March 2025

This Magazine is a Publication of the Asian Institute of Technology

TECHNOLOGY

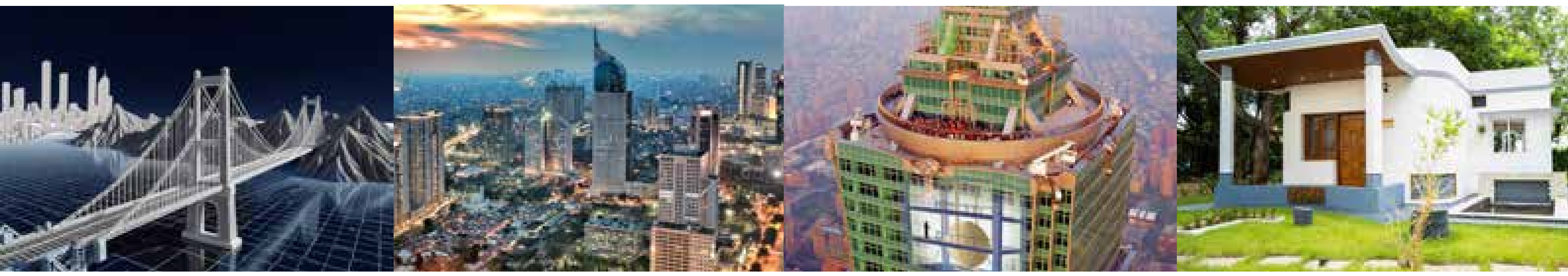
Asian Outlook on Engineering & Technology

BUILDINGS & ADVANCED TECHNOLOGIES

AIT Solutions

March 2025

CONTENTS



ISSN 2286-9158

Technology Asian Outlook on Engineering and Technology, is published by AIT Solutions
Asian Institute of Technology, P.O. Box 4, Klongluang, Pathumthani 12120, Thailand

Editor's Note

The application of advanced technologies in buildings and infrastructure projects is rapidly increasing, driving improvements in constructability, efficiency, sustainability, public safety, and resilience against natural disasters.

In this issue, we bring together experts from academia and industry to share their insights and experiences in design, construction, and monitoring using cutting-edge technologies. As you explore this edition, you will find researchers discussing their breakthroughs, challenges, and prospects in applying 3D printing technology to construction. You will also discover how AI-driven tools are transforming damage assessment, construction monitoring, and project management for buildings and infrastructure. Additionally, this issue features insights from professionals on the latest advancements in performance-based seismic design in Indonesia, highlighting its impact on improving the safety and resilience of tall buildings.

I extend my sincere gratitude to all contributors for sharing their expertise and perspectives on emerging technologies and their applications. I also appreciate the efforts of our editorial team in editing and designing this issue.

As a knowledge product of AIT Solutions, this magazine serves as a professional communication platform for experts and researchers, offering valuable insights into the latest technologies, events, and developments in the field.

We welcome your valuable feedback and look forward to engaging discussions.

Thaung Htut Aung
Executive Director, AIT Solutions
Asian Institute of Technology
thaunghtutaung@ait.ac.th

Editor in Chief
Thaung Htut Aung

Associate Editor
Justin Arnold Finch

Managing Editor
Jennifer Pangilinan

Layout and Design
Khattiyanee Khancharee
Pitiruedee Angkhananuchat

Contributors
Bhupinder Singh
Budihartono Wijanto
Davy Sukamta
Farrukh Arif
Indra Djati Sid
Iswandi Imran
Jayanta Pathak
Mohammad Najeeb Shariff
Nikhil P. Zade
Punchet Thammarak
Shabir Ali Talpur
Swapnil Balasaheb Ghodke

AIT Solutions
solutions@ait.ac.th
www.solutions.ait.ac.th

ACECOMS
acecoms@ait.ac.th
www.acecoms.ait.ac.th

58, Moo 9, km. 42 Paholyothin
Highway, Khlong Luang,
Pathumthani
12120, Thailand

Tel : +(662) 524 6388
: +(662) 524 5533
Fax : +(662) 524 6655

Advanced Technologies and Applications for 3D Geometric and Surface Condition Data Collection in Structural Engineering

One of the most effective ways to capture 3D geometry of objects, including structures, is through 3D point cloud data. This data serves as a digital representation of the object's shape, providing valuable insights for analysis, design, and maintenance.

Author:

Punchet Thammarak
CEO & Founder
Resolution Engineering
Co. Ltd., Thailand

The collection and documentation of 3D geometric data have become essential for various engineering, architectural, and conservation applications. One of the most effective ways to capture the 3D geometry of objects, including structures, is through 3D point cloud data. This data serves as a digital representation of the object's shape, providing valuable insights for analysis, design, and maintenance. Two major techniques used for acquiring 3D geometry data are photogrammetry and LiDAR, each suited for different scenarios based on accuracy, environment, and operational constraints. Photogrammetry relies on standard cameras and advanced algorithms to determine the 3D coordinates of points, using known reference points to establish scale and accuracy. In contrast, LiDAR (Light Detection and Ranging) utilizes laser pulses to directly measure distances, generating high-precision 3D point clouds independent of lighting conditions. These technologies have revolutionized structural assessment, enabling efficient and accurate data collection for a wide range of applications.

Understanding Photogrammetry and LiDAR: Techniques, Strengths, and Limitations

Photogrammetry is a technique that reconstructs 3D geometry by analyzing multiple images taken from different angles. The process begins with capturing a series of overlapping photographs of the object or structure. These images are then processed using advanced algorithms that identify common points across multiple views and calculate their precise 3D coordinates. Once these points are established, a dense point cloud is generated, which can further be converted into a detailed 3D mesh for visualization and analysis. One of the key advantages of photogrammetry is its flexibility in data collection—standard cameras, including those mounted on drones, can efficiently capture images from various perspectives, making it particularly useful for surveying large or inaccessible (due to height) structures. Moreover, the detailed surface condition of structures can be documented in the form of a tiled surface model. However, in indoor environments, where 360-degree coverage is required, the process becomes significantly more challenging. Collecting sufficient images to cover all angles can be labor-intensive, especially in confined spaces with occlusions and varying lighting conditions, making photogrammetry less practical for complex interior spaces compared to other methods like LiDAR.

Figure 1: *The illustration of the photogrammetry process.*

Figure 1 explains the concept of photogrammetry of a sample object of interest, a stone lion, where multiple images of a stone lion statue taken from different angles are used to reconstruct a 3D point cloud model. The images show feature detection points (marked in arrows) that correspond across different views, enabling the alignment of images. The central 3D point cloud visualization represents the initial stage of model reconstruction, where extracted key points and camera positions (blue rectangles around the statue) contribute to the spatial mapping of the object. Figure 2 showcases the stages of 3D reconstruction using photogrammetry. From left to right, it presents: (1) the 3D point cloud, (2) the generated 3D mesh model, and (3) the final textured tiled model, representing the complete digital replica of the stone lion statue.

Next, LiDAR is a technique for capturing 3D geometry using laser beams and ranging methods to measure distances by emitting laser pulses and calculating the time it takes for them to reflect off surfaces. Laser scanning is performed at high speed, typically exceeding 300,000 points per second for industrial-grade LiDAR. Additionally, the laser scanner rotates about two orthogonal axes, ensuring comprehensive coverage of the scanned structures. This process guarantees that all measured distances are real and highly accurate, making LiDAR a versatile method for both outdoor and indoor environments. In some challenging situations, such as featureless surfaces or areas with complex geometry, control points (predefined reference coordinates) may be required to enhance accuracy. LiDAR systems can be mounted on various platforms, including drones with high payload capacities of up to 3–4 kilograms, enabling efficient data collection in difficult-to-reach areas. However, unlike photogrammetry, LiDAR cannot generate tiled surface models with natural textures, as it primarily produces a detailed but untextured point cloud.

There are two main types of LiDAR scanners: **Terrestrial LiDAR Scanning (TLS)** and **Simultaneous Localization and Mapping (SLAM) LiDAR**, each with its own advantages and limitations. TLS is a stationary, high-precision scanning method (Figure 3) that captures detailed 3D point clouds, making it ideal for accurate surveying and structural analysis, but it requires multiple setups and is time-consuming. In contrast, **SLAM LiDAR (Figure 4)** is a mobile scanning technology that continuously maps the environment while moving, offering faster data collection and flexibility, though with lower accuracy compared to TLS. The choice between the two depends on the specific application and accuracy requirements.

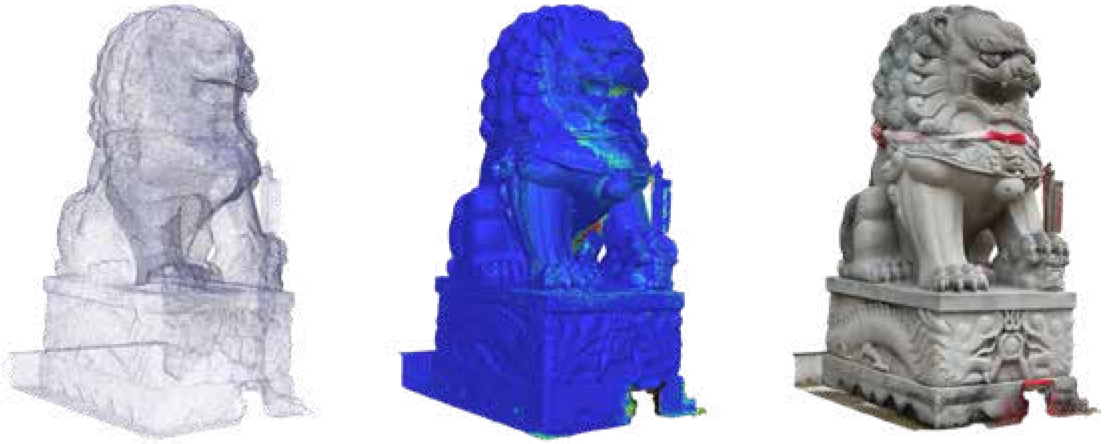


Figure 2: *Photogrammetric 3D reconstruction process.*

Figure 3: *Terrestrial LiDAR Scanner on tripod installation.*

Figure 4: *SLAM LiDAR scanner.*

Despite their differences, point clouds from both techniques can be merged or combined, allowing for enhanced coverage and improved data completeness. However, the computational and financial costs of these methods differ significantly. Photogrammetry requires extensive processing power to generate a 3D point cloud and may struggle with featureless or reflective surfaces, leading to errors in reconstruction. On the other hand, LiDAR requires a higher initial investment in equipment, but it involves minimal post-processing, mainly for accuracy enhancement. Choosing between the two methods depends on the project requirements, available resources, and the specific challenges of the scanning environment.

Applications of Photogrammetry and LiDAR in Structural Engineering Assessment

From a structural engineering perspective, the application of groundbreaking 3D geometric data collection techniques can be utilized in various ways to evaluate existing structures.

At a structural collapse site, the risk of further failure presents a significant hazard to surveyors. Given the often large and tall nature of infrastructure structures, unmanned aerial vehicles (UAVs) play a crucial role in safely surveying and documenting the site's 3D condition. By capturing high-resolution aerial imagery, UAVs facilitate the creation of an accurate 3D point cloud through photogrammetry, which is essential for forensic engineering analysis in assessing failure mechanisms. Figure 5 illustrates the practical application of UAV video footage combined with photogrammetry techniques to reconstruct a 3D point cloud of a collapsed launching gantry at a segmental box girder construction site.

Figure 5: *UAV-based 3D reconstruction of a collapsed launching gantry.*

Photogrammetry enables the systematic documentation of crack patterns in reinforced concrete structures by reconstructing their 3D surfaces. In large and complex structures such as bridges, dams, and other infrastructure, stress paths can be intricate, potentially leading to cracking that requires long-term monitoring. By generating orthographic projections of concrete surfaces, photogrammetry allows for comparisons over time, facilitating the assessment of structural changes. Additionally, it enables precise crack length measurements. Figure 6 presents an example of crack documentation on a bridge tower, from the ground level to the height of 40 meters, using UAVs and photogrammetry.

Regarding structural integrity evaluation of cable-stayed bridges, the accuracy of internal force calculations for the overall structural system—including pylons, cables, and girders—depends on precise bridge profile data. The quasi-static bridge profile is the most critical input for the finite element model, significantly influencing internal forces. This profile is primarily affected by temperature changes. The measurement of the bridge profile must be conducted quickly before temperature effects cause significant alterations. Using LiDAR technology, the total time required to collect the entire 300-meter-long bridge profile is less than one hour, shown in Figure 7.

