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Intersection of BIM, Facilities Management and Computer Vision: The State of the Art

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Abstract-In the last few years the construction industry has suffered growth diminishment in Brazil as in the rest of the world. Proposed recovery strategies have been focused in increasing productivity to bolster competitiveness. The state is the primary player in terms of construction volume as well as managed and operated facilities. The time that these facilities remain in operational status exceeds at least four-fold their construction times, this makes most improvement opportunities reside in Facilities Management. In the UK and other countries, the use of Building Information Modeling (BIM) is being required for public works as part of public policy with the intent of fostering an increase in productivity in the industry. Considering and integrating BIM in research has become necessary to be relevant and to facilitate the adoption of innovative technologies. Computer Vision is one of these innovative technologies that have been used to increase the efficiency of construction processes, which can be integrated with BIM to optimize energy consumption, user comfort, space utilization and maintenance by the facility's management. This paper utilizes ProKnow-C to produce a critical review of the State of the Art in the intersection of Facilities Management, BIM and Computer Vision, with the objective of serving as a theoretical base for further research exploring the reuse of security cameras in existing facilities. After the systematic selection of 21 papers which are representative of the state of the art, 9 lenses were analyzed and identified with tendencies, highlights and opportunities that future research will have to adopt in order to be considered innovative and useful for future developments.

Keywords*- BIM, Facilities Management, Computer Vision*

I. INTRODUCTION

In 2015, the construction industry provided 10.5% of Brazil's GDP, although this percentage represents a reduction in Brazil's productive chain. The GDP's accumulated loss was of 7.6% in relation to 2014, the associated productivity loss was of 4.2%. This situation leads to not meeting urban and economic infrastructure development needs, of which the country depends on for sustainable growth [1]. On the 11th Construbusiness the current situation of the construction industry was explored, with the FIESP concluding the following in regard to increasing the industry's productivity:

The base for sustainable growth and competitiveness is the continuous increase of productivity, which is obtained by means of technological innovation, of hand labor qualification, of reductions of inefficiency in the productive process and in the increase of production scale [2].

A similar scenery has developed in the UK and in the United States where the construction industry has not maintained parity in productivity with other sectors of the economy [3]. To counteract this, starting in the year 2011, the UK government started implementing a series of measures with the following amongst its chief objectives: reductions of the cost of goods and achieving better operation efficiency, facilitating better efficiency and efficacy of the construction supply chain, helping with the creation of an industry that looks towards the future in which the country's growth targets can be based upon [4]. The bedrock for the UK government's strategy consists in that acting as a client, it can derive reduced costs, better value and diminishment of carbon emissions by means of using open and shareable information of goods. The primary tool (within a group of tools) that is being implemented in the UK is called BIM (Building Information Modeling) [3], with which it is expected to achieve saving in the range of 15% to 30% for the construction industry apart from other benefits such as market expansion and cost optimization throughout the large public goods administration timeframe [5].

[6] Defines BIM as a digital representation of physical and functional characteristics of a building. A BIM consists in a shared building information resource forming a trustworthy base for decision taking throughout a building's life cycle; defined as existing from the first conception up until demolition.

According to [3,5,7-10] between 48% and 97% of players around the world have reported positive return on investment in the implemented stages of BIM, such as planning, design and construction, this considering that not enough time has gone by to evaluate the benefits in prolonged stages of operation, maintenance and demolition of works. In particular, the benefits of BIM can be divided in regard to the party involved; [9] identified that the primary beneficiary of BIM is the client, followed by building Operation and Maintenance. Considering that governments are amongst the largest clients, and that they are the biggest administrators of public properties, it can be said that governments have extra benefits apart from achieving macroeconomic targets. Fig. 1 illustrates the idea that the client and Facilities Management are the most benefited on account that using BIM allows maintaining a continuity in the increase of the value added from information as a construction project proceeds from one stage of its life cycle to the next. It can be highlighted that the operation stage of a building (20 years or more) is substantially longer than the construction stage (5 years on average).

Productivity Analysis techniques based on video image recognition have already been tested with proven increase in productivity in construction. Multiple technologies exist to achieve image recognition, but in broad terms the processing consists in the following steps: Capture, Pre-processing, Detection and Extraction of Features, Detection and recognition of objects and Tracking and Motion Estimation of objects [11]. The result of the implementation of these computer vision techniques are the identification of the human body's presence, it's performed activities and objects present in a scene [12], generating performance metrics and gathering data for the optimization of activities [13,14].

