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PATENTOMETRIC ANALYSIS OF AI BASED STRUCTURAL HEALTH MONITORING

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Abstract

The worldwide construction sector is moving towards digitization due to the development of Industry 4.0. However, when it comes to digitizing building techniques, structural health monitoring, or SHM, it is still one factor that needs to be considered. Artificial Intelligence (AI) is a remarkable invention in the construction sector. Artificial Intelligence can improve structural health monitoring and provide better solutions. Evaluating previous studies and current developments in AI-based structural health monitoring is essential to achieving this. Through a thorough Patentometric study using the industry-leading databases Espacenet and The Lens, the research seeks to present an analysis of AI in structural health monitoring. For analysis, patent information covering 2019 to 2023 is taken into account. The chosen data is evaluated for patents by nation and year, and the IPC and CPC codes for patents in artificial intelligence for structural health monitoring are also covered. The United States is currently at the forefront of patenting artificial intelligence AI-based structural health monitoring systems. This report presents an in-depth Patentometric analysis that enumerates state-of-the-art innovations. In addition to highlighting the previous art, it offers a route for strategic patenting with higher odds of publication and patent award.

Keywords:

Artificial Intelligence;
Patents;
Structural Health Monitoring;
NDT;
Non Destructive Testing

1 Introduction

After the agricultural sector, the construction industry is the second largest portion of the Indian economy. According to the union budget for 2023–2024, the construction industry makes up 9% of India's GDP. By 2025, India's building sector is anticipated to generate $1.4 trillion. Out of the 13 major sectors of the economy in India, the construction industry comes in at number three and generates the second-highest number of jobs after agriculture. Although the Indian construction industry has increased significantly in importance over the last five years, there is compelling evidence that Indian construction projects perform inconsistently, and this tendency is only getting worse [1]. It has been stated that projects are failing on all major performance metrics, such as quality, time, and money. Further research is needed to fully understand the inherent causes influencing each of these important performance measures [1]. In order to improve the demand of the residential sector it is necessary to improve the quality of work, budget of work and schedule of work [2]. The worldwide construction sector is moving towards digitization due to the development of Industry 4.0. However, when it comes to digitizing building techniques, structural health monitoring, or SHM, it is still one factor that needs to be considered. Technology-assisted solutions are being used more and more to support established procedures. Artificial Intelligence (AI) is a remarkable invention in the construction sector. An asset's digital representation is created by AI using a combination of structured and cross-disciplinary data based on an intelligent model.

1.1 Structural Health Monitoring (SHM)

In the early 2000s, long-span bridges were first monitored by structural health monitoring, which provides measurable and accurate data on a structure's integrity and can detect cracks and degradations. The discipline of structural health monitoring focuses on to systematically monitoring the state of structures to ensure their dependability, durability, and safety [3]. Determining a structure's current condition and behaviour with precision is the primary goal of structural health monitoring. Anomalies are correctly recognized, and the dependability of structures is evaluated almost immediately through an automated evaluation of measured data collected by monitoring devices within a structure. In addition, the precise progression of structural damage and impairment is visible. Since revitalization can be managed more efficiently than in the past, it significantly reduces the costs associated with maintaining structures [4]. SHM involves the measurement and processing of various data collected from structures, such as acceleration, temperature, displacement, force, and strain, to implement damage identification strategies [5] [6]. Synchronized measurements are necessary to calculate dynamic properties of the structure, such as natural frequency, damping rate, and mode-shapes [5][7].

According to Bassoli et al., ‘Structural Health Monitoring is the process of characterization of existing civil structures for structural identification and damage detection purposes [8]. Saisi et al. defines SHM as, ‘SHM is the continuous interrogation of sensors installed in the structure aimed at extracting features which are representative of the current state of structural health [8]. According to Guidorzi et al. ‘Structural Health Monitoring aims to give a continuous diagnosis of the ‘state’ of the different parts and of the full assembly of these parts constituting the structure as a whole [4].

Updating these systems and interpreting the sensor data posed the most challenges [9]. SHM can be attained by various techniques, including non-destructive image processing and traditional destructive ways of evaluating cracks by removing a core sample from the structure [9].

1.2 Non- Destructive Testing (NDT)

Type Techniques for testing that do not damage the structural integrity of the components are referred to as non-destructive tests or NDTs. NDT evaluates the components individually or collectively utilizing a variety of inspection techniques. Utilizing the tested components is an essential benefit of non-destructive testing [10]. In addition, components that are still in service can frequently be tested using non-destructive testing techniques. Many NDT methods make use of small, portable testing instruments. Therefore, inspecting parts in a working machine is a lot simpler. In destructive testing, concrete structure sample pieces get loaded or stressed to the point of breakage. These tests are referred to as "destructive" as they frequently result in sample damage. They are commonly used when a small sample correctly reflects the entire structure [3].