Figure 6: *Crack path documentation of a bridge tower.*

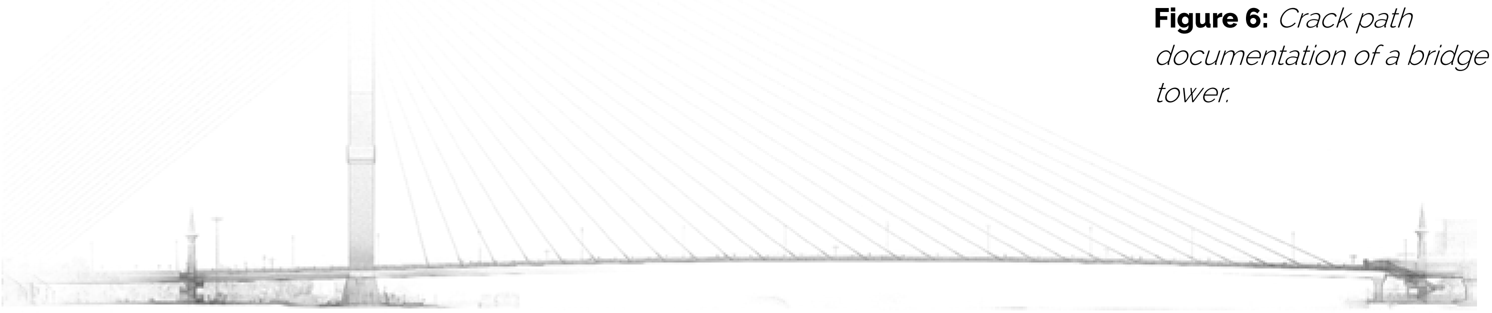


Figure 7: *Cable-stayed bridge profile collected by LiDAR scanner.*

Evaluating the structural integrity of large cylindrical storage structures, such as silos and tanks, is challenging due to their scale. Measuring deformations, including out-of-roundness and out-of-plumbness, is essential for assessing their condition. Modern tools like LiDAR scanners enable the precise collection of geometric data, allowing for the systematic identification of structural irregularities. Figure 8 presents a plot of the radial deformation of a silo affected by an internal grain arch formation. Figure 9 shows the elevation view of the 3D point cloud of a hydrocarbon storage tank, suffered from fire damage, being evaluated for roundness and plumbness.

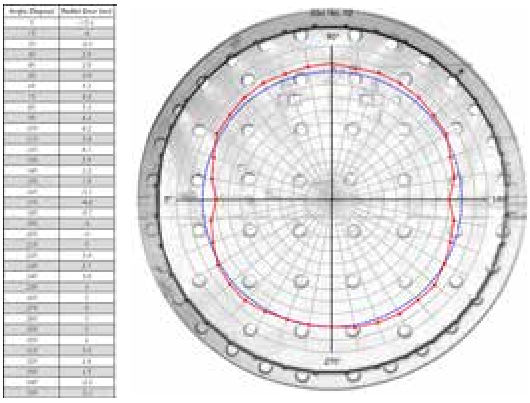


Figure 8: *The plot of radial deformation of a silo.*

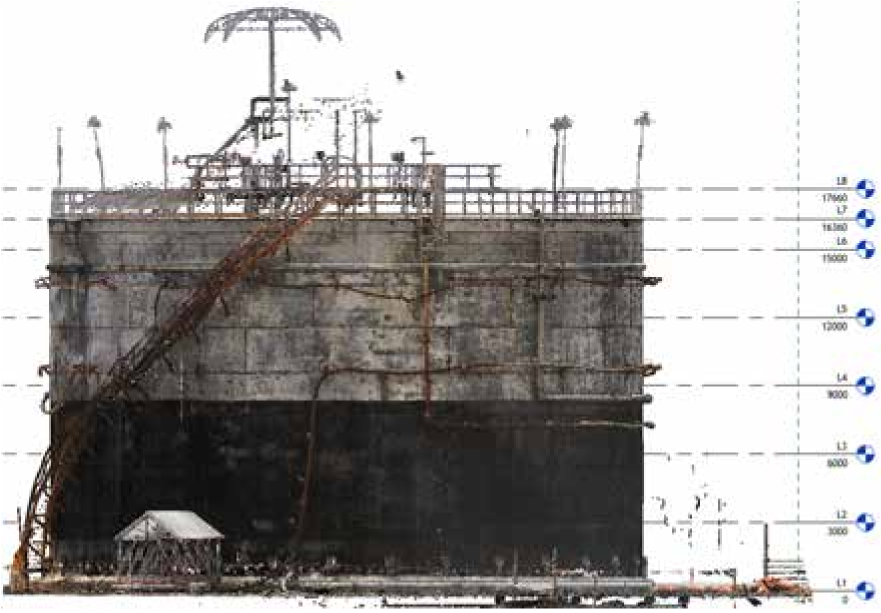
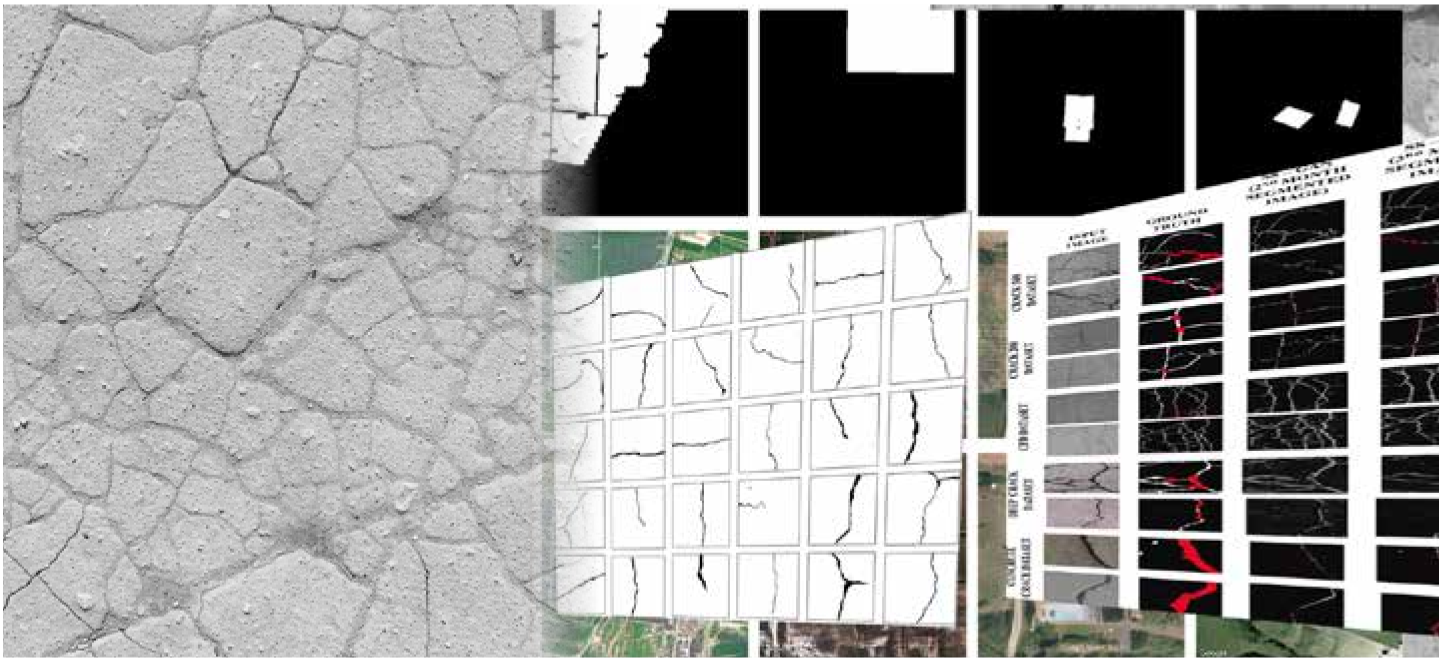


Figure 9: *3D point cloud of a hydrocarbon storage tank.*

Conclusion

The advancement of 3D geometry collection technologies, particularly photogrammetry and LiDAR, has significantly enhanced structural evaluation across various engineering applications. Photogrammetry, with its ability to generate detailed 3D models using standard cameras, proves highly effective for documenting surface conditions, crack patterns, and large-scale structural deformations or collapse configurations. Meanwhile, LiDAR's high-precision laser scanning enables accurate measurements of complex indoor and outdoor geometries, making it indispensable for evaluating structural integrity, deformations, and large-scale infrastructure such as bridges, silos, and storage tanks. The integration of these technologies, often supplemented by UAVs, allows for safer, faster, and more precise data collection, even in hazardous or inaccessible environments. As these methods continue to evolve, their application in forensic engineering, maintenance planning, and structural health monitoring will further optimize safety, efficiency, and decision-making in engineering practice. Since these two groundbreaking technologies empower structural engineers to develop innovative solutions, more 3D point cloud-based service products are expected to emerge in the future.

Transforming Concrete Crack Images to Binary Masks Using GANs: A Guide for Structural Health Monitoring



Deep learning techniques, particularly Generative Adversarial Networks (GANs), have emerged as powerful tools for automating crack detection and analysis.

Author:

Shabir Ali Talpur
Coordinator, Civil & Structural Engineering Unit
AIT Solutions
Asian Institute of Technology

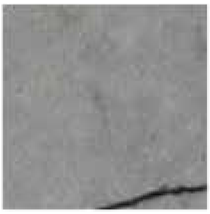
Structural health monitoring (SHM) plays a vital role in ensuring the safety and longevity of infrastructure such as bridges, buildings, and roads. Cracks in concrete are among the most common indicators of structural degradation, making their detection and analysis critical for timely maintenance and repair. Manual inspection and annotation of crack images are labor-intensive and prone to human error. To address this challenge, deep learning techniques, particularly Generative Adversarial Networks (GANs), have emerged as powerful tools for automating crack detection and analysis. This article explores how Pix2Pix GANs can transform raw concrete crack images into binary masks—black-and-white representations that highlight crack regions.

These binary masks can then be used for downstream tasks such as crack width measurement and quantification, enabling more efficient structural analysis.

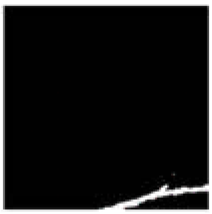
Pix2Pix is a conditional GAN architecture designed for image-to-image translation tasks. Unlike traditional GANs, which generate images from random noise, Pix2Pix uses paired datasets where each input image has a corresponding target output, making it ideal for supervised learning tasks like transforming raw crack images into binary masks. The framework consists of two neural networks: a generator and a discriminator. The generator takes an input image, such as a raw crack image, and produces an output image, such as a binary mask. The discriminator evaluates whether the generated output is realistic compared to the ground truth. During training, the generator learns to produce outputs that fool the discriminator while staying faithful to the input-output relationship. For this application, the generator learns to map raw crack images to their corresponding binary masks, with the discriminator ensuring that the generated masks closely resemble the annotated ground truth masks. Over time, the model becomes adept at isolating crack regions and producing accurate binary representations.

Binary masks simplify the process of crack analysis by clearly delineating crack regions from the background. In a binary mask, cracks are represented in white (pixel value = 1), while non-crack areas are black (pixel value = 0). This simplification enables precise measurements of crack dimensions, including length, width, and area, which are crucial for assessing structural integrity. Automating the generation of binary masks using Pix2Pix GANs eliminates the need for manual annotation, significantly reducing time and effort. Moreover, the consistency of machine-generated masks ensures higher reliability compared to human annotations, which may vary due to subjective interpretations.

A challenge in applying GANs to real-world crack images lies in the size of the input images. High-resolution images captured during inspections often exceed the input dimensions supported by standard GAN architectures. To overcome this limitation, the images are preprocessed by dividing them into smaller patches, typically of size 256x256 pixels. The original image is split into overlapping or non-overlapping patches of 256x256 pixels. Overlapping patches help preserve continuity at the edges when reassembling the final output. Each patch is passed through the trained Pix2Pix GAN to generate its corresponding binary mask, with the generator processing each patch independently to produce a binary representation of the crack regions within that patch. After all patches have been processed, they are stitched back together to form the complete binary mask of the original image. Careful alignment ensures that the transitions between adjacent patches are seamless. This patch-based approach allows for handling large images efficiently while maintaining high resolution and accuracy in the generated masks. Figure 1 shows the binary crack image generated from Pix2Pix GANs.



Source



Generated

Expected

Quantitative metrics such as Intersection over Union (IoU), pixel-wise accuracy, precision, recall, and F1 score are used to evaluate the performance of the GAN. Precision measures the proportion of correctly predicted crack pixels out of all pixels predicted as cracks, while recall measures the proportion of correctly predicted crack pixels out of all actual crack pixels. The F1 score combines precision and recall into a single metric, providing a balanced assessment of the model's performance. By checking each pixel of the generated image against the ground truth, the model's ability to accurately capture even fine details of cracks is validated, ensuring robustness and reliability.

The binary masks generated by the Pix2Pix GAN find numerous applications in SHM. By analyzing the thickness of white regions in the binary mask, engineers can estimate crack widths with high precision. The total area covered by cracks can be calculated to assess the severity of damage. Integrating the GAN into inspection workflows enables rapid and consistent crack detection across large-scale infrastructure projects. Additionally, the generated masks can be used to augment datasets for training other machine learning models, improving overall system performance.

