. Regarding the existing infrastructure, the interviewees indicated that they cannot work with the methodology because they do not know the conditions and changes made to the infrastructure in question. In other words, it is not possible to design a BIM model of an existing infrastructure, since the design collisions and their constructive resolution would be unknown, therefore, this is not advisable.

It is noteworthy that the interviewees indicate that in Guatemala there are educational institutions that offer BIM courses and technical and professional careers, mentioning INTECAP and KINAL, among the universities mentioned are UNIS and UVG.

Survey Results

As part of this research, a closed dichotomous survey was also conducted and within a population of 50 health care infrastructure modelers, designers and implementers, a random sample of 15 professionals was selected, being 4 hospital architecture modelers, 4 hospital construction project managers/supervisors, 2 architecture students supporting hospital architecture modelers, 2 MEP designers for health care infrastructure, and 3 BIM experts oriented to hospital infrastructure designs to answer the questions presented in Table 3.

As a follow-up to this activity, the survey was carried out with a Google Form that was validated in its content by an architect, designer, consultant and supervisor related to hospital infrastructure and an architect specialized in hospital design and expert in Safe Hospitals according to WHO/PAHO terminology, authorization was also requested from the companies and authorization from the ethics committee of said companies to which some of the surveyed participants belong and a letter of informed consent was given to the participants before filling out the survey.

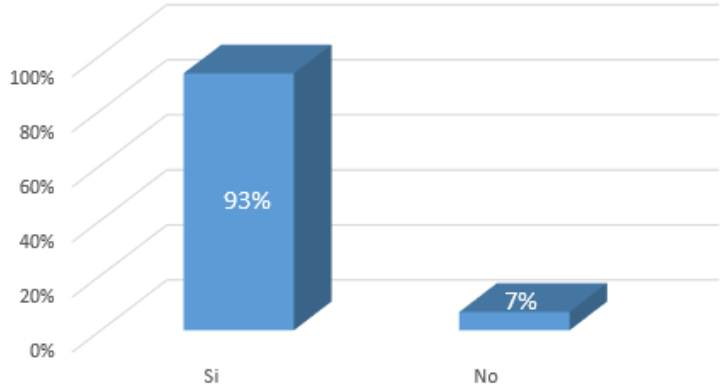
It is also important to mention that all interviewees and respondents were persons of legal age who were previously informed and asked for their support to participate in such events and that the Google Form only saved the answers for the privacy of the participants. The interviews and survey were conducted between May 2023 and February 2024 in Guatemala.

Table 3
Results of the survey instrument

ITEM	YES	%	NO	%	DESCRIPTION
1	14	93%	1	7%	Do you develop hospital infrastructure projects in Guatemala?
2	11	73%	4	27%	Do you know of any hospital construction projects using BIM methodology in Guatemala?
3	6	40%	9	60%	Do you know of any BIM implementation plan or program for infrastructure development in the country?
4	15	100%	0	0%	Do you consider it possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction using BIM methodology?
5	11	73%	4	27%	Do you consider it important to implement the BIM methodology in the construction of hospitals in Guatemala?

Below are the figures representing the quantities obtained based on the closed dichotomous responses to the survey and an analysis of the results, comparing these results with those indicated by experts who participated in the two interviews conducted, both in infrastructure development in general and in hospital infrastructure.

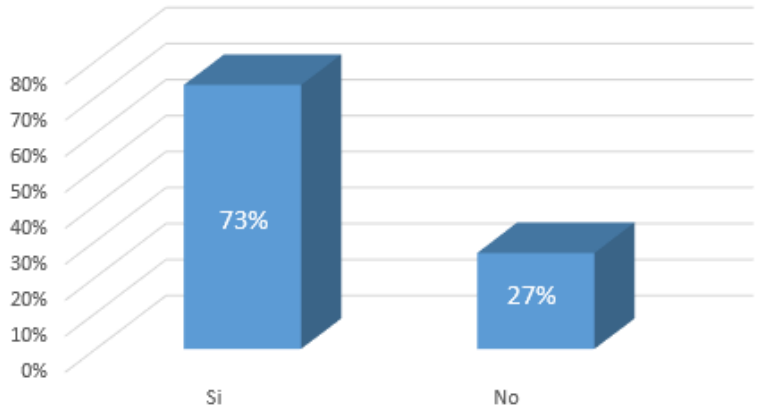
Figure 2
Question 1. Do you develop hospital projects in Guatemala?