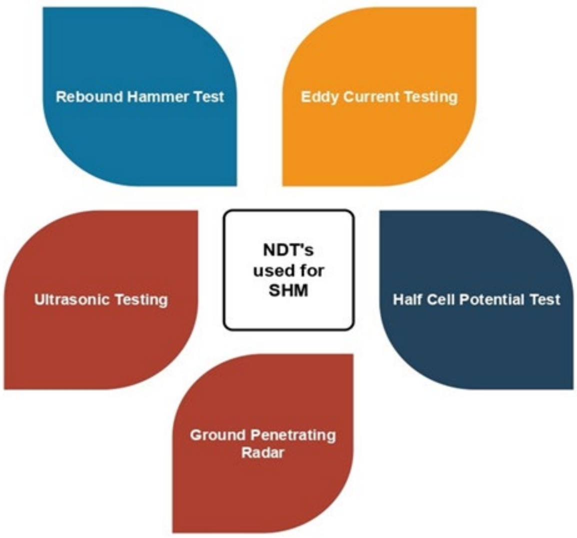

Fig. 1: Non-Destructive test’s used for structural health monitoring [11].

Because non-destructive tests are carried out without causing any damage to the structure, they help evaluate existing structures or buildings without causing harm. They offer details about the strength and quality of the concrete without removing samples. Structural audit of RCC structures is the process used to evaluate the state, integrity, and safety of buildings, bridges, and other structures made of reinforced concrete. These inspections are required to identify any signs of deterioration, corrosion, fractures, and other structural issues that may eventually compromise the stability and security of the structure [12]. Monitoring the durability and security of the structure, in addition to suggesting any required maintenance or repairs, are the primary objectives of a structural audit. The wide variety of non-destructive tests that have been developed all over the years is evidence of the effectiveness of these techniques. It is extremely useful to be able to check the state of a structure without placing it in risk or having to shut it down, particularly in a production environment. Non-destructive testing for RCC (Reinforced Concrete) structures has a promising future because of technological advancements and the increasing need for sustainable infrastructure management [12].

1.3 Artificial Intelligence in SHM

A variety of AI-based techniques, such as machine learning techniques, have been put out in recent years for feature extraction, data interpretation, model update, and diagnostics for infrastructure systems' health monitoring [13]. This rapidly growing field of study has shown promise for a wide range of real-world uses and has proven superior in system identification, extraction of features, damage identification, and even the direct response prediction of dynamical systems. This Special Issue aims to emphasize how important it is to create and use AI-based approaches for structural health monitoring [13]. With an extensive background in computer science, artificial intelligence (AI) offers a wide range of solutions to monitor problems that are challenging to resolve with only traditional computing techniques. Furthermore, a synchronized SHM system has been designed using Internet of Things technology. This system uses synchronized accelerometer sensors to collect acceleration signals from specific locations within the structure and then wirelessly transfers the data to the central node and a remote server for damage identification and detection [6].

Fig. 2: Tools of artificial intelligence used for structural health monitoring.

1.4 Non- Destructive Testing (NDT)

Additionally, inspectors' abilities are severely limited due to the complicated surrounding of facilities and infrastructure, such as when examining tunnels, tall infrastructure, and bridges. As a result, infrastructure monitoring and inspection inspectors have to be replaced quickly with automated intelligent technology [13].

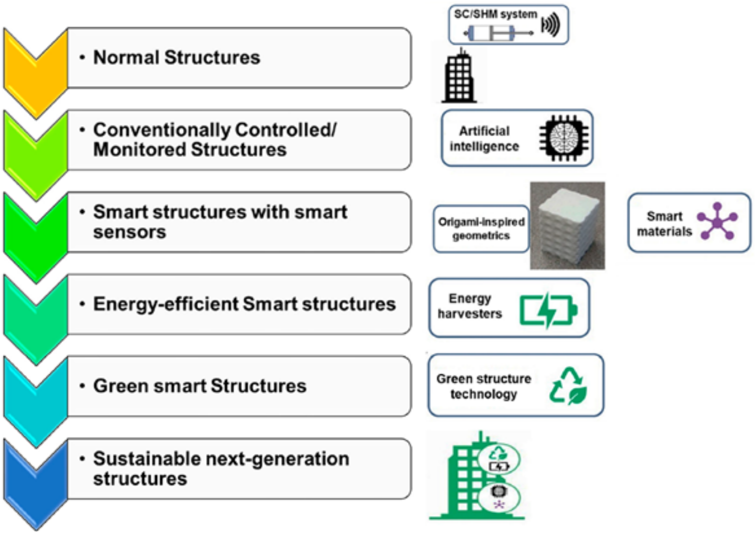

Fig. 3: The key phases of a typical structural control and health monitoring integration system.

It's essential to keep in mind that factors including technical viability, cost-effectiveness, legal constraints, and market demand will all have an impact on how widely these trends are adopted. To keep up to date on the latest developments in non-destructive testing for reinforced concrete constructions consider studying academic articles, attending conferences, and joining professional societies [8]. These are some critical distinctions between monitoring and inspection. By detecting physical quantities like defect size, vibration frequency, accelerations, and displacement, monitoring offers a quantitative insight of the infrastructure's current state [14]. Generally, multi-sensor systems are used to do this. Finding superficial defects in building materials and defects in infrastructure is the primary goal of inspection. These are mostly done using optical cameras and the recognition of object algorithms [15].