In conclusion, the use of Pix2Pix GANs for transforming raw concrete crack images into binary masks represents a significant advancement in structural health monitoring. Automating the annotation process not only saves time and resources but also enhances the accuracy and reliability of crack analysis. Breaking large images into manageable patches ensures scalability, making the technique suitable for real-world applications. Demonstrations through visualizations and quantitative evaluations reveal that the Pix2Pix GAN delivers impressive results, generating high-quality binary masks that closely align with ground truth annotations. These masks pave the way for more efficient and precise crack measurements, ultimately contributing to safer and more durable infrastructure. With ongoing advancements in GAN technology and increased adoption in SHM, the potential for AI-driven solutions in civil engineering is immense. By embracing these innovations, smarter, safer, and more resilient structures can be built for the future.

References

Radford, A. (2015). Unsupervised representation learning with deep convolutional generative adversarial networks. arXiv preprint arXiv:1511.06434.

Zhang, K., Zhang, Y., & Cheng, H. D. (2020). CrackGAN: Pavement crack detection using partially accurate ground truths based on generative adversarial learning. IEEE Transactions on Intelligent Transportation Systems, 22(2), 1306-1319.

Chen, G., Teng, S., Lin, M., Yang, X., & Sun, X. (2022). Crack detection based on generative adversarial networks and deep learning. KSCE Journal of Civil Engineering, 26(4), 1803-1816.

Zhang, G., Pan, Y., & Zhang, L. (2021). Semi-supervised learning with GAN for automatic defect detection from images. Automation in Construction, 128, 103764.

Performance-Based Design Practices in Indonesia

Recent earthquakes in Indonesia has increased public and government awareness to have a safer and more secure buildings with better measured performance under earthquakes, especially in major and densely populated cities like Jakarta.

Authors:

Iswandi Imran
Faculty of Civil and Environmental Engineering, ITB
Indonesian Society of Civil and Structural Engineers

Indra Djati Sidi
Faculty of Civil and Environmental Engineering, ITB
Indonesian Society of Civil and Structural Engineers

Davy Sukamta
Indonesian Society of Civil and Structural Engineers
Davy Sukamta & Partners

Budihartono Wijanto
Indonesian Society of Civil and Structural Engineers
PT. Wiratman

Performance-Based Design (PBD) practices for seismic design of high rise buildings in Indonesia is gradually advancing as the need for more realistic approaches for designing earthquake-resistant tall buildings grows, particularly given that Indonesia is one of the most seismically active countries in the world. Indonesia is located in the ring of fire. In the last ten years, Indonesia has faced a great number of earthquakes. This has increased public and government awareness to have a safer and more secure buildings with better measured performance under earthquakes, especially in major and densely populated cities like Jakarta.

The Indonesian seismic code SNI 1726 with comprehensive seismic hazard map was first published in 1989 (BSN, 1989). In the map, Indonesia is divided into 6 (six) seismic zones, i.e. from seismic zone 1 (the lowest seismicity) to seismic zone


a. View from West
b. View from East

Figure 1: *Autograph Tower (a), and Luminary Tower (b)*

6 (the highest seismicity). The Indonesia Seismic Code (ISC) was then revised in 2002 with updated seismic hazard map (BSN, 2002). The main parameter in this seismic hazard map is Peak Ground Acceleration (PGA) at base rock, which was developed using earthquakes with the probability of being exceeded of 10% in 50 years. Using more recent seismic data, the ISC was then revised again in 2012 with updated seismic hazard maps (BSN, 2012). The main parameters of the map are spectral values at 0.2 second and 1 second periods at base rock, with the probability of being exceeded of 2% in 50 years. These spectral values are formulated as the risk-targeted maximum considered earthquake (MCE_R). Compared to the two previous Indonesian seismic codes, this updated Code is more comprehensive. It also accomodates the provision for designing base-isolation system in building structures and the provision for nonlinear time history analysis. This SNI code and the corresponding seismic hazard map was later updated again in 2019, to accommodate the data from recent earthquakes (BSN, 2019). Since the update of the seismic code of 2012, the ASCE 7 seismic provision has been used as the main reference.

Current Practices in Indonesia

The current SNI code is mostly prescriptive and still adopts the force based approach for seismic design. The level of seismic demand can be reduced by a factor of R (i.e. response modification factor) to allow for inelastic behavior in the structures. However, the requirement of minimum base shear mostly governs the seismic base shear demand for tall buildings. Nevertheless, SNI 1726-2019 also provides provisions for performance based procedures for seismic building design. Two procedures are provided, i.e.: i) explicit procedure, in which conditional probability of failure caused by the MCE_R shaking is set to be not more than 10% for risk category II (please note that tall buildings in Indonesian practices are commonly assigned to risk structures based on desired performance during an earthquake, rather than simply following minimum code requirements.) This means PBD is getting more popular lately in Indonesia. Some motivations of using PBD in Indonesia:

a. As a means of verifications of the performance of the tall buildings being designed

b. To get away from the requirement of minimum base shear (C_{smin}*W) for tall buildings (There are still some unresolved issues regarding this as the SNI 1726 still requires the fulfillment of the minimum base shear even though the building is designed with the nonlinear time history analysis)

c. To use structural systems that are not covered yet in the Indonesian seismic code, such as structural system with outrigger/belt-truss.

d. To use structural systems that are not permitted in the region with high seismicity, such as core wall + gravity frame systems etc.

e. As a means for optimization, especially for super tall buildings (in which the base shear is usually governed by the minimum base shear requirement). Reinforced concrete is still the most popular construction material in Indonesia, even for the super tall buildings. This PBD practice can alleviate rebar congestion in structural elements and therefore, increase constructability.

The Government of Indonesia, through national center for earthquake study, recently provided necessary guidelines or standard to support the implementation of PBD, especially for the development of selected ground motions to be used in the nonlinear time history analysis. Some of the documents are:

a. De-aggregation map of seismic hazards of Indonesia, National Center on Earthquake Engineering Studies of Indonesia

b. Procedure for selecting and modifying earthquake ground motions, SNI 8899-2020

The design of high rise buildings in Indonesia should go through review process by high rise building committee. Each city has its own building committee. There is an additional requirement for the approval of buildings designed with PBD, i.e.: the detail engineering design should be peer-reviewed by a consultant with many experiences on the use of PBD for high rise buildings. Right now, not many local consultants are qualified for peer review process in Indonesia. The peer review process is then mostly conducted by foreign consultants. References that are mostly used and have been accepted by the high rise building committee for PBD are TBI, LATBSDC, ASCE 41, ACI 369.1, and ASCE 7.

There are only two levels of seismic hazard to be considered for PBD implementation in Indonesia, i.e. i) service level earthquake (SLE) (43-year return period) and ii) maximum considered earthquake (2500 -year return period). The strength design

Figure 2: *Wisma Sudirman (Left) and Indonesia One (Right)*

is commonly carried out using base shear coefficient of SLE or 2/3 MCE_R/R (or C_{smin}). However, in the city of Jakarta, building approval can sometime be obtained partially. As an example, approval for the foundation can be obtained first in order to be able to start the foundation work sooner. As the review process of PBD design usually takes longer time, then the foundation strength design is sometime still carried out with the prescriptive procedure using base shear coefficient of the largest of 2/3 MCE_R/R or C_{smin}. The overstrength factor, Ω, is also applied to achieve strength hierarchy between foundation and upper structures. There is also other case of building designed using PBD in Indonesia, in which the building was initially designed with prescriptive code, but later switched to PBD during the construction.

In summary, these are the examples of current PBD practices in Indonesia:

a. Preliminary strength design of the buildings is done based on base shear coefficient of the largest of 2/3 MCE_R/R (=DBE/R) and C_{smin}.

b. Preliminary strength design is done based on the modified seismic response coefficient (say, a number between 2/3 MCE_R/R and C_{smin}). This is sometime done as the service level earthquake is not yet available. However, there is no strong basis on the use of this approach. If in the end it has to be used then the probability of failure should be computed explicitly under MCE_R and should satisfy the requirement of SNI 1726.

c. Preliminary strength design is done based on SLE. But, to get partial approval for foundation, the foundation strength design is then carried out based on base shear coefficient of the largest of 2/3 $MCE_R/R^*\Omega_o$ and $C_{smin}{}^*\Omega_o$

The risk-targeted maximum considered earthquake (MCE_R) is later used to validate the strength design of both upper structures and foundations. In many cases, those PBD practices are proven successful with minimum design adjustment when the building design is subjected to MCE_R. So far, from Indonesia experiences of implementing PBD, the ratio of base shear demand from MCE_R to DBE ranges from 2.5 to 2.9. So, this is close to Ω_o of SNI 1726-2019, which is equal to 3. However, these conclusions are only valid if the upper structures are designed efficiently, especially for deformation controlled elements, as those elements in fact determine the lateral strength of the upper structures.

Examples of Buildings in Indonesia Designed using PBD

There have been several buildings in Jakarta that are recently designed using PBD procedure. The construction some of these buildings have been completed. Some examples of the buildings are:

a. Autograph Tower (the tallest building in Indonesia and also in the Southern Hemisphere), with the total height of 385 m

b. Luminary Tower with the total height of 304 m

c. Indonesia One with the total height of 303 m

d. Wisma Sudirman with the total height of 260 m

e. Ciputra Tower with the total height of 250 m

f. Oasis Central with the total height of 320 m

In addition to that, some existing buildings in Jakarta are also evaluated seismically using performance-based procedure. This is usually done to ensure that the performance of the existing buildings is still acceptable even though there are an increase in hazard level in the updated seismic hazard map.

References

ASCE 7-16 (2016), "Minimum Design Loads for Buildings and Other Structures. New York: American Society of Civil Engineers.

BSN (1989). "Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung (SNI 03-1726-1989)", BSN, Jakarta, Indonesia.

BSN (2002). "Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung (SNI 03-1726-2002)", BSN, Jakarta, Indonesia.

BSN (2012). "Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung (SNI 1726-2012)", BSN, Jakarta, Indonesia.

BSN (2019). "Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung (SNI 1726-2019)", BSN, Jakarta, Indonesia.

An Insight to Structural Control Devices for Urban Seismic Risk Reduction

The last three decades have seen sustained research and development leading to large-scale implementation of structural control systems in buildings and bridges worldwide to mitigate urban earthquake disasters. There is also considerable implementation of such systems in industrial infrastructure, and power infrastructure viz. oil & gas production facilities, hydropower substations, and nuclear power stations to enhance safety.

The structural control systems encompass energy-absorbing devices which are installed into the structure to dissipate a large portion of the induced energy and such energy absorption elements are not normally the main load-bearing components of a structure. There have been serious efforts undertaken in the last three decades to develop the structural control concept into a workable technology.

The structural control systems encompass energy-absorbing devices which are installed into the structure to dissipate a large portion of the induced energy and such energy absorption elements are not normally the main load-bearing components of a structure.

Author:

Jayanta Pathak
Professor & Head,
Department of Civil Engineering,
Assam Engineering College,
Guwahati, India

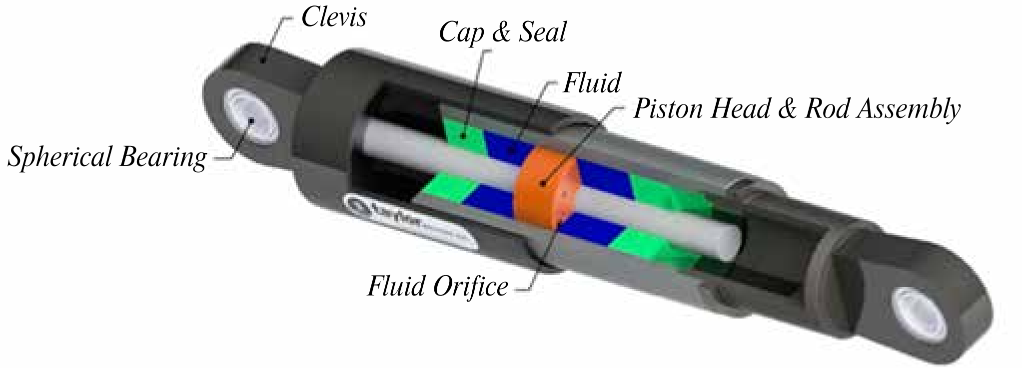


Figure 1: *Fluid Viscous Dampers by Taylor Devices [17]*

Full-scale implementation of active control systems has been accomplished in several structures, mainly in Japan; however, cost-effectiveness and reliability considerations have limited their widespread acceptance. Because of their mechanical simplicity, and low power requirements, passive systems provide an attractive alternative to active and hybrid control systems [8][15][18].

The end of the Cold War in 1990 heralded a restructuring period for the defense industry. One of the outcomes of this new era was that the technologies restricted previously to military use were gradually available to the general public. In the civil engineering field, high-capacity fluid dampers have transitioned from defense-related structures to commercial applications on buildings and bridges. [17].

In 1993, the Energy Dissipation Working Group (EDWG) of the Base Isolation Subcommittee of the Structural Engineers Association of Northern California (SEAONC) developed tentative design requirements applicable to a wide range of damping device hardware. The devices included metallic, friction, viscoelastic, and viscous energy dissipation mechanisms [12]. The general philosophy of the design requirements was to have the main structural members remain elastic and confine the inelastic deformations primarily to the energy dissipation devices for the Design Basis Earthquake (DBE). These initial coral recommendations further evolved to several established standards, viz. a) ASCE/SEI 7-16 (ASCE 7-16) - Minimum Design Load for Buildings and Other Structures [1], b) European Standard Anti-seismic Devices EN 15129 [4], and c) NTCS-17 - Technical Regulations for Seismic Design (Normas Técnicas Complementrias para Diseño por Sismo [13]. These documents correspond to the USA, Europe and Mexico, respectively. The critical design and modelling concern for researchers has been the proper distribution of suitable devices in the building; the effectiveness

Figure 2: *17-story State of California Resources Building built in 1962, with steel truss moment frames, 128 nos. FVDs installed to retrofit by Taylor Devices [17]*

of devices throughout the structure and the cost of the devices to achieve the desired response [3][5].