In this regard, it is interesting to note in Figure 2 that 93% of those interviewed are currently involved in the development of hospital infrastructure projects in Guatemala, while 7% of those interviewed are not developing this type of project. This provides a valid and favorable opinion regarding health center construction projects, since most of the respondents are involved in this type of project.

Figure 3

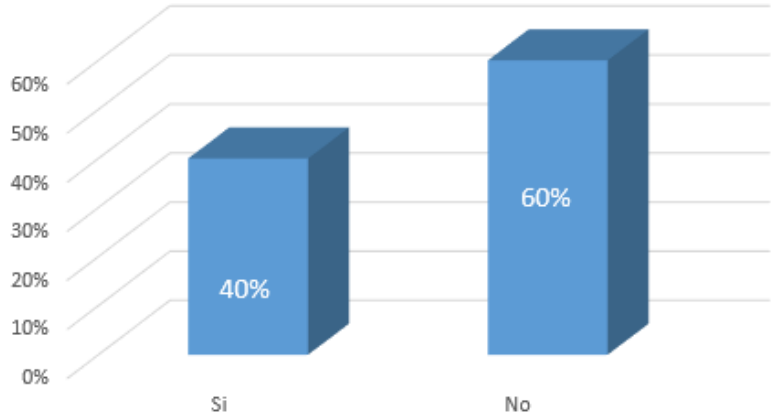
Question 2. Do you know of any hospital construction projects using BIM methodology in Guatemala?



On the other hand, it is possible to observe in Figure No. 3 that 73% of the interviewees indicate that they have knowledge of some hospital construction project developed with the BIM methodology in Guatemala and 27% indicate that they have not used it or have no knowledge of this type of project; it is possible that they are not dedicated to the development and design of infrastructure for hospitals and do not have BIM knowledge or are not interested in it.

Figure 4

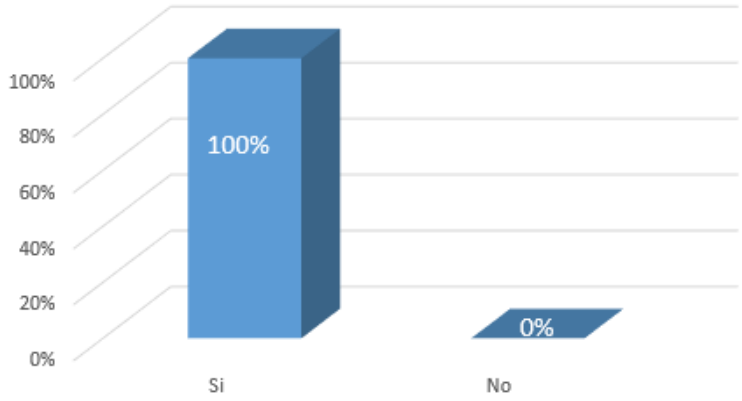
Question 3. Do you know of any BIM implementation plan or program for infrastructure development in the country?



Among the professionals who responded to the survey and according to Figure No. 4. Forty percent indicated having knowledge of a plan or program to implement BIM in the development of infrastructure in Guatemala, while 60% said they had no knowledge of this, while the interviewees indicated that they were unaware of any plan or program to implement BIM in Guatemala, this may be due to the fact that there are companies dedicated to the development of infrastructure construction that have regulations within their lines of work oriented to the use of BIM for these projects.

Figure 5

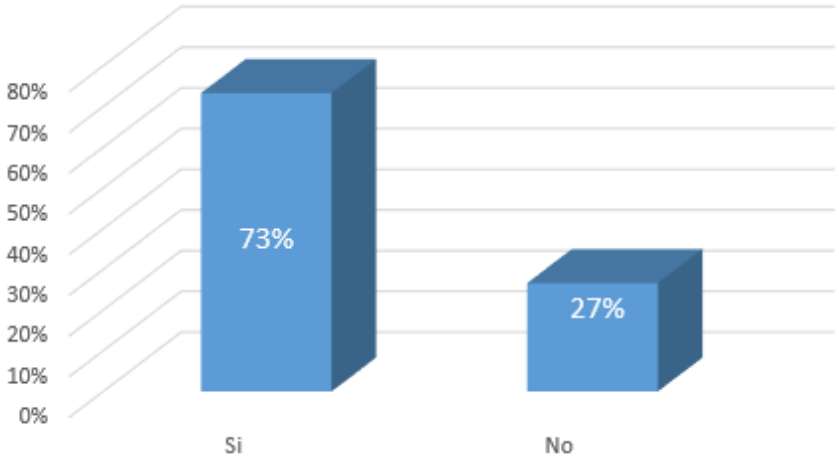
Question 4. Do you consider it possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction using BIM methodology?