Considering that the government possesses the most opportunities to benefit from the increase in productivity and that the highest cost in a building's life lies in facilities management due to building's long maintenance time, interest arises in performing research that incorporate productivity gains achieved with computer vision and BIM, with the purpose bolstering efficiency and efficacy of facilities management in Brasil. The objective of this research is to utilize the ProKnow-C methodology to perform a bibliographic revision with the intent of identifying the state of the art on the subject and to have it serve as a theoretical base determining the highlights and the primary opportunities that exist in order to develop an innovative investigative project.

II. RESULTS ACCORDING TO PROKNOW-C METHODOLOGY

A. *Search Terms and Databases*

In order to obtain search terms, the keywords from 20 relevant papers previously known by the author where obtained, grouped by each fundamental aspect of the research. Group A: 6 papers on Facilities Management, Group B: 8 papers about BIM and Group C: 5 papers regarding Computer Vision.

The selected keywords (grouping synonyms) for the three groups where the following:

Group A: AEC, As-Built BIM, Asset Management, BIM (x5), BIM Adoption, BIM advantages, BIM Disadvantages, Carbon Emission (x2), Construction, Deconstruction, Demolition, Dismantling, Education, Energy Management (x2), Existing Buildings, Facility Management (x4), HVAC Control, Information Exchange, Information Management (x2), Information Technology, Maintenance, Markov Decision Problems, Multi-agent systems, Multi-objective optimization, Occupant comfort, Project Life Cycle (x2), Project Management, Residential, Retrofit, Reverse Engineering, Scan-to-BIM, Training.

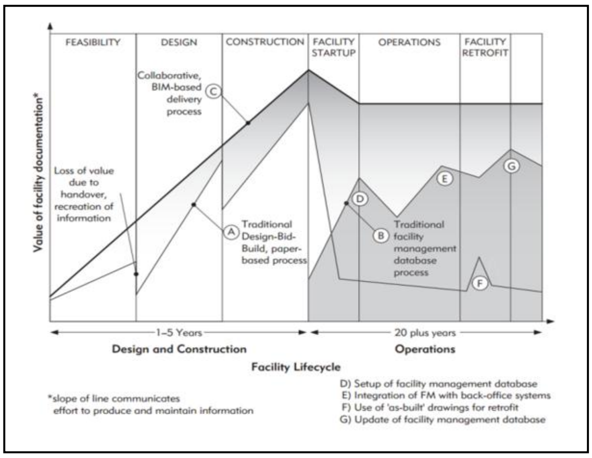

Figure 1. Value of information vs. life cicle stage [7]

Group B: Bi-directional coordination, BIM (x2), Building Standards, Building Structures (x2), Construction, Cyber-Physical Systems, Demand driven, Design Engineering, Digital Simulation, Dynamic Building Model, Energy Management (x2), Facility Management, HVAC, IFC (x2), Information Management, Intelligent Buildings, Laser Scanner, Modelling, Non-intrusive sensor, Opening Detection, Occupancy Monitoring, Public Domain Software, RFID, Scan to BIM, Structural Health Monitoring, Temporal Database, Wall Analysis.

Group C: Human Detection(x2), Occupancy Monitoring(x3), Activity Characterization, Laser Scanner, Background Subtraction, Tracking, Classification, Evaluation, Three-Dimensional Data, CAD Model, Automated Object Retrieval, Dimensional Quality Control.

The keyword selection evidences the common relationship between the three groups, due to the fact of the same keywords appearing in more than one paper group (BIM, Facility Management, Scan-to-BIM, Occupancy Monitoring, Energy Management, HVAC, Laser Scanner, Construction e Information Management).

Based on the previously identified keywords, three groups where created to combine and generate the search terms, these keywords included the synonyms found to reference the same subject.

In the *Facilities Management* group, the chosen keywords where: Facilities Management, Building Maintenance and Existing Building.

In the *BIM* group, the chosen words where all synonyms or variations of the term BIM (due to BIM having gained popularity just recently, a single unique word has not yet been consolidated to make reference to the concept) where five: Building Information Modelling, Intelligent Building, Building Automation, and Dynamic BIM.