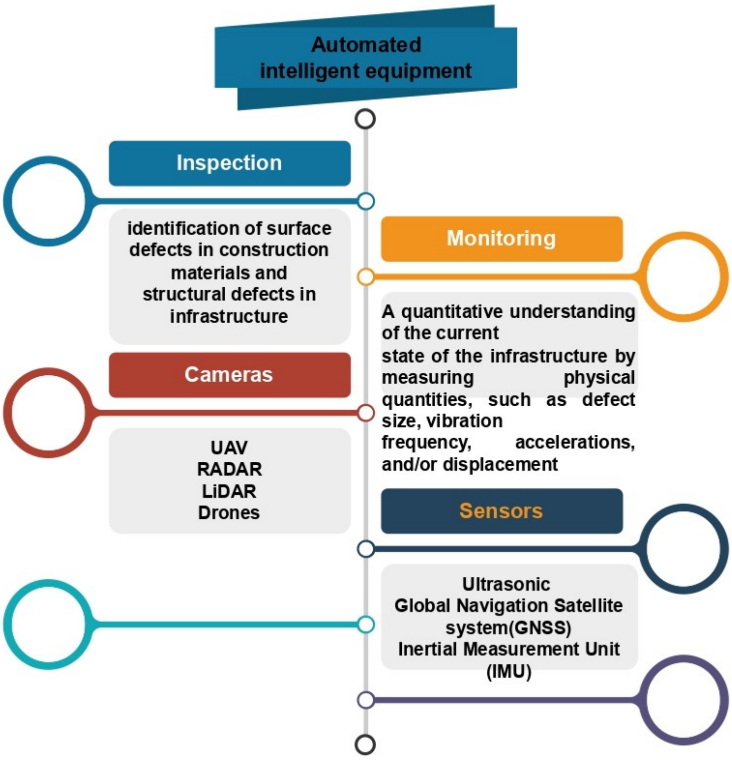

Fig. 4: Automated intelligent equipment's used for structural health monitoring.

2 Strategies for searching

Table 1 represents set of keywords used for the patent analysis for Structural Health Monitoring (SHM) using Non Destructive Technique (NDT) and Artificial Intelligence (AI) [16]

Table 1: Keyword strategy for Espacenet and The Lens database

Sr. No.	Keywords	No. of Documents	
		Espacenet	The Lens
1	Structural health monitoring OR SHM AND NDT OR Non-destructive testing	9163	36
2	Structural Health Monitoring OR SHM AND NDT OR Non-destructive testing AND Artificial Intelligence OR AI	186	7

Source- worldwide.espacenet.com and www.Lens.org

When investigating, an extensive search area will be considered, and the keywords Structural Health Monitoring OR SHM AND Non Destructive Techniques OR NDT will be set. Additionally, the keyword set Structural Health Monitoring OR SHM AND Non Destructive Techniques OR NDT AND Artificial Intelligence OR AI is searched for more focused results. The second set yields much fewer search results than the first keyword set.

3 Patent Analysis

To fully comprehend the extent of research and innovation, it is essential to analyse patents [17]. A comprehensive patent analysis is conducted using keywords set II, Structural Health Monitoring OR SHM AND Non-Destructive Techniques OR NDT AND Artificial Intelligence OR AI, to assess the trend of innovation in AI for SHM. A workflow is created for the chosen collection of keywords, as illustrated in Fig. 5.

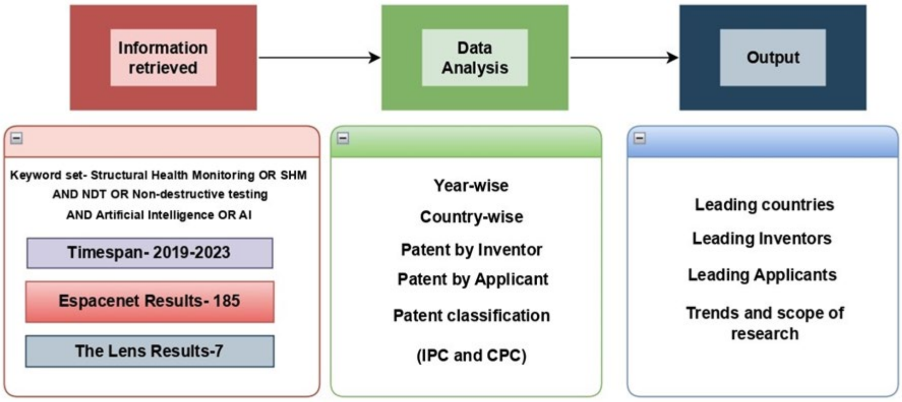

Fig. 5: A method utilized to search databases.

3.1 Documents based on Year-wise analysis

The year the patent was published makes it easier to determine when research is done in a particular field and whether that field has expanded or reduced over time [18]. The data was considered for the study because all of the findings are current, spanning 2019 through 2023. Figures 6 and 7 display the patent publications by year in the corresponding search.

There were 17 articles in the domain until 2019 on the Espacenet platform; nevertheless, beginning in 2017, the number of patents progressively climbed until 2023, when the number peaked. The pattern indicates that the research on AI applications for SHM continues to expand.