According to Figure 5, 100% of the respondents indicate that it is possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction using BIM methodology, which is in agreement with what was indicated by all the professionals interviewed.

Figure 6

Question 5. Do you consider it important to implement the BIM methodology in the construction of hospitals in Guatemala?



According to the survey, 73% of the participants indicated that it is important to implement the BIM methodology in the construction of hospitals in Guatemala and 27% indicated that it is not important. The results obtained were generated through a contrast between the interviews, the survey and the documentary research.

Discussion and Conclusions

Based on the results obtained (period May 2023-February 2024) it is possible to affirm that the implementation of BIM methodology is of utmost importance as a mitigation measure in the design and construction of hospital infrastructure in the face of

the natural phenomena that affect Guatemala and according to the documentary research, interviews and the survey conducted it can be concluded that:

1. Do you develop infrastructure projects with BIM methodology in Guatemala?
   Ninety-three percent of the professionals surveyed mentioned being involved in the development of hospital infrastructure, while 7% were not involved in this type of project. For their part, the experts interviewed in the two groups mentioned that they are working on the development of projects for the construction of health care centers in the country, unlike before the pandemic, there were few hospital development projects, from which it can be deduced and concluded that there is a boom in hospital construction processes in the country and that the answers given in the survey indicate that most of them correspond to people developing hospital infrastructure.
2. Do you know of any hospital construction projects using BIM methodology in Guatemala?
   The results of the survey indicate that 73% of the people surveyed indicate that they have knowledge of hospital construction with BIM methodology, and consulting with the professionals interviewed, they indicate that they have also developed projects of this type of infrastructure with BIM. However, the experts in BIM methodology interviewed in the first group indicate that in Guatemala they have worked in the development of hospital projects, mainly in remodeling or expansions, and they mention four professionals who are working on accompanying a hospital design with the methodology, but this is being carried out by an international firm.
   As a complement, the indicated agrees with the answers of the previous question, that, the majority of respondents have developed infrastructure projects with BIM including hospitals. Regarding the percentage, both in the survey and the professionals interviewed who indicate that they have not used it or have no knowledge of this type of projects with BIM, it is possible that they are not dedicated to the development and design of infrastructure for hospitals and that their projects are developed in a traditional manner, without the use of the methodology.
3. Do you know of any BIM implementation plan or program for infrastructure development in the country?
   Forty percent of the respondents indicated that they were aware of any BIM implementation plan or program in the development of infrastructure in Guatemala, while 60% said they were not aware of any BIM implementation plan or program in Guatemala, which may be due to internal regulations or those of certain companies. Unlike the experts interviewed in the first and second groups, who indicate that they are not aware of any public or private plan, program or regulation in the country for the mandatory use of the BIM methodology and that the efforts for its implementation have been individual, they also indicate that some companies, especially foreign ones, request their designs for construction with BIM. In this regard, the documentary research indicates that there are no policies or mandatory dissemination and implementation programs for the design and construction of hospitals using BIM in Guatemala, but some companies, on their own initiative, are in the process of transitioning to the use of this methodology; within the working groups of the different institutions there are personnel who have been trained by their own means.