In the Computer Vision group the chosen words where six: Human Detection and Occupancy, with the addition of Computer Vision, Artificial Intelligence, Sensor and Tracking.

To capture the knowledge on this research's specific interest, the three groups where combined (Fig. 2) generating 120 search terms that where utilized to perform subsequent searches (an example of a resulting search term combination would be "Facilities Management" + "BIM" + "Human Detection").

The searches where performed utilizing the tool *Harzing's Publish or Perish* taking advantage of its capacity to perform the searches in all the Google Scholar index in order to achieve the maximum reach possible, including the Science Direct and ASCE databases that were identified as relevant for the subject matter.

B. Bibliographic Porfolio

To limit the temporal scope the first 1,035 results obtained without date restriction were analyzed; it was found that 635 results were published in the last 5 years, 866 were published in the last 10 years and 90 did not have the publication date available. The temporal sample chosen was of papers from the last 10 years or less, representing 83.7% of results, excluding only 7.6% that were older than 10 years.

To departmentalize the search process, the search terms were divided in three groups depending on the terms chosen to represent facilities management:

- "Facilities Management" + BIM terms + Computer Vision terms: 30 combinations resulting in 6,715 results.
- "Building Maintenance" + BIM terms + Computer Vision terms: 30 combinations resulting in 2,392 results.
- "Existing Building" + BIM terms + Computer Vision terms: 30 combinations resulting in 5,713 results.

1) Redundancy

In total 14,820 results were obtained. Due to the utilization of synonyms to maximize search coverage and due to the search having been performed on the whole body of the papers, 9,786 results (66.03%) were redundant.

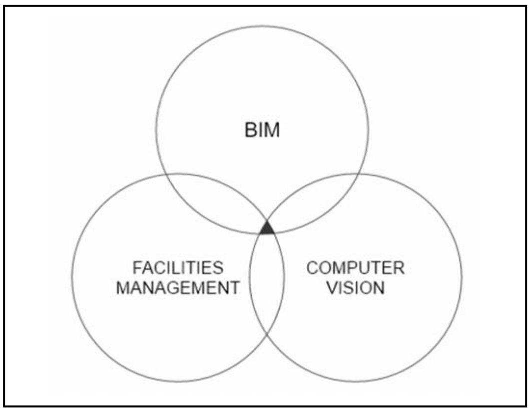

Figure 2. Intersection of BIM, Facilities Management and Computer Vision

2) Nature

A characteristic of Google Scholar is the variety of types of results obtained, for this it was necessary to employ a filtering by nature or type: 233 books, 130 citations and 386 patents were discarded.

3) Formatting

A total of 1,201 results were discarded because they did not provide the journal publication name and 467 results did not provide year of publication. It can be assumed that papers without this information possess little academic relevance, considering these are basic requirements for recognized academic publishing institutions.

4) Representation

By applying the pareto rule it was determined that 85% of citations (24,468 out of 28,809 citations) corresponded to 657 papers, discarding more than 1,960 papers with 9 citations or less each.

5) Title and abstract adherence

Following the review of titles 443 papers were discarded and after careful reading of the remaining paper abstracts a further 193 papers were discarded seen as not aligned with the research subject matter.

The result of this filtering phase was the selection of 21 papers that are representative of the state of the art (Tables 1 and 2) which were thoroughly studied to determine views and tendencies in the subject matter.

C. Reseach lenses and bibliographic portfolio analysis

The research lenses were determined by a systematic analysis of the 21 papers selected, of which highlights and unique concepts were extracted [35].

Initially, 33 unique concepts were found in the papers. These concepts were evaluated and distilled within each of the three main underlying subjects studied (Facilities Management, BIM and Computer Vision) therefore isolating 17 concepts with the addition of 2 common concepts for a total of 19 concepts that were subsequently categorized by similarity in order to arrive on the following research lenses:

c.1 Common:

c.1.1 – Contextualization.

c.2 Computer Vision / Artificial Intelligence:

c.2.1 – Visual Approach.

c.2.2 - Reliability.

c.2.3 – Prediction / Artificial Intelligence.

c.3 BIM:

c.3.1 - Productivity.

c.3.2 – Knowledge Base.

c.3.3 - Practicality.

c.4 Facility Management:

c.4.1 - Occupancy / Comfort.

c.4.2 - Maintenance.