Figure 3: *Fluid Viscous Dampers were used for a new bridge section in the Taiwan High Speed Rail system, completed in 2003 [17]*

The passive control devices, viz. **Friction & Metallic devices, Fluid Viscous Devices** (FVD), and Viscoelastic Devices have their advantages with high reliability with the Metallic devices offering high energy dissipation per cycle. The additional advantage of the Metallic Devices is that they are insensitive to temperature, relatively inexpensive, and easy to construct. However, the behaviour of the Metallic Devices is highly non-linear and is sacrificial, requiring replacement after a major earthquake. The Friction Devices have reliability concerns with highly non-linear responses and add large initial stiffness. The FVDs primarily dissipate energy through fluid friction, relying solely on the resistance of a fluid to flow, while a Viscoelastic Device combines both fluid-like viscosity and solid-like elasticity. [3][5][14].

The use of **Fluid Viscous Dampers (FVDs)** to retrofit and in new construction applications is growing and being used as supplemental energy dissipation devices to significantly reduce the seismic response of buildings, particularly in high-rise structures. Figure 1 shows the construct of a Fluid Viscous Damper. In retrofit applications, FVDs allow existing structures to meet increased demands from updated codes or to reduce drifts to accommodate structural system limitations [11]. **Figures 2,3 and 4** show such application of FVDs in retrofitting buildings and response reduction in bridges to enhance safety. The design aims at the optimal damping ratio based on structural characteristics and desired performance level. The design process also includes deciding on the strategic location of dampers within the structure to maximize energy dissipation. The effectiveness of the dampers is evaluated using time-history analysis, response spectrum analysis, and modal analysis. The research trends in the application of FVDs are exploring new damper configurations with improved performance or adaptability, development of hybrid damping systems, smart damping systems by integration of sensors and control systems to optimize damper performance based on real-time loading conditions [2][3][6][17].

Figure 4: *FVDs implantation to reduce responses in bridges by Taylor Devices [17]*

Traditionally, dampers have been primarily designed and integrated as brace-type members, which at times, create complications in RC frame structures, particularly in the connection zones where concrete is prone to damage during seismic events. The wall-type dampers or

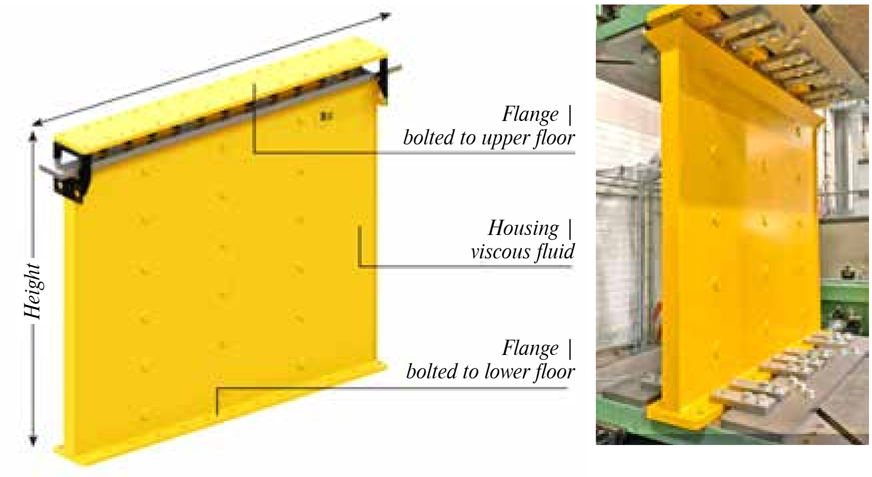


Figure 5: *Viscous Wall Dampers by GERB [7]*

Viscous Wall Dampers (VWDs) present a significant advantage for the retrofitting of RC structures. Generally, a viscous wall damper is comprised of a slender steel tank, which is affixed to the lower floor and filled with viscous fluid as shown in **Figure 5**. Inside this tank, an inner steel plate is connected to the upper floor. The damping force generated by the shearing action of the fluid is influenced by both the displacement and the velocity of the relative motion.

The various types of hysteretic dampers which are widely implemented are **Bilinear Hysteretic Dampers (BHDs)** - A common type with a simple force-displacement curve, exhibiting a linear elastic region followed by a plastic yielding phase. **Buckling-resistant unbonded Braces (BRBs)** – utilize the buckling behaviour of steel members to dissipate energy, comprising of a slender steel core, encased by a concrete or metal casing, with an unbonded layer between them, preventing the core from buckling under compression while allowing it to deform plastically and absorb seismic energy through yielding in both tension and compression. The general schematic and construct of BRBs is shown in **Figure 6. Chevron braces** - A type of brace with a chevron-shaped cross-section designed to provide high energy dissipation capacity.

All these hysteretic dampers are used as structural components, designed to absorb seismic energy during an earthquake by

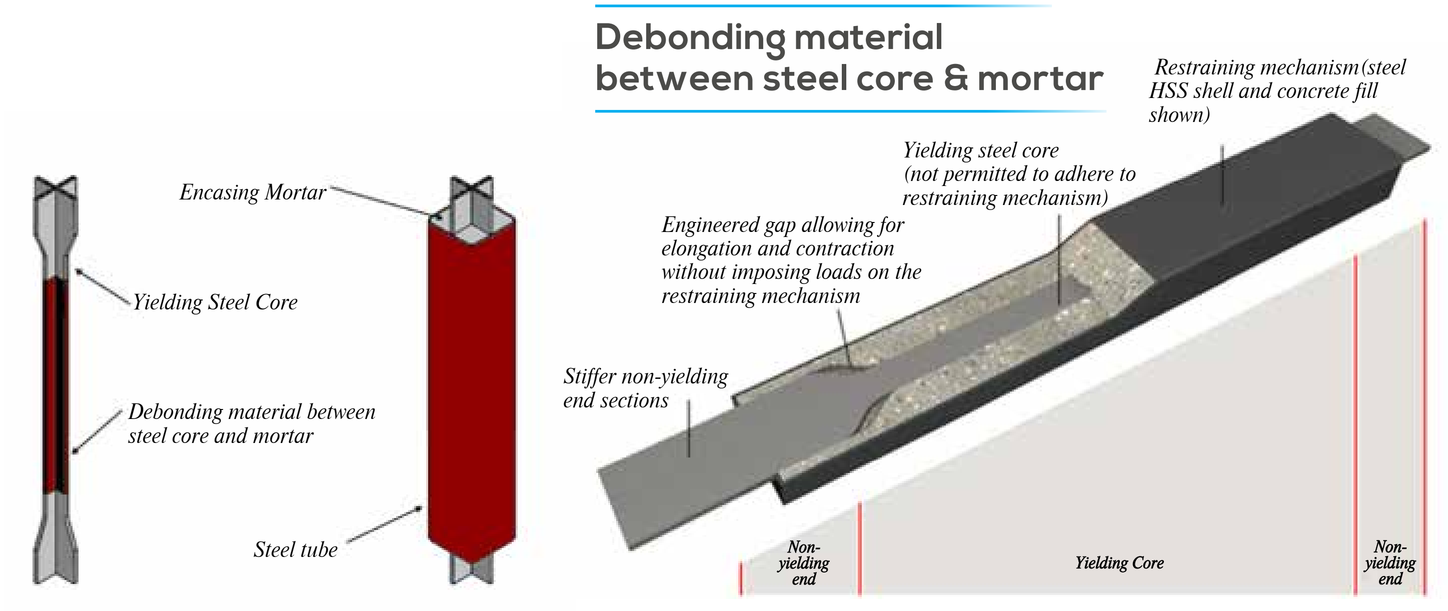


Figure 6: *Schematic of a BRB – Source : American Institute of Steel Construction*

undergoing controlled plastic deformation (yielding) within its material, essentially, they act as sacrificial elements that dissipate energy through repeated loading and unloading cycles, often installed within braced frames of a building. The Friction Dampers, another type of hysteretic dampers, are designed to activate before structural members yield. The Friction Dampers act as a reusable fuse which simultaneously dissipates energy and in doing so, the building can withstand an earthquake without sustaining significant damage to its structure. The efficiency of **Friction Dampers** depends on their optimum slip load design. The slip load design for friction dampers is based on the aspect that the dampers should not slip during intense wind, but they should slip during intense seismic loading before the yielding of structural elements[2][5].

The advantage of **Buckling Resistant unbonded Braces (BRBs)** is that they show the same load-deformation behaviour, whether under compression or tension. In the event of a moderate earthquake, buckling-restrained braces increase the stability of buildings and in the event of major earthquakes; the buckling-restrained braces create plastic hysteretic deformation to dissipate energy [16].

According to the different properties of the stiffness and damping elements, energy dissipation devices may also be divided into two categories: linear energy dissipative devices and nonlinear energy dissipative devices. **The Tuned Mass Dampers (TMDs)** and the **Tuned Liquid Dampers (TLDs)** are the most common linear energy dissipative devices, both of which are required to tune their natural vibration frequencies to the fundamental frequency of the main structure [9]. Tuned Mass Damper (TMD) typically consists of a mass connected to the main structure by a linear spring and a linear viscous damper. The Tuned Mass Damper installed in Taipei 101, is shown in **Figure 7 and Figure 8** shows a Tuned Mass Damper installation at Bucharest. When the main structure starts to move, the TMD system generates a force in the opposite direction of the main structure and the dynamic responses of the main structure are effectively reduced [6].

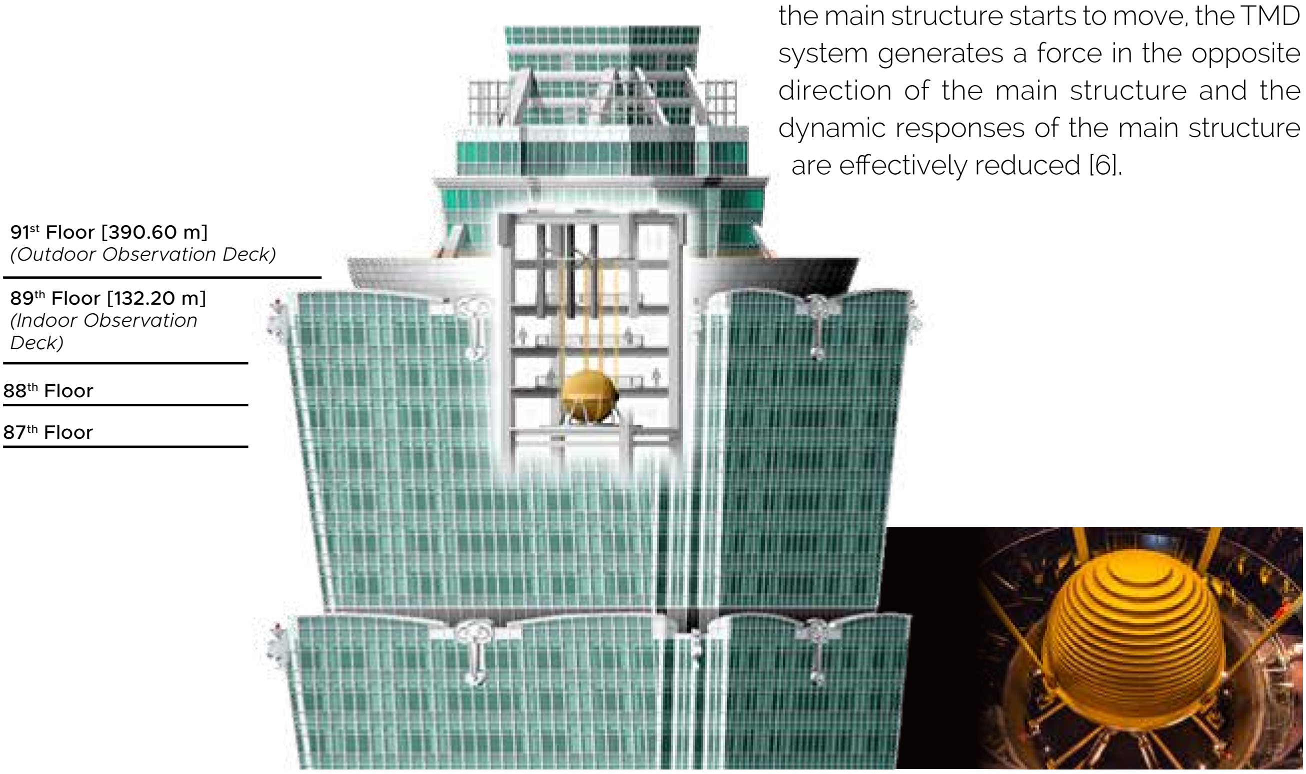


Figure 7: *Tuned Mass Dampers Taipei 101: Taipei, Taiwan (728 Ton Pendulum)*

Figure 8: *Tuned Mass Dampers installation at Bucharest Romania by GERB [6]*

Tuned Liquid Dampers (TLDs) are primarily used to reduce vibrations in tall buildings and structures by harnessing the sloshing motion of a fluid within a tank, which is tuned to match the natural frequency of the structure, effectively absorbing energy from wind or seismic excitations making it particularly applicable to high-rise buildings, chimneys, and offshore platforms [9]. To prevent damage and to reduce the adverse effects of sloshing, baffles or deflectors are often installed so that the original height of the liquid level is quickly restored after structural vibration has occurred.