4. Do you consider it possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction using BIM methodology? How will the impact of natural disasters on Guatemala's hospital infrastructure be reduced?
   To this effect, 100% of those surveyed and interviewed indicated that it is possible to mitigate the impact of natural disasters on hospital infrastructure through design and construction with BIM methodology. This is in agreement with the secondary research conducted, since it is possible to test the 3D model, analyze the behavior and solve problems before construction, and there are programs or software to perform functional tests in the various specialties, whether architecture or engineering, with a link to the BIM methodology, which can reduce the impact of natural disasters on hospital infrastructure in Guatemala. The experts interviewed in the first and second group of participants indicate that it is important to have previous studies of the site and based on this to make a final model to which performance tests are made in the face of various phenomena, the behavior is analyzed and solved in the model generated prior to the construction process, it is also affirmed that it is possible to give continuity to any construction designed and built with BIM through what is indicated in the BIM Dimensions and giving continuity to the BIM model of the infrastructure in reference to the changes made in the infrastructure being transferred to the aforementioned model. Regarding infrastructure already built, the interviewees indicated that they cannot work with the methodology because they do not know the conditions and changes made to the infrastructure in question. It is important to mention that one of the interviewees indicated that it was possible to give continuity with BIM to remodeling projects, but concluded that it only applies to environments built with the methodology.
5. Do you consider it important to implement the BIM methodology in the construction of hospitals in Guatemala?
   It is noteworthy that 73% of the survey participants indicated that it is important to implement the BIM methodology in hospital construction in Guatemala and 27% indicated that it is not important. In this regard, the experts interviewed in both groups mentioned that policies and programs should be created at the national level to disseminate the topics of BIM and hospitals that are resilient to natural phenomena, and that the public or private institutions in charge of developing such projects should ensure that their work teams are trained in BIM methodology, with a view to creating the different profiles for the development of construction using the methodology.

Recommendations and Proposal for Continuity

1. It was documented that due to the disasters caused by natural phenomena that have occurred and continue to occur in Guatemala and have left heavy losses both human and material and due to the need to build infrastructure for resilient health care centers, as well as the reduction of costs of services such as electricity, reduction of greenhouse gas emissions, better access to drinking water, among others, it is advisable to implement BIM in the design and construction of hospitals in the country, since the 3D models generated make it possible to simulate the behavior of the infrastructure in the face of the aforementioned natural phenomena and to solve before building with much

more detail than with only 2D plans, making it possible to build hospitals that are resilient to disasters caused by the phenomena described.

2. Evidence based on documentary research, interviews and surveys indicates that in order to implement hospital construction projects using the BIM methodology in Guatemala, programs and dissemination policies are needed, and it is important to publicize the short, medium and long-term goals, as well as the social and institutional commitments generated at the national level through the implementation of BIM in the design and construction of hospitals in Guatemala.
3. Based on interviews with BIM experts, it is not possible to give continuity through BIM to all infrastructure that was not built with the methodology. If the design and construction development is carried out with BIM, it is possible to give it continuity, even up to its demolition and recycling of materials, through the methodology tools, as well as to give continuity to extensions or remodeling designed and built with the methodology.
4. Based on the primary and secondary research presented, it is possible to indicate that in order to carry out the development of hospital infrastructure using BIM, it is necessary to develop mandatory standards and regulations for its use in the construction of centers dedicated to the health of the population. Likewise, the institutions in charge of developing such projects in their design, construction and maintenance stages, whether public or private, must ensure that their work teams are trained in the terminology and application of the methodology, as well as develop and train personnel to form work teams with the profiles required by this methodology.
5. For future research from the present work, one can mention the selection of pay-per-use or free-to-use software for BIM development in the country for healthcare facility project development, BIM use software recommended for each concurrent specialty involved, BIM software for green hospital infrastructure development, bIM hospital infrastructure development through the use of building materials that can be recycled, BIM hospitals and the environment during their life cycle, BIM dimensions and self-sustainable hospital infrastructure, BIM technical and professional profiles for the development of infrastructure and maintenance of hospitals in Guatemala, updating the BIM model beyond the construction of infrastructure, among others.

Acknowledgments

Thanks to: God for being my guide and strength during this research work, to my tutor Dr. Ramírez Vargas for her kind instructions during the development and presentation of the research work, to the professionals who kindly assisted me so that this work could be successfully completed, to my family for always giving me their support and to the MLS Project, Design and Management (PDM) magazine for allowing me to contribute to the community by presenting my article.

References

Arevalo Pizarro, A. S. & Soto Arrieta, J. R. (2022). Building Information Modeling (BIM) y su Desarrollo en la Industria de la Construcción. https://pirhua.udep.edu.pe/backend/api/core/bitstreams/2ef13495-b055-4d17-8f4f-d1eabed46664/content

Barillas, M. (2022). *El antes, durante y después de la gestión de desastres en Guatemala*. *Colorado School of Mines.* https://reliefweb.int/report/guatemala/el-antes-durante-y-despues-de-la-gestion-de-desastres-en-guatemala

Bohorquez Lozano, C. L., & Osorio Cubas, V. E. (2024). Simulación BIM 4D para la predicción de riesgos en la fase de planificación en la construcción de la Infraestructura de la Universidad Faustino Sánchez Carrión en Oyón, 2023. https://repositorio.utp.edu.pe/handle/20.500.12867/8874