TABLE I. FILTERS APPLIED IN THE SELECTION OF PAPERS

Search Term Results	14,820
Redundancy	(9,786)
Books	(233)
Citations	(130)
Patents	(386)
Without source	(1,201)
Without year	(467)
Scientific recognition (less than 9 citations)	(1,960)
Aligned titles	(443)
Aligned abstracts	(193)
Selected papers	21

C.2.1 – Visual Approach: One of the main challenges in field work is capturing data in real time to feed decision making systems to help construction and facility management teams make accurate decisions in a timely manner to increase productivity and efficiency. It has been proven that the use of image recognition techniques and computer vision is an effective mechanism to realize an effective monitoring of projects, with favorable perspective on improved results with the development of new techniques. The need also exists to produce long term research to create standards for an accelerated adoption of the technology in the industry. The latent opportunity in this lense is the addition of an innovating context for the application of computer vision technologies, which promise to evaluate if it is possible to bring the reported benefits of lower cost, fast implementation, high precision and BIM compatibility to Facilities Management, where it has not been studied to this date. [22-25]

C.2.2 – Reliability: Reliability groups range, precision, robustness, use conditions and limitations of the technologies studied. The reliability of technologies based on image recognition is the capacity to maintain a consistent performance, resilient in the face of changing conditions such as context complexity and changes in illumination throughout the day. In civil engineering, there is a need to rely on formal factors that allow achieving specific precision levels in order to produce reliable measurements within known tolerance ranges [26,27]. [12] presents image recognition precision that ranges up to 95.5%, which can be achieved with cameras on construction sites, these results may serve as a frame of reference for other research. In particular, [22,28] studied the conditions and optimal use cases for the use of cameras, but without studying cases in facilities management, this is an opportunity to study the applicability in one more context. [16,19,25,27,29,30] studied the precision and use cases of other technologies (RFID, LiDAR, Decision Trees, temperature sensors, light sensors and smart energy meters) to obtain similar results in a facilities management context. These can serve as a benchmark for comparison between different technologies.

C.2.3 – Prediction / Artificial Intelligence: Heat generated within buildings is generally wasted or discarded except in cases where there are mechanisms established to predict its generation, demand and behavior, [16] studied user behavior in a chemistry laboratory and could predict with up to 71% certainty the thermal comfort perception reported by its users, resulting in strategic control recommendations such as feedback for process control systems. Based on historical use data, [15] created models that could predict the energy demand behavior of the buildings of the University of León (ULE) campus in Spain, saving up to 15% of the campus' energy costs. [31] Demonstrated the use of multiple sensors (temperature, humidity, CO2 concentration, illumination, sound and motion) to predict the behavior of users of two shared laboratories with a precision of up to 87.62% by creating a tool to feed HVAC operations in a demand function. [17] Used Neural Networks to predict the energy consumption of a building as a function of building parameters such as area and quantity of occupants. [18] Developed a system for the automatic analysis, prediction and update of space usage as a function of the semantic relationship between the concepts of users, activities, spacers, requirements and space usage, the results showed that in comparison to traditional methods the system produces better consistency, transparency and efficacy of space usage analysis. The results present in the samples reflect proven benefits of using prediction techniques for various disciplines.

The computer vision techniques are an alternative to those found on the sample and are based on the production of models that, after being trained, can be used to predict the behavior and meaning of the images being captured, creating a tool that may be used for energy, comfort and space use optimization.

C.3.1 – Productivity: The productivity lens incorporated various aspects of visualization, monitoring and BIM. It is the most seen lens in the paper sample, given that:

- Six papers incorporate visualization of the state of a building in real time or the visualization of their results as a fundamental part of their research, finding that it favors the interpretation of information for decision making [18,24-26,28,32].
- Nine papers found a need for effective monitoring to base decision making processes for construction as well as facilities management and that as update frequency is higher, the effective quality and effectiveness of optimization results goes up, including data mining as well as real time systems [15,18,19,23,24,27-29,31].
- Ten papers evaluated the advantages of using BIM with highlights in the improvement of integration, data sharing and transfer, improvement on the accuracy of data available to facilities management and the increase in efficiency of the execution of maintenance works [18-21,23-25,30,32,33].

The authors reiterate the need to produce a larger number of researches on the incorporation of visualization, monitoring and BIM, primarily in the operation stage of a building's life cycle. The proposed research exposes the opportunity to integrate Computer Vision' integrated visualization as part of a BIM system focused on facilities management.