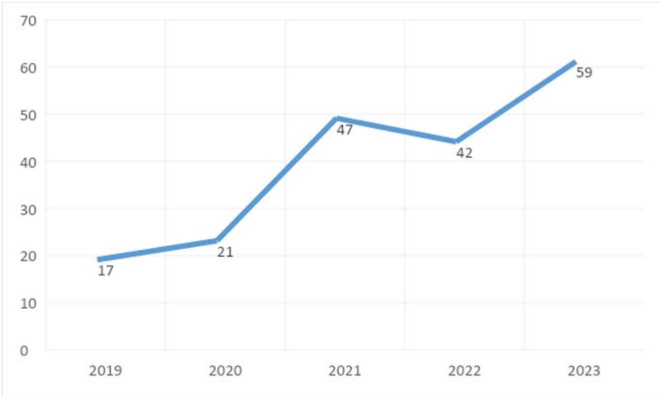

Fig. 6: Year-wise number of patents published on Espacenet platform
(Source- worldwide.espacenet.com)

There was just one patent in the domain up to 2019 on The Lens platform; nevertheless, in 2020, multiple patents progressively increased until the number of patents peaked. In the subsequent years, the number of patents published will remain the same. The pattern suggests that more research was conducted on AI applications for SHM during the COVID-19 pandemic.

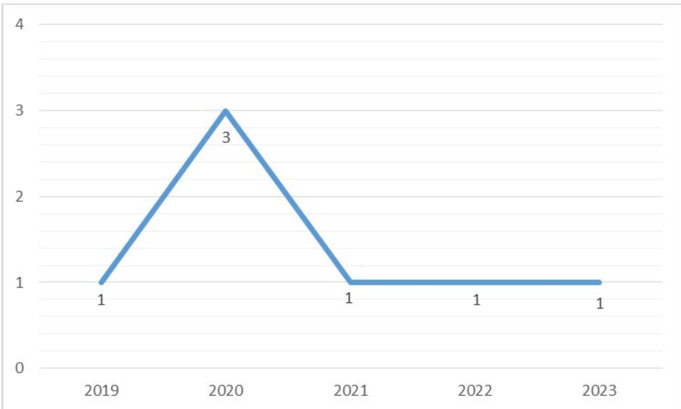

Fig. 7: Year-wise number of patents published on The Lens platform
(Source- www.Lens.org)

3.2 Documents based on Country-wise analysis

Analysing the country with the most significant number of patents in structural health monitoring (SHM) entails analysing the information regarding the use of AI worldwide. Seventeen countries publish a total of 186 documents. Specific country codes represent the patent distribution by nation. The two letters comprising the country code mean where the patent was issued.

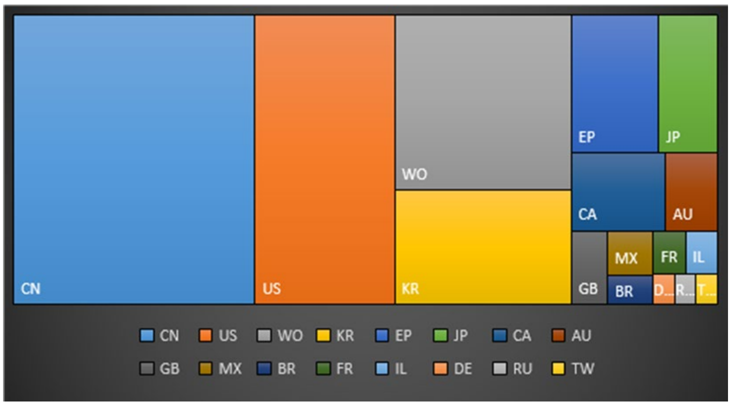

Fig. 8: Country-wise number of patents published on Espacenet platform
(Source- worldwide.espacenet.com)

On The Lens platform 7 documents were found and united states has more numbers i.e. 5 compare to china and European countries.

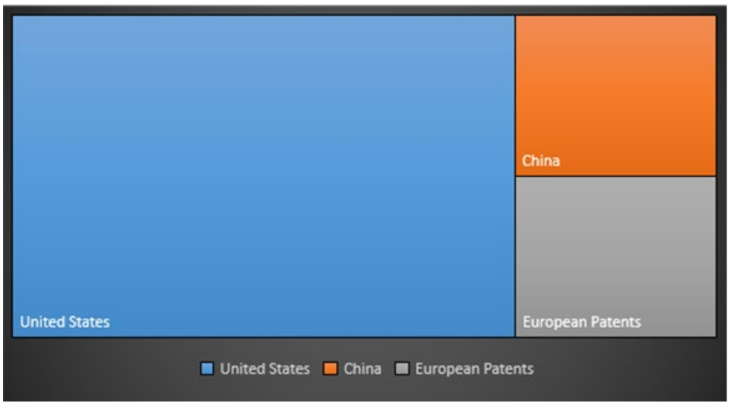

Fig. 9: Country-wise number of patents published on The Lens platform
(Source- www.Lens.org)

Search on both the platforms shows less focus of research in the domain of AI based SHM in India.

3.3. An inventor's patent

An overview of the inventor's contributions, Figs. 10 and 11 show the most prominent inventors by number of patents who have advanced the field of AI for SHM.