Bolaños, R. M. (2020). 15 Desastres naturales que han impactado Guatemala durante los últimos 22 años. *Prensa Libre*. https://www.prensalibre.com/guatemala/comunitario/15-desastres-naturales-que-han-impactado-guatemala-en-los-ultimos-22-anos/

Bustos Álvarez, M., & Sosa Pedroza, T. E. (2021). *Edificaciones resilientes para las urbes latinoamericanas. MIC (BIM) como metodología integradora.* http://zaloamati.azc.uam.mx/handle/11191/8813

Coordinadora Nacional para la Reducción de Desastres CONRED. (2021). *Actualización 2021 países con mayor riesgo de desastres.* [Comunicado de prensa]. https://conred.gob.gt/actualizacion-2021-de-paises-con-mayor-riesgo-a-desastres/

Coordinadora Nacional para la Reducción de Desastres CONRED (2013). *OPS/OMS Continúan proceso de fortalecimiento de Hospitales Seguros.* https://conred.gob.gt/ops-oms-continuan-proceso-de-fortalecimiento-de-hospitales-seguros/

Dávila Pincay, J. F., & Baltán Larrosa, S. L. (2024). Control de inundaciones en propuesta de diseño de muro de gaviones aplicando metodología BIM. Estudio de caso. [Bachelor's Thesis, ULVR]. http://repositorio.ulvr.edu.ec/handle/44000/7248

Estruga, N. (2021). *Qué son y cómo funcionan las dimensiones de BIM*. https://www.ealde.es/dimesiones-bim/

Equipo BIMnD (2013). *Una breve historia del LOD (Nivel de desarrollo) en BIM.* https://www.bimnd.es/una-breve-historia-del-lod-nivel-de-desarrollo-en-bim/

García Sanjuan, C. C., & Torres Menco, É. A. (2021). *Implementación de las metodologías Bim 5D y líneas de balance en la optimización de la planeación de proyectos de viviendas de interés social, caso de estudio: mz. 72 barrio Bicentenario*. [Trabajo de Grado, Universidad de Cartagena]. https://repositorio.unicartagena.edu.co/handle/11227/13530

Imasgal (2022). *Nivel de desarrollo (LOD) en BIM.* https://imasgal.com/nivel-desarrollo-bim-lod/

Meléndez, I. M. S., Gutiérrez, L. V., & Fontes, C. J. L. (2019). Ventajas de la implementación de la metodología BIM utilizando Revit en el desarrollo de proyectos de edificaciones. *Serie Científica de la Universidad de las Ciencias Informáticas, 12*(10), 151-163. https://dialnet.unirioja.es/servlet/articulo?codigo=8590213

Ministerio de Salud Pública y Asistencia Social MSPAS (2022). *Índice de Seguridad Hospitalaria ISH 2015-2022.*

Morales, V. B., & Galindo, S. O. (2022). Caracterización de los beneficios de la metodología BIM identificando las principales causas que ocasionan falencias dentro de la construcción generando una consulta a profesionales del sector. Ingeniería civil, 600. [Trabajo de Grado, Universidad Católica de Colombia]. https://repository.ucatolica.edu.co/server/api/core/bitstreams/4ebd5334-394c-44c3-a8c9-3d0bccef202e/content

Organización Mundial de la Salud/Organización Panamericana de la Salud (2023). *La OPS avanza en 13 países de las Américas con su iniciativa "Hospitales Resilientes frente a Emergencias de Salud y Desastres".* https://www.paho.org/es/noticias/14-4-2023-ops-avanza-13-paises-americas-con-su-iniciativa-hospitales-resilientes-frente

Organización Mundial de la Salud/Organización Panamericana de la Salud OMS/OPS (2010). *Índice de Seguridad. Hospitalaria.*

Organización Mundial de la Salud/Organización Panamericana de la Salud (2018). *Herramienta de hospitales inteligentes.* PAHO HQ Library Cataloguing in Publication Data. https://www.paho.org/es/documentos/herramienta-para-hospitales-inteligentes

Sánchez Ortega, A. (2016). *LOD o Nivel de Desarrollo BIM ¿Qué significa?* https://www.espaciobim.com/lod

Vitorino Bravo, P. A. (2021). *Las 7 dimensiones BIM.* https://konstruedu.com/es/blog/las-7-dimensiones-de-bim