In summary, we are moving significantly towards adopting a Performance Based Design (PBD) approach across various design fields, especially in designing critical infrastructure, tall buildings and complex structures, PBD approach allows for a more customized and innovative design approach compared to traditional prescriptive design approach addressing target safety concerns against anticipated hazard. The structural control devices are going to play a much greater role as they are a key element within a PBD framework to achieve optimal structural behaviour under challenging loading conditions. Moreover, dissipating seismic energy through the usage of large ductile steel or concrete sections is highly inefficient and uneconomical and a cost-effective structural control system contributes toward reducing carbon footprints in the construction industry.

References

1. *ASCE/SEI 7-16 (2016) "Minimum design loads for buildings and other structures", American Society of Civil Engineers, Reston, Virginia, USA, 2016. R6*
2. *CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS E-ISSN 2450-8594 CEER 2019; 29 (2): 074-100 DOI: 10.2478/ceer-2019-0018 Original Research Article VIBRATION CONTROL DEVICES FOR BUILDING STRUCTURES AND INSTALLATION APPROACH: A REVIEW. R9*
3. *D. I. Narkhede & R. Sinha(2012), "Shock Vibration Control of Structures using Fluid Viscous Dampers" 15 th World Conference on Earthquake Engineering Lisbon, Portugal, 2012 R-5 DOI: 10.1002/eng2.12075 2019 R-9*
4. *EN 15129 (2009), European Standard, Anti-seismic devices , CEN, European Committee for Standardization. R7*
5. *G. W. Housner et al. (1997), "Structural Control: Past, Present, and Future", Journal of Engineering Mechanics Volume 123, Issue 9 https://doi.org/10.1061/(ASCE)0733-9399(1997)123:9(897) R5*
6. *GERB - EARTHQUAKE PROTECTION GERB Schwingungsisolierungen GmbH & Co. KG https://www.gerb.com/wp-content/uploads/2022/10/GERB_Earthquake-Protection_EN-2022-09.pdf R13*
7. *GERB - Viscous Wall Dampers (GVWD) Protection of buildings & structures against earthquakes and wind-induced vibrations GERB Schwingungsisolierungen GmbH & Co. KG https://www.gerb.com/wp-content/uploads/2023/04/GERB_Viscous-Wall-Damper_GVWD_for_Earthquake_protection-2023-04.pdf R14*

8. *Iemura, H. (1994), Active and Hybrid Control Development in Japan. In: Soong, T.T., Costantinou, M.C. (eds) Passive and Active Structural Vibration Control in Civil Engineering. CISM International Centre for Mechanical Sciences, vol 345. Springer, Vienna. https://doi.org/10.1007/978-3-7091-3012-4_17 R2*
9. *Konar T, Ghosh A Dey (2022), "A review on various configurations of the passive tuned liquid damper". Journal of Vibration and Control. 2023;29(9-10):1945-1980. doi:10.1177/10775463221074077*
10. *Majd Armaly Hala Damerji Jaafar Halla, Mahmoud Fakih (2019) RESEARCH ARTICLE "Effectiveness of friction dampers on the seismic behavior of high rise building VS shear wall system", Engineering Reports: Volume 1, Issue 5 Wiley Online Library*
11. *N.E. Canney, K.B. Eriksen & A.T. Tiapon (2003) "A review of the state of practice for fluid viscous damper applications in North America and New Zealand" NZSEE 2023 Annual Conference, Taylor Devices, Inc., North Tonawanda, NY, USA. -4 R12*
12. *NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for Seismic Regulations for New Buildings, 1994 Edition, 2 volumes and maps, 1994. R4*
13. *NTCS-17 (2017), "Complementary technical standards for earthquake design" in Regulation of Constructions of the Federal District, Official Gazette of the City of Mexico, Mexico. R8*
14. *Samuele Infanti , Jamieson Robinson , Rob Smith (2008), "VISCOUS DAMPERS FOR HIGH-RISE BUILDINGS" 14 th World Conference on Earthquake Engineering, 2008, Beijing, China R-6*
15. *Spencer, Jr. B. F. and Nagarajaiah, S. (2003), State of the Art of Structural Control, Journal of Structural Engineering, Volume 129, Issue 7, https://doi.org/10.1061/(ASCE)0733-9445(2003)129:7(845))-R1*
16. *T. Albanesi , A. V. Bergami and C. Nuti (2008), "DESIGN PROCEDURE FOR BUCKLING RESTRAINED BRACES TO RETROFIT EXISTING R.C. FRAMES", The 14 th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China R11*
17. *Taylor Devices, Inc.(2019), Fluid Viscous Dampers General Guidelines for Engineers Including a Brief History. R10*
18. *Whittaker, A .S. et al. (1993, "Code Requirements for the Design and Implementation of Passive Energy Dissipation Systems," Proc. ATC 17- 1 on Seismic Isolation, Energy Dissipation, and Active Control, Applied Technology Council, Redwood City, CA, 1993, pp. 2:497-508. R3*
19. *Zheng Lu , Zixin Wang , Ying Zhou , Xilin Lu (2018), "Nonlinear dissipative devices in structural vibration control: A review", Journal of Sound and Vibration Volume 423 https://doi.org/10.1016/j.jsv.2018.02.05*


Powered by
SAPFIRE®
SAP2000
STRUCTURAL ANALYSIS AND DESIGN


Powered by
SAPFIRE®
CSiBridge®
BRIDGE ANALYSIS, DESIGN AND RATING


Powered by
SAPFIRE®
ETABS®
BUILDING ANALYSIS AND DESIGN


Powered by
SAPFIRE®
SAFE®
ANALYSIS AND DESIGN OF FLOOR SYSTEMS


Perform® 3D
PERFORMANCE-BASED DESIGN OF 3D STRUCTURES


CSiPlant™
PIPE STRESS ANALYSIS AND DESIGN


CSiCol™
DESIGN OF REINFORCED CONCRETE COLUMNS

Coarse Aggregate Based 3D Concrete Printing: Engineering the Future of Construction


image source: Reuters

3D concrete printing is a novel construction technique that provides several advantages, such as faster construction, material efficiency, geometric freedom, labour savings, low cost, etc.

Authors:

Swapnil Balasaheb Ghodke
Research Scholar,
Department of Civil Engineering,
Indian Institute of Technology,
Roorkee, India

Bhupinder Singh
Professor,
Department of Civil Engineering,
Indian Institute of Technology,
Roorkee, India

3D concrete printing eliminates the use of formwork, and hence, the rheological properties of the printed material are crucial for achieving desired flow characteristics and attributes of stability like shape consistency and the ability of freshly printed layers to resist the weight of subsequent layers. This novel construction technique provides several advantages, such as faster construction, material efficiency, geometric freedom, labour savings, low cost, etc. One of the major challenges faced by the printed structure is the development of anisotropic behaviour due to layer-by-layer printing. In order to control costs and in order to mass-scale 3D printing, it is imperative to extend this technology to concrete containing coarse aggregates

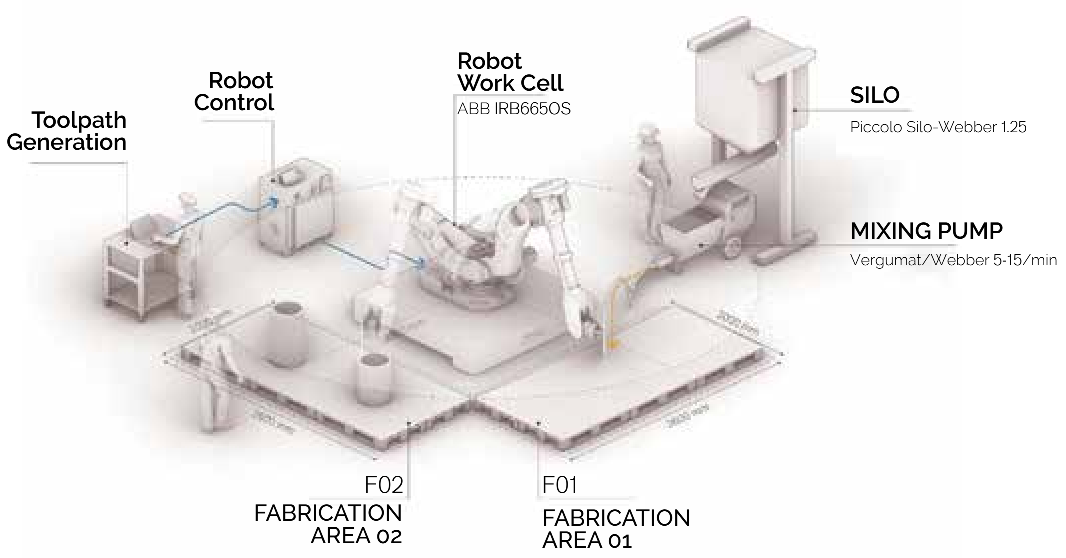


Figure 1: *3D Concrete Printing Process (Breseghello, 2021)*

instead of the more restrictive material composition currently used for 3D printing that precludes the use of conventional coarse aggregates. Some of the challenges and opportunities in coarse aggregate-based 3D Concrete Printing (3DCP) are discussed in this investigation.

Terminologies

Flowability: It is the material's ability to deform and retain stability under pressure while preserving its original properties.

Extrudability: It is the capability of the material to squeeze out from the printer nozzle continuously while maintaining its dimensional precision and layer quality.

Buildability: It refers to the ability of the material to support the weight of the subsequently placed layers without significant deformation/distortion while maintaining dimensional stability.

Open Time: Duration during which the material maintains its ease of flow through the nozzle and there is no blockage during flow.

Static Yield Stress: It is the maximum stress required to initiate a flow of the material.

Dynamic Yield Stress: It is the minimum stress required to maintain a flow of the material.

Plastic Viscosity: It refers to the internal resistance to flow in the material.

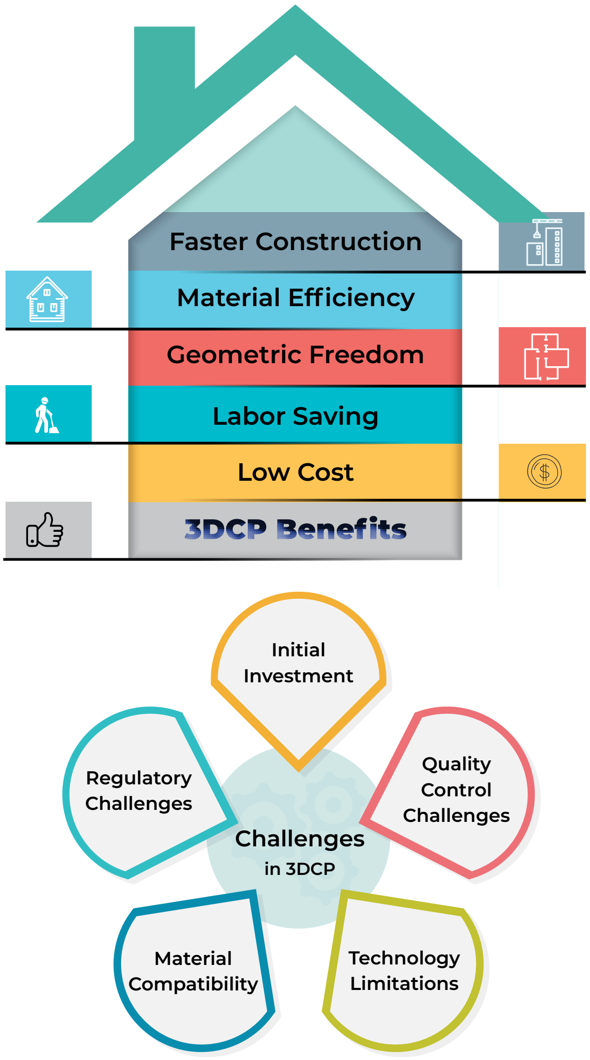


Figure 2: *Benefits and Challenges in 3DCP*

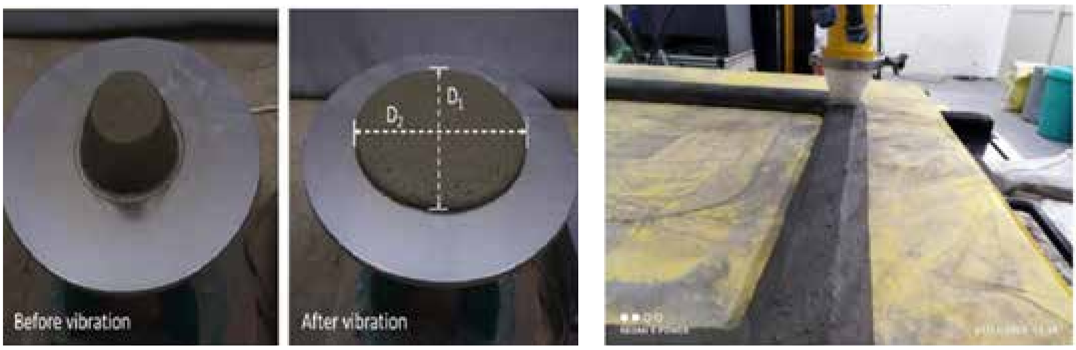
Figure 3: *Sustainable Development Goals achieved through 3DCP construction*