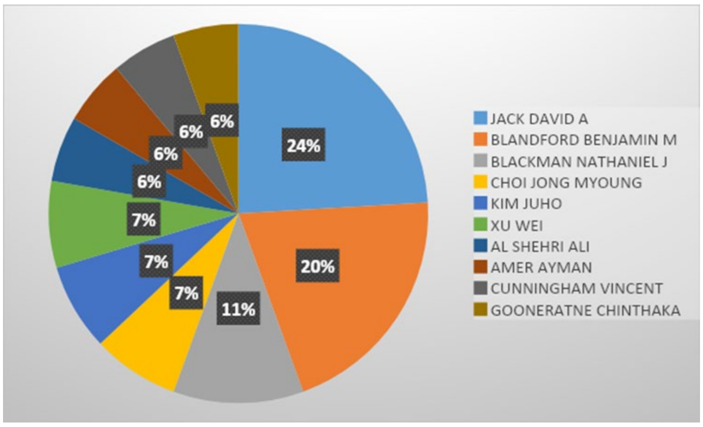

Fig. 10: Patents by inventor published on Espacenet platform
(Source- worldwide.espacenet.com)

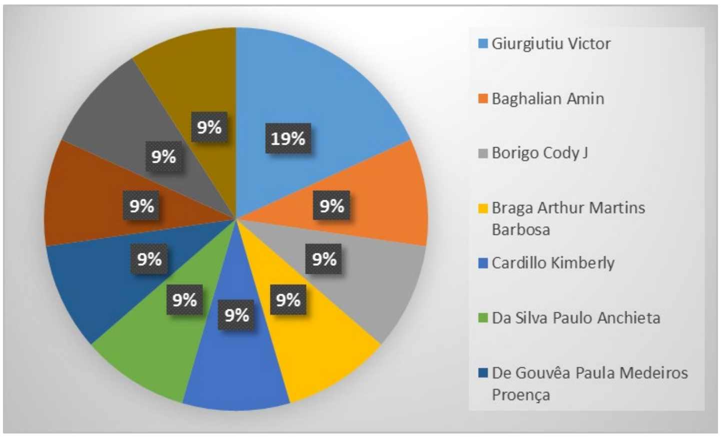

Fig. 11: Patents by inventor published on The Lens platform
(Source- www.Lens.org)

3.4. Patent by applicants

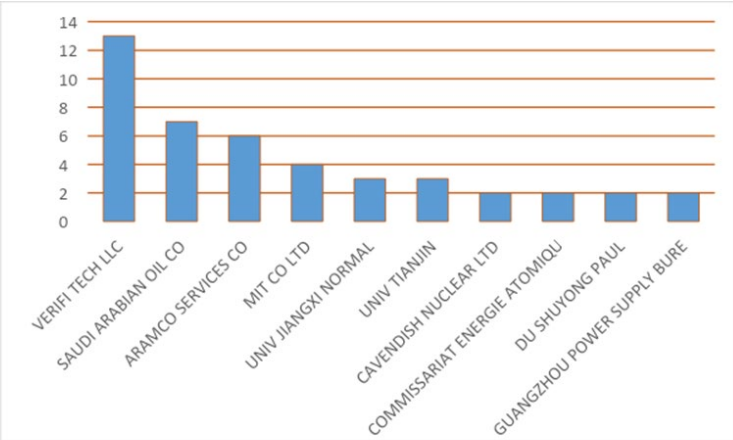

Fig. 12: Patents by Applicants published on Espacenet platform
(Source- worldwide.espacenet.com)

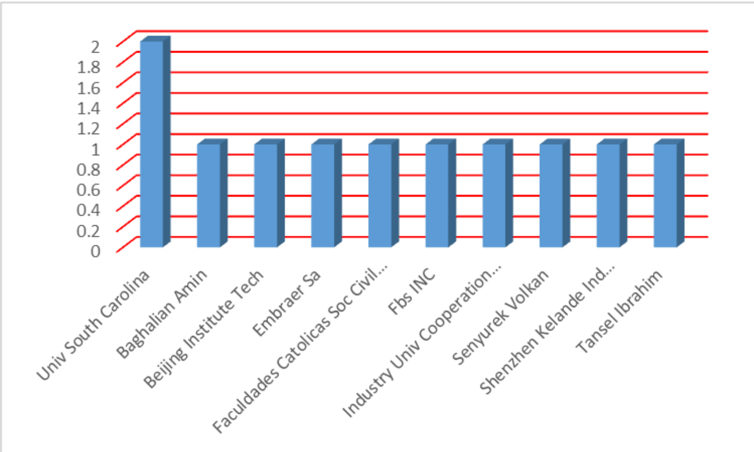

Fig.13: Patents by applicants published on The Lens platform
(Source- www.Lens.org)

To demonstrate how much each applicant has contributed, the top applicants in the field of AI for SHM are shown in Figs. 12 and 13.

3.5. Patent Classification

The systems for corporate property classification (CPC) and intellectual property classification (IPC) include Sections (Technical Field) A through H and Y. Section A deals with essentials for humans. In contrast, Section B deals with operations and transportation. Textiles and paper are covered in Section D; Chemistry and Metallurgy Fixed Constructions are covered in Section E; Mechanical Engineering, Lighting, Heating, Weapons, and Blasting Physics are covered in Section G; Electricity is covered in Section H; and Technical Topics covered in the previous USPC are covered in Section Y. The topic or subject of the inquiry is the primary basis for IPC class and CPC class data representations, which give an investigator specific information through a particular domain [19].