TABLE II. SELECTED PAPERS (BIBLIOGRAPHIC SET)

BECERIK-GERBER, B. et al. Application Areas and Data Requirements for BIM-Enabled Facilities Management. **JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT,** 2012
BOHN, J.; TEIZER, J. Benefits and Barriers of Construction Project Monitoring Using High-Resolution Automated Cameras. **JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT,** 2010.
DOMINGUEZ, M. et al. Power monitoring system for university buildings: Architecture and advanced analysis tools. **Energy and Buildings**, 2012.
FATHI, H. et al. Automated as-built 3D reconstruction of civil infrastructure using computer vision: Achievements, opportunities, and challenges. **Advanced Engineering Informatics**, 2015.
GAO, Y. et al. Using Data Mining in Optimization of Building Energy Consumption and Thermal Comfort Management. **The 2nd International Conference on Software Engineering and Data Mining**, 2010.
HAJIAN, H.; BECERIK-GERBER, B. A Research Outlook for Real-time Project Information Management by Integrating Advanced Field Data Acquisition Systems and Building Information Modeling. **Computing in Civil Engineering**, 2009.
KASSEM, M. et. al. BIM in facilities management applications: a case study of a large university complex. **Facilities management applications,** 2014.
KAZMI, A. et al. A Review of Wireless - Sensor - Network - Enabled Building Energy Management Systems. **ACM Transactions on Sensor Networks**, 2014.
KIM, J.; CALDAS, C. Vision-Based Action Recognition in the Internal Construction Site Using Interactions Between Worker Actions and Construction Objects. **2013 Proceedings of the 30th ISARC**, 2013.
KIM, T. et al. A knowledge-based framework for automated space-use analysis. **Automation in Construction**, 2012.
LI, N. et al. Deployment Strategies and Performance Evaluation of a Virtual-Tag-Enabled Indoor Location Sensing Approach. **JOURNAL OF COMPUTING IN CIVIL ENGINEERING,** 2012.
LIU, X.; AKINCI, B. Requirements and Evaluation of Standards for Integration of Sensor Data with Building Information Models. **Computing in Civil Engineering**, 2009.
MOTAMEDI, A. et al. Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management. **Automation in Construction**, 2014.
PLOENNINGS, J. et al. Virtual sensors for estimation of energy consumption and thermal comfort in buildings with underfloor heating. **Advanced Engineering Informatics.** 2011.
RUPARATHNA, R. et al. Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings. **Renewable and Sustainable Energy Reviews**, 2015.
SHEN, W. et al. Systems integration and collaboration in architecture, engineering, construction, and facilities management: A review. **Advanced Engineering Informatics**, 2009.
SU, Y. et al. Enhancing Maintenance Management Using Building Information Modeling in Facilities Management. **Proceedings of the 28th international symposium on automation and robotics in construction**, 2011.
TANEJA, S. et al. Sensing and Field Data Capture for Construction and Facility Operations. **JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT**, 2011.
VOLK, R. et al. Building Information Modeling (BIM) for existing buildings — Literature review and future needs. **Automation in Construction**, 2013.
YANG, Z. et al. A Multi-Sensor Based Occupancy Estimation Model for Supporting Demand Driven HVAC Operations. **Proceedings of the 2012 Symposium on Simulation for Architecture and Urban Design,** 2012.
YU, Z. et al. Extracting knowledge from building-related data — A data mining framework. **Building Simulation**, 2013.

C.3.2 – Knowledge Base: Knowledge bases arise from the accumulation of treated data over a period of time in the past that offers the ability to study historical behavior. It is this knowledge that allows the creation of the prediction models that were previously presented. In the paper sample, Data Mining was identified as the group of systems used to capture raw data with the purpose of detecting patterns or meaning that is hidden at first sight. The implementation of a Computer Vision system possesses the capacity to capture the visual medium which is rich in information that get archived and catalogued in a way that permits the generation of a substantial amount of useful knowledge about an observed object [15-17].