Mix Design in Coarse Aggregate (CA) - based 3D Printable Concrete (3DPC)

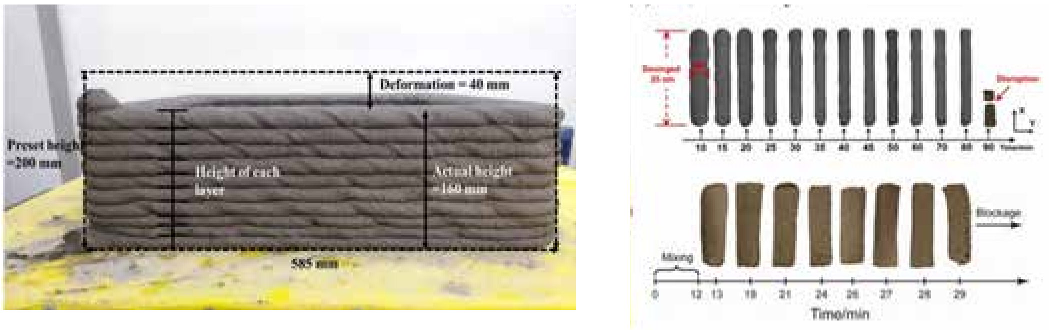
There are typically two methods for achieving mix designs using coarse aggregate in 3DPC that were explored by many researchers. In the first instance, a printable mortar-based mix is developed using well-established principles. Subsequently, in the first method, a part of the fine aggregates in the mortar are replaced with coarse aggregates, whereas in the second method, coarse aggregates are incorporated to the desired degree by replacement of mortar. In both these cases, coarse aggregate incorporation may be done either through weight or through volumetric replacement. For a consistent yield of printable concrete, volume replacement is preferable to weight replacement. Both these methods will have different effects on the printability properties. Therefore, careful considerations are required for an optimal mixture design to achieve the desired rheological, mechanical and printability behaviour.

Importance of Rheology in CA-based 3DPC

Due to the requirement of different behavioural characteristics of 3DPC before and after extrusion, rheological performance is critical in 3DPC. To have proper flowability and extrusion, the material should have low dynamic yield stress and optimum plastic viscosity, whereas to achieve appropriate buildability, the material should develop high yield stress within a shorter duration after extrusion. In the first method of mix design, in which fine aggregates are increasingly replaced with coarse aggregates, the flowability of 3DPC increases monotonically, which may pose a challenge for extrudability and buildability. One option for addressing these issues is to decrease the superplasticiser dosage. On the other hand, when coarse aggregates are incorporated through mortar substitution, the flowability decreases due to a decrease in paste film thickness and due to changes in the size and surface area of the aggregates, etc. The decrease in flowability is usually corrected by increasing the superplasticiser dosage. In the context of rheological performances, the mortar replacement method is preferable. Since this protocol enables a better appreciation of the effect of coarse aggregate inclusion on 3DPC rheology. It may be noted that the rheological appraisal of 3DPC is rendered affected by the absence of a standard protocol for rheological testing of 3DPC. Most of the reported studies in the technical literature use the single batch approach for the evaluation of time-dependent rheological properties of 3DPC.



(a) Flowability Test (b) Extrudability test at IIT Roorkee



(c) Buildability Test at IIT Roorkee (d) Open Test

Figure 4: *Fresh Properties Testing (Kaliyawardhan et al., 2022)*

Significance of CA in 3DPC

a) Sustainability/Environmental Impact

Use of coarse aggregates in 3DPC can effectively reduce the overall cement content in the mix, thereby lowering its carbon footprint. The utilisation of Natural Coarse Aggregates (NCA) along with Recycled Coarse Aggregates (RCA) from construction and demolition waste can address landfill concerns in the context of RCA disposal and will promote a circular economy. However, if the transportation cost of RCA exceeds the critical transport distance, the environmental benefits of using RCA instead of NCA will be lost (Dong et al., 2024).

b) Enhancement in Buildability

Several studies have indicated that CA addition improves 3DPC buildability by increasing shear and compressive yield stress, elastic modulus, internal friction angle, skeleton effect, and dewatering during extrusion (Chen Y 2021; Zhang et al. 2022). However, these benefits are dependent upon the selection of the 3DPC mix design method.

c) Improved Mechanical Properties

The addition of NCA reduces the anisotropic behaviour of printed specimens and enhances mechanical properties, including compressive, flexural, and interlayer bond strengths, as well as elastic modulus. These improvements may be attributed to the increasing internal friction angle and dewatering during the extrusion process. Additionally, the enhancement in flexural strength may result from the more tortuous crack paths in 3DPC containing CA (Dong et al., 2024).

d) Resistance to Shrinkage and Creep

The paste matrix primarily governs the creep and shrinkage behaviour. The utilisation of coarse aggregates reduces the paste content, thereby enhancing the shrinkage and creep resistance of printed specimens. There is very little research on the shrinkage behaviour of 3D-printed CA concrete, mainly due to practical challenges in testing, such as attaching 'DEMEC pins' to printed specimens (Rahul et al. 2022). Additionally, the higher stiffness of CA's improves the elastic properties of the printed specimens, potentially enhancing long-term dimensional stability. The interfacial transition zone (ITZ) between the paste and aggregates also plays a crucial role in governing both shrinkage and creep properties, highlighting the need for further investigation of these aspects in 3DPC. (Song et al., 2024).

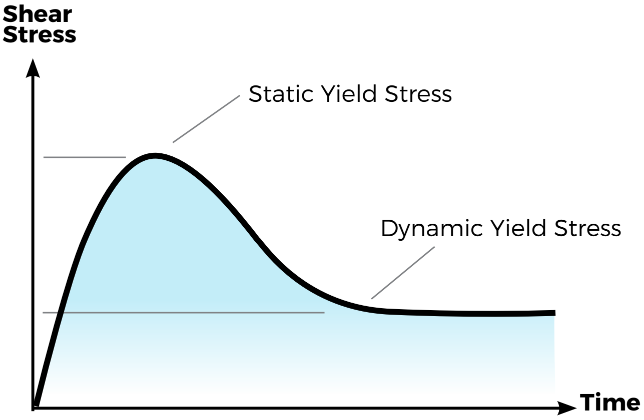


Figure 4: *Typical stress vs time graph obtained from rheometer testing (Kruger et al., 2019)*

Challenges and Recommendations for using a CA in 3DPC

a) Pumpability and Extrudability Issues

An increase in coarse aggregate content can lead to clogging within the pump and nozzle during the extrusion process. Therefore, to have a smooth pumping and extrusion process, it is recommended that the maximum aggregate size in a printable mix should not exceed 1/10th of the nozzle diameter (Kaliyavaradhan et al., 2022).

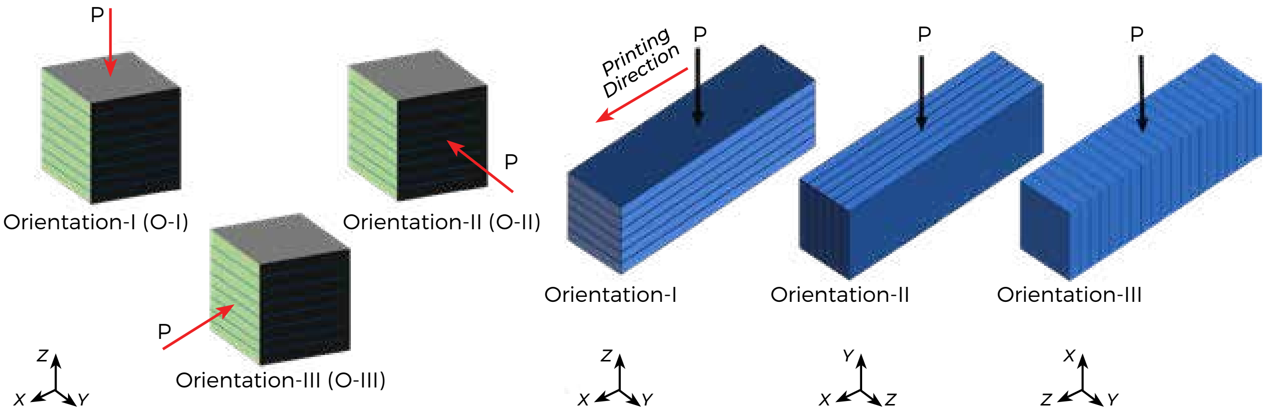


Figure 5: *Loading directions with respect to printing directions for compressive strength and flexural strength testing (Kaliyawardhan et al., 2022)*

Figure 6: *Typical specimen preparation and flexural testing procedure obtained at IITR (Swapnil et al., 2024)*

b) Segregation and Workability

Sometimes, the denser CA particles are susceptible to settling, resulting in segregation and uneven material distribution. Therefore, achieving a balanced particle packing to provide a stable and flowable mixture is key to avoiding segregation during the printing process (Li et al., 2023; Rahul, 2020).

c) Mix Design Complexity and Rheological Incompatibility

The use of CA in 3DPC complicates the mix design due to challenges in achieving optimal particle packing. CA inclusion may increase or decrease yield stress and plastic viscosity (depending upon variations in aggregate gradation and paste compositions) and potentially affect the rheological balance required for smooth flow and extrusion. To overcome these issues, careful aggregate gradation, appropriate paste volume (in terms of paste film thickness), and admixture optimisation are essential to ensure a stable and printable CA-based mix (Zhang et al., 2022).

Research on CA-based Printing at the Indian Institute of Technology, Roorkee

The authors are currently investigating the use of natural and recycled coarse aggregates below 10 mm in 3DPC through a comprehensive analysis of the fresh and hardened properties of such concretes. Rheological properties and flexural response under four-point bending have been investigated. The research indicates that substituting fine aggregates with coarse aggregates results in an increase in flow, attributable to the alteration in the overall surface area of the mixture and an increase in the paste film thickness surrounding the coarse aggregates (Swapnil et al., 2024). Moreover, four-point bending experiments demonstrate that an increase in CA content correlates with a reduction in anisotropic behaviour. This may be ascribed to the enhancement in interlayer bond strength. It has also been noted that there is an enhancement in the flexural strength of CA-based printed specimens relative to mortar specimens, regardless of the loading directions (Swapnil et al., 2024).

Conclusion

CA-based 3DPC can make this material more sustainable and rheologically suitable, thus pushing the boundaries of traditional mortar-based printing. By utilising the natural and recycled coarse aggregates in a printable mix, this technology improves the mechanical performances and economic feasibility of the printed specimens. Despite several challenges, including mix design complexity, rheological incompatibility, segregation and workability, pumpability and extrudability issues, ongoing research is focused on addressing these issues through statistical approaches for the mix design, developing novel pumping and extrusion techniques, developing CA-based printing requirement-specific additives, etc. As the industry adopts automation and sustainability, CA-based 3DPC can help to reduce cement consumption and material wastage and enhance structural integrity. This research strategy will be crucial in transforming the future of the construction industry through ongoing research and technical breakthroughs, improving efficiency and environmental responsibility.

References

Kaliyavaradhan, S. K., Ambily, P. S., Prem, P. R., & Ghodke, S. B. (2022). Test methods for 3D printable concrete. Automation in Construction, 142, 104529.

An, D., Zhang, Y. X., & Yang, R. (2024). Incorporating coarse aggregates into 3D concrete printing from mixture design and process control to structural behaviours and practical applications: a review. Virtual and Physical Prototyping, 19(1), e2351154.

Chen Y, Zhang Y, Pang B, et al. Extrusion-based 3D printing concrete with coarse aggregate: printability and direction-dependent mechanical performance. ConstrBuild Mater. 2021;296:123624.

Zhang C, Jia Z, Wang X, et al. A two-phase design strategy based on the composite of mortar and coarse aggregate for 3D printable concrete with coarse aggregate. J Build Eng. 2022;54:104672

Rahul, A. V., Mohan, M. K., De Schutter, G., & Van Tittelboom, K. (2022). 3D printable concrete with natural and recycled coarse aggregates: Rheological, mechanical and shrinkage behaviour. Cement and Concrete Composites, 125, 104311.

Song, G., Zou, N., Wei, Y., Aili, A., & Liang, S. (2024). Numerical investigation into the influence of interfacial transition zone on elastic modulus, creep, shrinkage of concrete. Construction and Building Materials, 447, 138112.