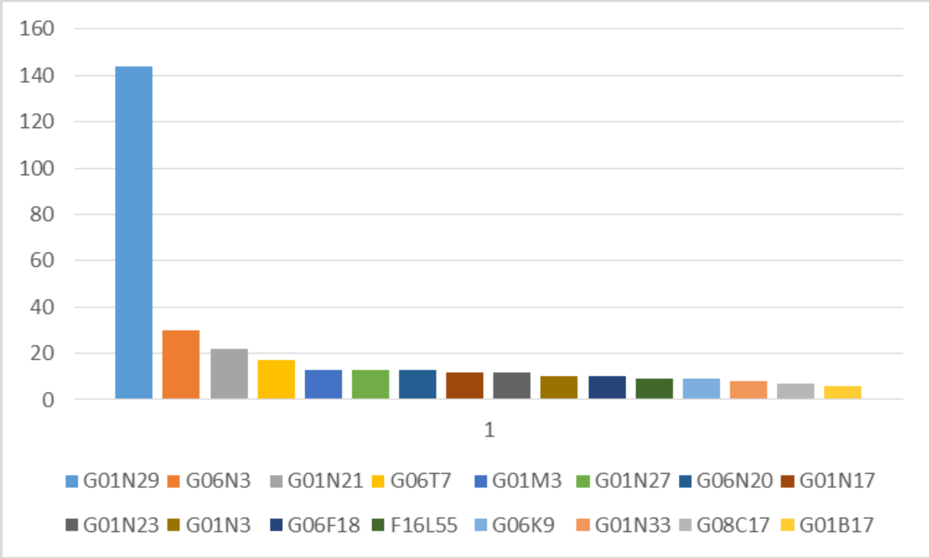

Fig. 14: Patent publication in IPC main group published on Espacenet platform (Source- worldwide.espacenet.com)

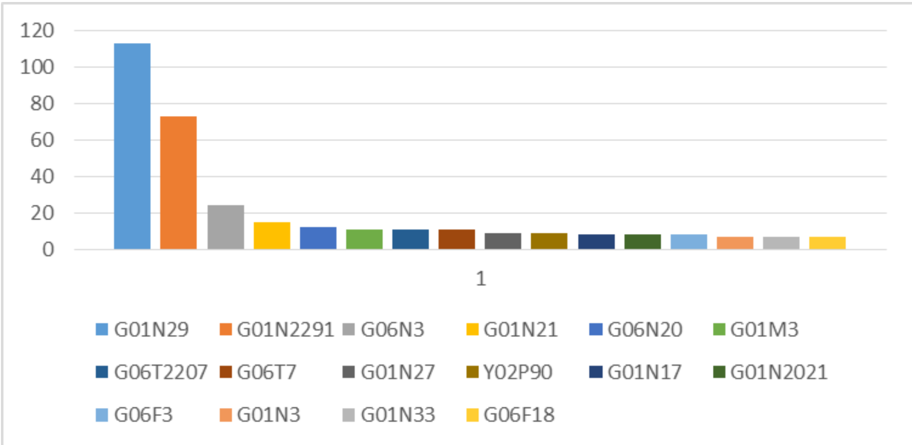

Fig. 15: Patent publication in CPC main group published on Espacenet platform (Source- worldwide.espacenet.com)

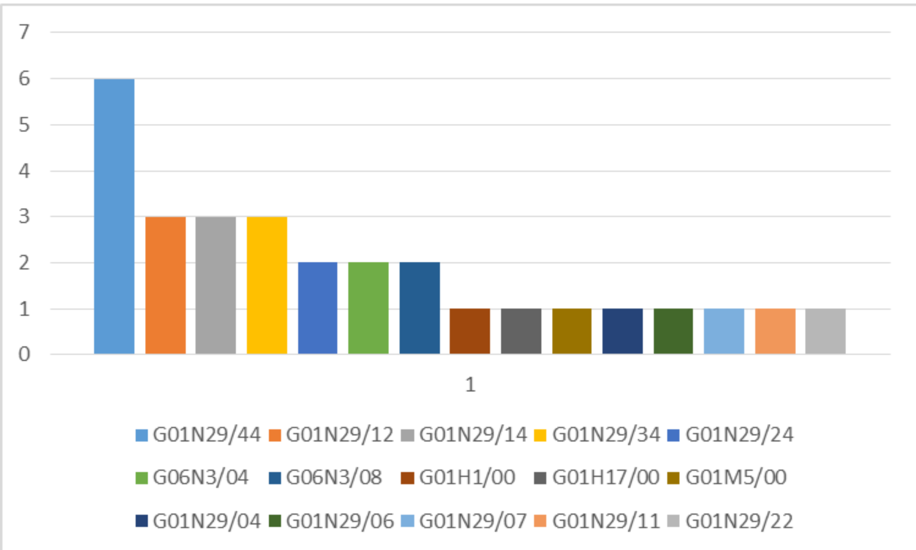

Fig. 16: Patent publication in IPC main group published on The Lens platform (Source- www.Lens.org)