C.3.3 – Practicality: The practicality lens allows for the reutilization of pre-existing equipment for data capture in the studied buildings, with the least amount of modification to them. Only [15,16,19-21] considered the utilization of previously installed equipment such as energy and temperature meters, which already possess some integrated degree of data capture and monitoring system feeds. The proposed research considers the reutilization of typical security cameras in an innovative way, using the captured visual information for the management of aspects beyond security for which they were originally installed. This would add additional value to systems already contemplated for building management.

TABLE III. NUMBER OF PAPERS PER LENS

Lens	Papers
Productivity	16
Contextualization	13
Reliability	11
Visual Approach	9
Occupancy / Comfort	9
Performance / Artificial Intelligence	5
Practicality	5
Knowledge Base	3
Maintenance	2

TABLE IV. LENSES-PER-ARTICLE MATRIX

Title	Lenses	Common	Computer Vision			BIM			FM	
		Contextualization	Visual Approach	Reliability	Performance / Artificial Intelligence	Productivity	Knowledge Base	Practicality	Occupancy / Comfort	Maintenance
Power monitoring system for university buildings: Architecture and advanced analysis tools	7	X			X	X	X	X	X	
Using data mining in optimization of building energy consumption and thermal comfort management	7	X		X	X		X	X	X	
Extracting knowledge from building-related data - A data mining framework	6	X			X		X		X	
A multi-sensor based occupancy estimation model for supporting demand driven HVAC operations	5		X		X	X			X	
A knowledge-based framework for automated space-use analysis	5	X	X		X	X			X	
Automated as-built 3D reconstruction of civil infrastructure using computer vision: Achievements, opportunities and challenges	4	X	X	X		X				
A research outlook for real-time project information managements by integrating advanced field data acquisition systems and building information modeling	4	X	X	X		X				
Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management	4		X			X			X	X
Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings	4			X		X			X	
Virtual sensors for estimation of energy consumption and thermal comfort in buildings with underfloor heating	4	X		X		X		X		
A review of wireless-sensor-network-enabled Building Energy Management Systems	3	X		X		X				
Application areas and data requirements for BIM-enabled facilities management	3	X				X			X	
BIM in facilities management applications: a case study of a large university complex	3	X				X		X		
BIM for existing buildings – Literature review and future needs	3		X	X		X				
Requirements and evaluation of standards for integration of sensor data with BIM	3	X				X		X		
Vision-based action recognition in the internal construction site using interactions between worker actions and construction objects	3		X	X					X	
Benefits and barriers of construction project monitoring using high-resolution automated cameras	2		X	X						
Deployment strategies and performance evaluation of a virtual-tag-enabled indoor location sensing approach	1			X						
Enhancing maintenance management using BIM in facilities management	2					X				X
Sensing and field data capture for construction and facility operations	2			X		X				
Systems integration and collaboration in architecture, engineering, construction and facilities management: A review	2		X			X				

C.4.1 – Occupancy / Comfort: The occupation and utilization of a space refer to the way that human beings react to the physical space it occupies, generating comfort [27] and productivity metrics [34]; these frequently differ from the way they were designed or simulated [17,18]. The occupation and utilization of space is also one of the primary causes of variation on buildings' energy consumption during their utilization, using lights, altering HVAC temperatures, opening or closing windows and doors and operating other equipment [15,31,32]. Security camera patterns facilitate their use for capturing occupancy and usage data for spaces without needing significant reforms, providing a viable platform for the implementation of computer vision techniques

C.4.2 – Maintenance: The maintenance lens incorporates two aspects of facilities management found the in the papers sample: the evaluation of root failure causes [18] and the maintenance of buildings, furniture and equipment [33]. Considering the scope of data that will be captured and the flexibility of computer vision models for learning behaviors, it is plausible that detected behavioral patterns can be associated not just to space usage, but also for the identification of tendencies related to maintenance, such as frequency of operation and wear of doors, windows, furniture and equipment.

III. CONCLUSIONS

This research presented an extensive exploration using the ProKnow-C methodology that allowed to identify 21 papers that represent the state of the art about BIM knowledge areas, Facilities Management and Computer Vision. This portfolio was analyzed through lenses that represent trends, comparison parameters and opportunities for the development of a series of innovative studies, that uses security cameras in a building to, through the recognition of images, generate a knowledge base that feeds real-time BIM models of the current state of occupation and use of buildings. By the nature of Computer Vision systems, the model would generate enough data to make predictions that can feed decision making and optimize energy consumption, user comfort and property maintenance, including furniture and equipment.

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