Li, J., Xiang, J., Tian, Z., Lu, W., Xie, L., & Zhao, Y. (2023). Experiment and simulation study on coarse aggregates settlement in vibrated concrete based on transparent granular suspensions. Journal of Building Engineering, 76, 107381.

Rahul, A. V., & Santhanam, M. (2020). Evaluating the printability of concretes containing lightweight coarse aggregates. Cement and Concrete Composites, 109, 103570.

Ghodke Swapnil Balasaheb., Chowdhury Roy Shubhankar., Singh Bhupinder, " Rheological characterisation of 3D printable concrete made with coarse aggregates technique", 14th Structural Engineering Convention Dec 2024.

Ghodke Swapnil Balasaheb., Chowdhury Roy Shubhankar., Singh Bhupinder, "Characterising flexural behaviour of coarse aggregate based 3D printed concrete beams using acoustic emission technique", Fracture Mechanics of Concrete and Concrete Structures XII 2025.

Breseghello, L., & Naboni, R. (2021, July). Adaptive toolpath: enhanced design and process control for robotic 3DCP. In International Conference on Computer-Aided Architectural Design Futures (pp. 301-316). Singapore: Springer Singapore.

Kruger, J., Zeranka, S., & van Zijl, G. (2019). 3D concrete printing: A lower bound analytical model for buildability performance quantification. Automation in Construction, 106, 102904.

3D CONCRETE PRINTING: TRANSFORMING CONSTRUCTION WITH INNOVATION AND CHALLENGES


image source: ResearchGate

3D Concrete Printing has several advantages compared to conventional method of construction such as improved efficiency, sustainability, and design flexibility.

Authors:

Mohammad Najeeb Shariff
Assistant Professor,
Department of Civil Engineering,
Indian Institute of Technology Bombay, India

Nikhil P. Zade
Post Doctoral Fellow,
Department of Civil Engineering,
Indian Institute of Technology Bombay, India

The construction industry is undergoing a transformative shift with the application of 3D Concrete Printing (3DCP). This technology has several advantages compared to conventional method of construction such as improved efficiency, sustainability, and design flexibility. Fig. 1 presents the Indias first 3D-printed residential unit inaugurated in 2021.

One of the significant advantages of 3DCP is the formwork-free construction. In traditional construction, formwork accounts for 35–60% of the total cost of concrete construction (Paul et al., 2018; Zhu et al., 2021). About 70% reduction in the project duration and a 60% reduction in waste generation can be achieved by using 3DCP technology (Iribar, 2023). Despite 3DCP's several advantages their applications in the construction sectors are still limited. Present article discussed challenges in 3DCP which hinder their applications in large scale projects and the way forward for their wide applications.

Understanding 3d Concrete Printing

3DCP is an additive construction (AC) process following a layer-by-layer extrusion process of cementitious materials to construct complex structures without conventional formwork. A design concrete mix is extruded through a nozzle, which follows a digital path to build the part of structural element or the entire structure. The technique eliminates excess waste and reduces dependence on manual labour, making construction faster and cost-effective.

Beyond 3DCP advantages in speed and sustainability, the structural performance of 3D-printed concrete is a key consideration. The critical aspects which define its feasibility are: (i) the fresh and hardened state properties of 3D-printable concrete (3DPC); and (ii) its long-term strength and serviceability, which determine its durability and structural reliability over time.

Figure 1: *First 3D-printed residential unit in India*

Material Aspect

Conventional concrete used in reinforced concrete (RC) construction differs significantly from 3D-printed concrete in terms of material composition (excluding coarse aggregates), its layer-by-layer construction process, and the lack of compaction. Additionally, 3D-printable concrete must meet specific requirements, one of the most critical being 'printability'. These differences in construction methodology lead to notable changes in both the fresh and hardened state properties of the concrete. Table 1 presents the basic difference between conventional concrete and 3D-printed concrete.

Table 1: Requirements and characteristics of 3D-printed concrete and conventional concrete

Property		Conventional concrete	3D-printed concrete
Mixture design		**Well-established standard guidelines**	**No standard guidelines; developed via trial and error**
Fresh state properties	Workability and Pumpability	Well establish test procedures and limits as per functional requirements	No standard guidelines (trial and error)
	Extrudability and Buildability	Not Applicable	Additional requirement, no standard guidelines (trial and error)
Hard state properties	Compressive strength	Well establish test procedure requirements: specimen dimensions, curing, isotropic.	No such guidelines, anisotropic
	Modulus of elasticity; Flexural strength; Tensile strength	Well-co-related to compressive strength, isotropic	No such correlation, directional dependency
	Interlayer bond strength	Not Applicable	Additional requirement

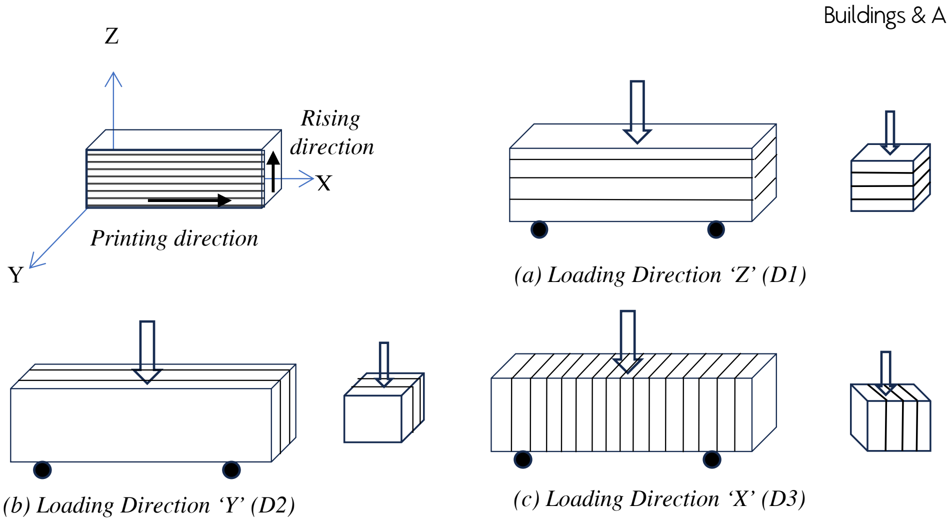


Figure 2: *Schematic presentation of different orientation testing for mechanical strength evaluation of 3DPC*

The layer-by-layer extrusion process and the absence of compaction in 3DPC results in inhomogeneity and anisotropy in its strength properties, making them direction-dependent (Fig. 2). These directional dependencies are influenced by various printing process parameters, one of which is nozzle pressure.

Extensive research is available on the fresh and hardened state properties of 3DPC (Sanjayan, & Nematollahi, 2019; Suthar et al., 2024; Han et al. 2023; Jayathilakage et al., 2020) addressing issues such as topology optimization, printability, structural performances and others. However, the field lacks standardized testing procedures, clear guidelines for minimum sample sizes and specimen dimensions, and established benchmarks for both fresh and hardened properties specific to 3D printing. These gaps present challenges to the broader adoption and reliability of 3DCP in construction.

In conventional concrete, compressive strength serves as a key parameter due to well-established correlations with other mechanical properties, such as tensile strength, flexural strength, and modulus of elasticity. However, no such correlation has been developed for 3D-printed concrete. The author has explored the possibility for such correlations in 3DPC through a review of available literature (Fig. 3).

In the absence of a mixture design tailored to specific functional requirements, determining these properties often relies on a trial-and-error approach to achieve successful printing. A suitable correlation between the mixture design and time-dependent fresh state properties, directional dependencies of hardened state properties could be established and standardized to minimize the trial-and-error approach and to reduce the several experimental test requirements in 3DCP.

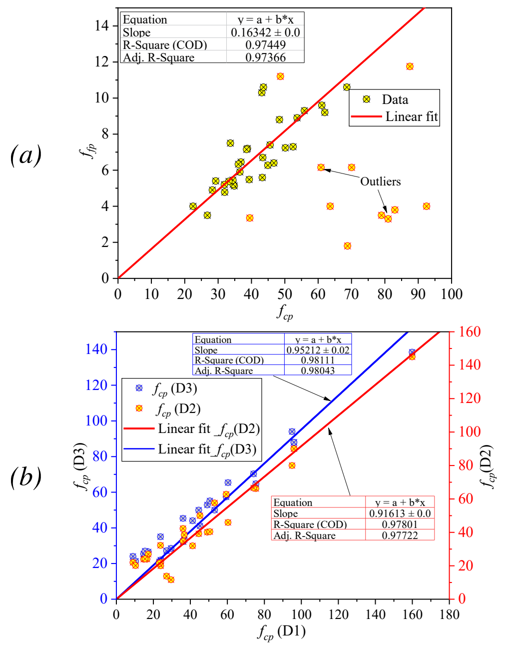
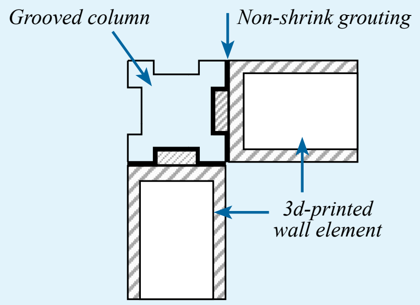
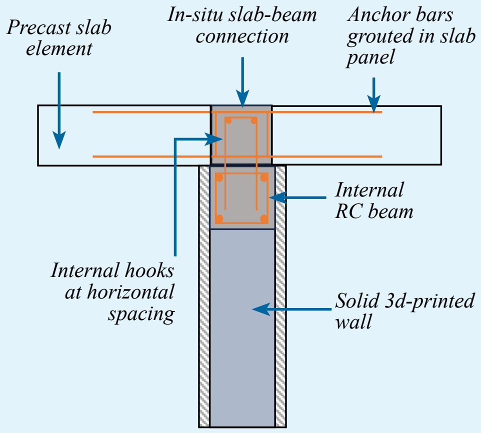


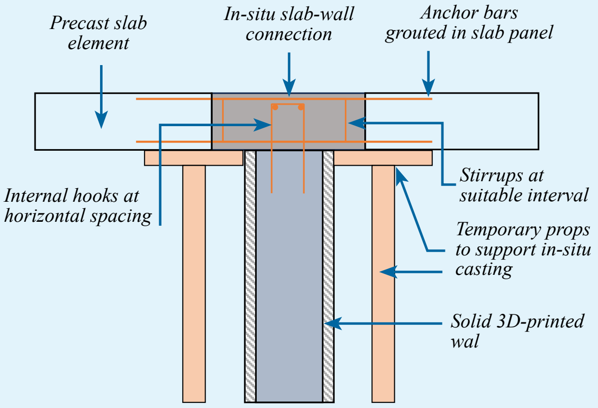
Figure 3: *Possible correlation: (a) compressive strength (f_{cp}) and flexural strength of printed (f_{fp}) specimen; (b) directional dependency in the 3DCP specimens*



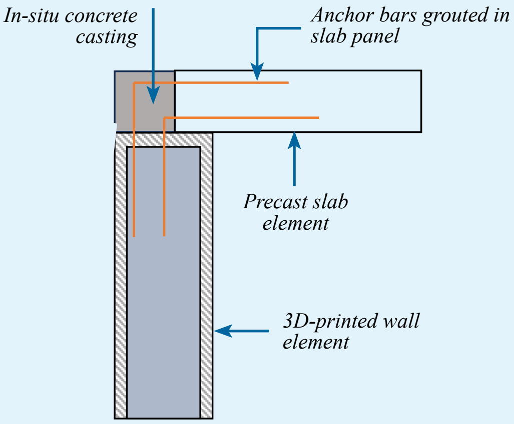
(a) wall to column



(b) wall to slab through beam



(c) wall to slab at intermediate



(d) wall to slab at edge

Figure 4: *Possible connection for 3DPC elements: wall-to-column and wall-to-slab*

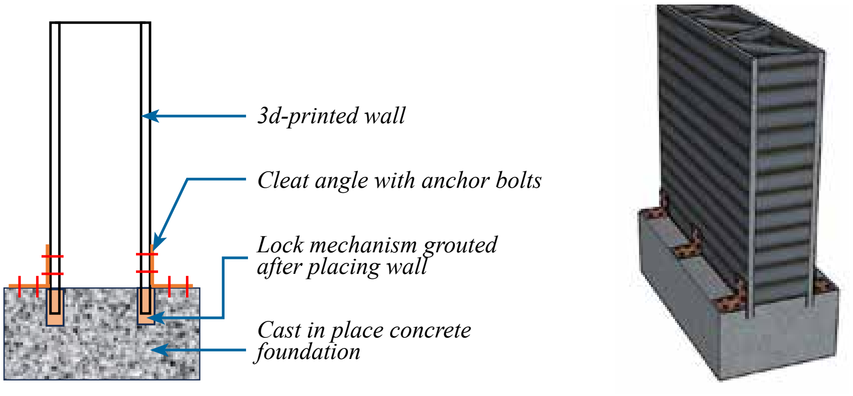
Structural Aspect of 3DCP

The integration of the reinforcement, connection detailing, stringent precision requirements with limited tolerance are some of the limitations of 3DCP. This section discusses potential challenges and some remedial solutions in 3DCP.