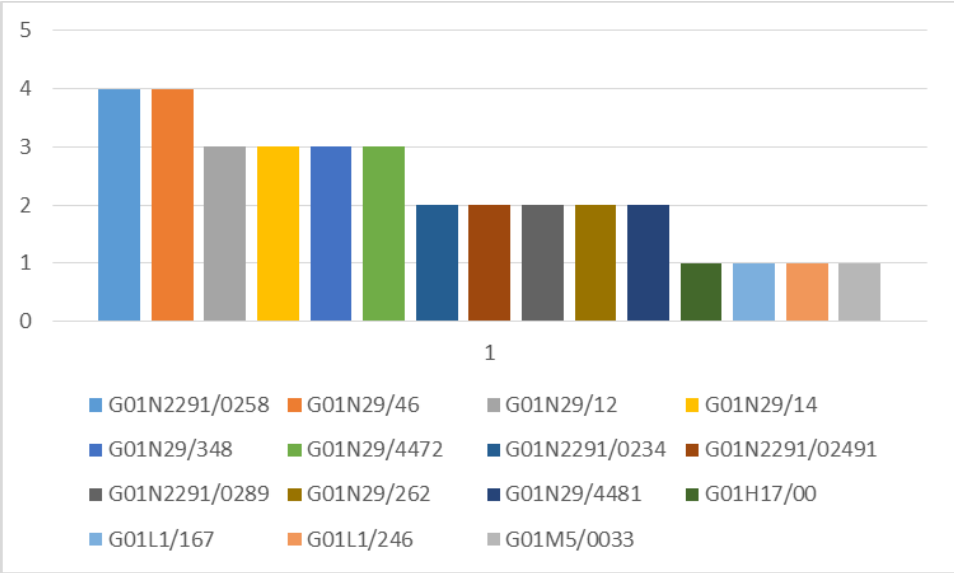

Fig. 17: Patent publication in CPC main group published on The Lens platform (Source- www.Lens.org)

For instance, G06F30 indicates that the patent class implies instruments (counting or calculating), F stands for electric digital data processing, and 30 represents computer-aided design (CAD). The patent part is related to physics. The coding specifications of the IPC group and CPC group let researchers extract data from a particular area and are mostly based on the subject or discipline in which the study is conducted. Figures 14, 15, 16, and 17 show how many patents are classified under the IPC and CPC [20].

4 Conclusion

The information was taken from the annual Accidental Deaths and Suicides in India (ADSI) report published by the National Crime Records Bureau. According to records, there were 1576 incidents that were linked to building collapses in 2021. The data for the ten-year period (2012 to 2021) shows a fluctuating pattern. A significant portion of these incidents are linked to those brought on by the collapse of a residential structure. 73% of all incidents in 2021 that were caused by structures collapsing included residential areas. The percentage of accidents impacting residential areas has increased during the past ten years. The amount of research on artificial intelligence (AI) applications for monitoring the health of structures is constantly increasing. However, there are few investigations, and barely any nation provides them regarding patentability. While searching and analysing the data related to the intended domain, no Indian patents were found. Furthermore, the absence of Indian researchers from inventor trend assessments implies that this is an area that needs to be approached by India to compete globally. Indeed, both internationally and domestically, AI applications for structural health monitoring have not received enough attention in India. It demonstrates how much scope is available for Indian researchers to go into this field.

The study shows that AI-based structural health monitoring primarily uses an integrated strategy incorporating cutting-edge technology like LiDAR, UAVs, sensors, and more. The ultimate monitoring and inspection solutions can be obtained when these technologies are combined with AI, which is impossible with traditional methods. It also highlights AI's admirable ability to interface with different technologies, and it has the potential to improve inspection and monitoring standards significantly to provide effective structural health monitoring.

Each construction project has to prioritize the structural health monitoring domain, a requirement for careful thought from the outset. It has been noted that most research involves real-time monitoring during the construction phase, yet, implementing AI at the preconstruction phase is crucial. In addition, irrespective of the purpose of the construction project, structural health monitoring is vital. Large-scale research on the use of AI in infrastructure projects has demonstrated the necessity of implementing AI's advantages for various projects, including both residential and commercial ones.

References

[1] DOLO H. – SAWHNEY A. – IYER K. C. – RENTALA S.: Analysing Factors Affecting Delays In Indian Construction Projects. Int. J. Proj. Manag., Vol. 30, No. 4, Pp. 479–489, 2012, Doi: 10.1016/J.Ijproman.2011.10.004.

[2] ALALOUL W. S. – MUSARAT M. A. – RABBANI M. B. A. –IQBAL Q.–MAQSOOM A.–FAROOQ W.: Construction Sector Contribution To Economic Stability: Malaysian Gdp Distribution. Sustain, Vol. 13, No. 9, Pp. 1–26, 2021, Doi: 10.3390/Su13095012.

[3] CIVERA M. – SURACE C.: Non-Destructive Techniques For The Condition And Structural Health Monitoring Of Wind Turbines: A Literature Review Of The Last 20 Years. Sensors, Vol. 22, No. 4, 2022, Doi: 10.3390/S22041627.

[4] HASSANI S. – MOUSAVI M. – GANDOMI A. H.: STRUCTURAL Health Monitoring In Composite Structures: A Comprehensive Review. Sensors, Vol. 22, No. 1, Pp. 1–45, 2022, Doi: 10.3390/S22010153.

[5] TOSCANI D. A. – ROCCHI R. – PINARDI M. B.: Low-Cost Structural Health Monitoring System for Smart Buildings. Second International Conference On Sustainable Mobility Applications, Renewables And Technology (Smart), 2022.

[6] TUDOSA I. – PICARIELLO F. – BALESTRIERI E. – CARNI D. L. – LAMONACA F. : A Flexible Daq Hardware Architecture Using Socs For Iot Based Structural Health Monitoring Systems.2019 Ieee Int. Work. Metrol. Ind. 4.0 Iot, Metroind 4.0 Iot 2019 - Proc., No. I, Pp. 291–295, 2019, Doi: 10.1109/Metroi4.2019.8792900.

[7] ABDULKAREM M. – SAMSUDIN K. – ROKHANI F. Z. – RASID M. F, "Wireless Sensor Network for Structural Health Monitoring: A Contemporary Review of Technologies, Challenges, and Future Direction. Struct. Heal. Monit. Vol. 19, No. 3, Pp. 693–735, 2020, Doi: 10.1177/1475921719854528.

[8] PALLARÉS F. J. – BETTI M. – BARTOLI G. – PALLARÉS L.: Structural Health Monitoring (Shm) and Nondestructive Testing (Ndt) Of Slender Masonry Structures: A Practical Review. Constr. Build. Mater. Vol. 297, 2021, Doi: 10.1016/J.Conbuildmat.2021.123768.

[9] SHIBU M. – KUMAR K. P. – PILLAI V. J. – MURTHY H. –CHANDRA S.: Structural Health Monitoring Using Ai and Ml Based Multimodal Sensors Data. Meas. Sensors, Vol. 27, No. September 2022, P. 100762, 2023, Doi: 10.1016/J.Measen.2023.100762.

[10] NANUKUTTAN S. –YANG K. –BASHEER P. A. M.: Non-Destructive Testing and Structural Health Monitoring. Ice Handb. Concr. Durab. A Pract. Guid. To Des. Resilient Concr. Struct. No. Ml, Pp. 449–491, 2023, Doi: 10.1680/Icehcd.63754.449.

[11] KOT P. –MURADOV M. –GKANTOU M. – KAMARIS G. S. –HASHIM K. –YEBOAH D.: Recent Advancements in Non-Destructive Testing Techniques for Structural Health Monitoring. APPL. Sci., Vol. 11, No. 6, 2021, Doi: 10.3390/App11062750.

[12] KESHMIRY A. – HASSANI S. – MOUSAVI M. – DACKERMANN U.: EFFECTS OF ENVIRONMENTAL and Operational Conditions On Structural Health Monitoring And Non-Destructive Testing: A Systematic Review. Buildings, Vol. 13, No. 4, 2023, Doi: 10.3390/Buildings13040918.

[13] ALTABEY W. A. – NOORI M.: Artificial-Intelligence-Based Methods for Structural Health Monitoring. Appl. Sci., Vol. 12, No. 24, Pp. 12–15, 2022, Doi: 10.3390/App122412726.

[14] ZHOU H. –XU C. –TANG X. –WANG S. – ZHANG Z.: A Review of Vision-Laser-Based Civil Infrastructure Inspection and Monitoring. Sensors, Vol. 22, No. 15, 2022, Doi: 10.3390/S22155882.

[15] SHIRAZI A. A. –MUSTAPHA F. –AHMAD K. A.: Damage Identification Using Wireless Structural Health Monitoring System through Smart Sensor Application. Int. J. Adv. Appl. Sci., Vol. 4, No. 2, Pp. 38–43, 2017, Doi: 10.21833/Ijaas.2017.02.007.

[16] SHALAKA H. – SAYALI S. – KIRTI R.: Technology Landscape for BIM in Construction Site Safety Management. No. November, Pp. 931–943, 2024, Doi: 10.1007/978-3-031-39663-2_78.

[17] TIWARI A. – RATURI M. –MUKHERJEE S. –KUMAR SAHOO P.: Patinformatics-An Emerging Scientific Discipline. Introduction and Objectives. 2002. [Online]. Available: Http://Ssrn.Com/Abstract=1566067

[18] DESAI P. – SANDBHOR S. – KAUSHIK A.: AI and Bim-Based Construction Defects, Rework,

And Waste Optimization. 2023 Int. Conf. Emerg. Smart Comput. Informatics, Esci 2023, Pp. 1–6, 2023, Doi: 10.1109/Esci56872.2023.10099726.
[19] European Patent Office and United States Patent and Trademark Office (2018) CPC Scheme And CPC Definitions. Coop Pat Classif. Available: Https://Www.Cooperativep Atentclassification.Org/Cpcschemeanddefinitions/Table.Html
[20] www.lens.org
[21] worldwide.espacenet.com