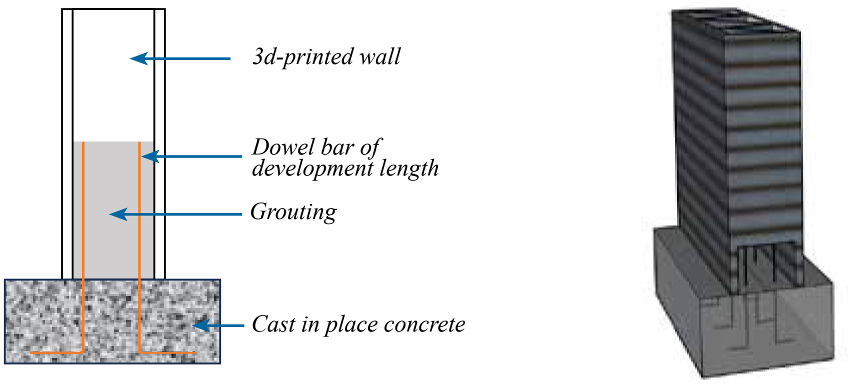
Concrete is known for its high compressive strength but weak tensile resistance. Therefore,using 3DPC for purely compression members is justified. However, completely avoiding tensile forces in structural applications is often inevitable and the challenge of integrating reinforcement during the printing process limits its widespread adoption in the construction industry. Different reinforcement strategies include: textile and mesh reinforcement, penetration of steel bars and screws, bed-joint reinforcement, pre-stressing techniques, reinforcement cage integration and others. Some of the reinforcement strategies and different schematic connections between 3DPC elements are shown in Fig. 4-5.

In addition, building envelope requires connections between elements like walls, frames, slabs, columns, and beams. However, the non-monolithic, formwork-free nature of 3D printing limits the ability to create rigid joints, crucial for load transfer and structural stability. With no standardized design approach for these connections, addressing this challenge requires integrating conventional construction principles while accounting for 3D printing's unique constraints.

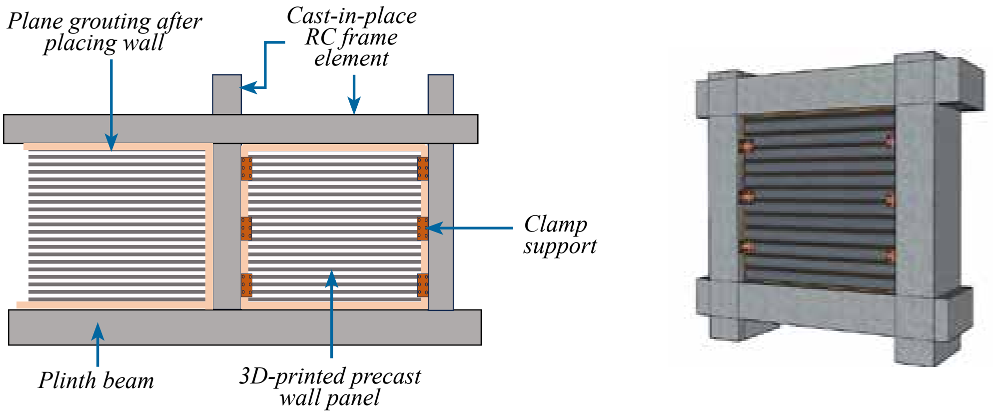
One key aspect of connection strategy is the integration of dowels during the printing process. However, dowels can introduce challenges, as the printing arm requires an unobstructed path for operation. This limitation can be addressed by providing the "couplers," which enhance



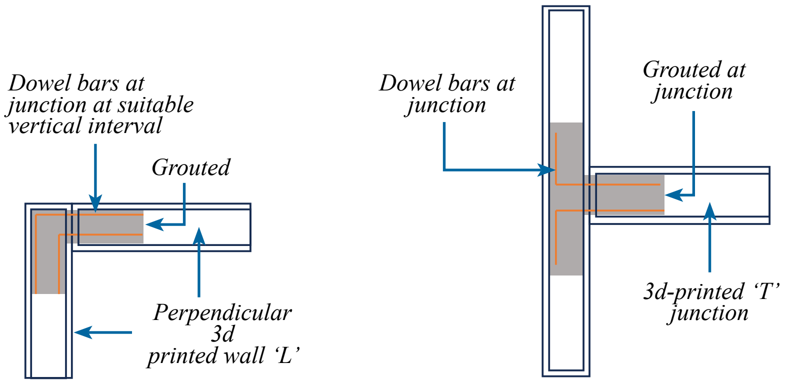
a) Foundation with lock mechanism



b) Moment connection for wall foundation



(c) wall to frame connection out-of-plane



(d) wall to wall 'L'connection

(e) wall to wall 'T' connection

Figure 5: *Possible connection for 3DPC elements: wall-to-foundation and wall-to-wall connection*

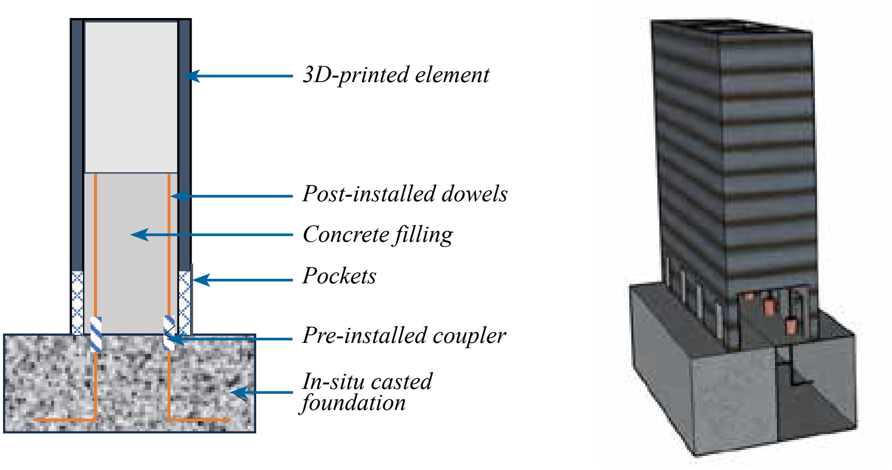


Figure 6: *Use of couplers for reinforcement of 3DPC elements*

both functionality and compatibility with the printing process. Once the elements are printed, the reinforcement bars can be anchored to the pre-installed couplers before filling the cavity with concrete. This anchoring can be facilitated by incorporating designated pockets that allow the application of the necessary torque and access to the couplers, as illustrated in Fig. 6. Several projects are currently in progress under ASTM and ISO standards to address these available gaps in AC and to respond to concerns raised by the construction sector.

One of the RILEM's initiative aims to advance 3D printing in construction by establishing clear testing and assessment guidelines for printable and printed concrete. Technical Committees TC 303-PFC and TC 304-ADC conduct interlaboratory studies to evaluate rheological, mechanical, and durability properties, forming the basis for future codes and standards. The 'RILEM TC ADC Interlaboratory Study' fosters global collaboration to standardize testing methods, ensuring consistency and reliability, ultimately supporting the integration of 3D printing in construction (Mechtcherine & Bos, 2021a,b).

CONCLUSION

The evolution of 3D concrete printing (3DCP) is set to revolutionize construction by enhancing speed, cost efficiency, and sustainability. While a few research laboratories and industries have demonstrated successful implementation of 3DCP for in-situ load-bearing structures, its widespread adoption at a global level remains limited due to challenges such as mixture optimization, buildability, anisotropic behaviour, reinforcement integration and the high initial cost of 3D-concrete printers. Standardizing correlations from compressive strength and directional dependencies could reduce experimental testing, saving time and costs. Additionally, proposed and existing connection strategies require experimental validation under gravity and lateral loads. Full-scale testing is crucial to establishing benchmarks for material properties, specimen sizes, and performance criteria, ensuring consistency, reliability, and to built the confidence among stakeholders for the adoption of 3DCP in construction industry.

References

Han, X., Yan, J., Liu, M., Huo, L., & Li, J. (2022). Experimental study on large-scale 3D printed concrete walls under axial compression. Automation in Construction, 133. https://doi.org/10.1016/j.autcon.2021.103993

Ibon Iribar. (2023). How 3D printing in the construction industry works. https://www.cemexventures.com/3d-printing-in-construction/. Cemex Ventures. (Accessed on Dec, 10, 2024)

Jayathilakage, R., Rajeev, P., & Sanjayan, J. (2020). Yield stress criteria to assess the buildability of 3D concrete printing. Construction and Building Materials, 240, 117989. https://doi.org/10.1016/J.CONBUILDMAT.2019.117989

Mechtcherine, V., & Bos, F. (2021a). 303-PFC: Performance requirements and testing of fresh printable cement-based materials, RILEM, available from: rilem.net .

Mechtcherine, V., & Bos, F. (2021b). 304-ADC: Assessment of Additively Manufactured Concrete Materials and Structures, RILEM, available from: rilem.net.

Paul, S. C., Tay, Y. W. D., Panda, B., & Tan, M. J. (2018). Fresh and hardened properties of 3D printable cementitious materials for building and construction. Archives of Civil and Mechanical Engineering, 18(1), 311–319. https://doi.org/10.1016/j.acme.2017.02.008.

Sanjayan, J. G., & Nematollahi, B. (2019). 3D Concrete Printing for Construction Applications. 3D Concrete Printing Technology: Construction and Building Applications, 1–11. https://doi.org/10.1016/B978-0-12-815481-6.00001-4

Suthar, M., Shariff, N. M., & Nanthagopalan, P. (2024). Performance Assessment of Topologically Optimised 3D Printable Concrete Sewer Cross-Section Using Finite Element Simulation. In M. D. Goel, R. Kumar, & S. S. Gadve (Eds.), Recent Developments in Structural Engineering, Volume 1 (pp. 547–556). Springer Nature Singapore.

Zhu, B., Nematollahi, B., Pan, J., Zhang, Y., Zhou, Z., & Zhang, Y. (2021). 3D concrete printing of permanent formwork for concrete column construction. Cement and Concrete Composites, 121. https://doi.org/10.1016/j.cemconcomp.2021.104039

AIT Solutions

SIGNATURE SERVICES

Together we can build a resilient future using advanced engineering technology

Wind Tunnel Testing

We conduct wind tunnel laboratory testing to assess the wind loads and responses of buildings and structures in a controlled environment using an atmospheric boundary layer wind tunnel, with a working section of 2.5m x 2.5m x 23m.

Structural Health Monitoring

Our expert team uses advanced analysis technique to monitor the health of instrumented structures and assess their safety and reliability.

Structural Failure Investigations and Retrofit Design

Our expert team investigates and evaluates the causes of structural failures and develops retrofit designs to enhance the safety and reliability of existing structures.

Performance-based Seismic Design

We use advanced analytical methods to ensure the safety and performance of structures during earthquakes.

Software Development & IT

Creating customized desktop, web, mobile, and cloud-based applications in various fields, including structural engineering, mobile computing, knowledge products, construction monitoring and management.

Computational Modeling and Analysis of Complex Structural Systems

Our expert team uses state-of-the-art software and modeling techniques to simulate various scenarios and assess the performance of complex structural systems under various loading conditions.

Structural System Development & Code-based Design Review

To ensure that our clients' structures are designed to meet their specific needs while being safe and compliant with local codes and regulations.

www.solutions.ait.ac.th

Advancing Digital Transformation in Building Construction through Disruptive Technologies: Key Findings from Research Case Studies

Construction industry has shaped the past, present, and future of many societies and countries. However, it needs to adapt Digital Technology Developments to remain relevant in the era of the fourth industrial revolution.

Author:

Farrukh Arif
Associate Professor
Department of Civil Engineering
Director - NED University
Virtual Reality Center
NED University of Engineering &
Technology, Karachi, Pakistan

Construction Industry is often marked as one of the biggest drivers of economy all around the world. It has shaped past, present and future of many societies and countries. It is one of the biggest employers of direct and indirect workforce, providing bread and butter to many families. Currently, however, it can be safely said that the industry is undergoing a mix of challenges and innovations. The significant contemporary trends in construction are related to: post-pandemic recovery, need for sustainable and green construction, automation and digitalization, smart cities and infrastructure, modular construction, increased demand for efficient housing, and labor or workforce shortages. These challenges are not isolated in nature but are webbed in such a manner that some may impede and others may facilitate the progress towards other. Hence, it needs to find a common target or "goal" to ensure that construction industry remains relevant to not only addressing these challenges, but do so on its own as an industrial response in this era of 4th industrial revolution. In authors opinion, digital transformation of building construction through disruptive technologies can be the goal that can help it to cater challenges of the future as well.

The Philosophy of Disruptive Technologies

The idea of "Disruptive Innovation" was propagated by Clayton Christensen starting 1990's, who described it as an innovation that significantly alters the way that consumers, industries, or businesses operate. Disruptive technologies can significantly alter the habits and characteristics of system that it replaces or augments. In order to adopt such technology, it is not necessary to have cardinal changes to start with, however, consistent application, innovation and continuous learning will be necessary components. The scale of application also has no restrictions, and even a small-to-medium size company can look for integrating disruptive innovation into its business. Perfect example of such instances is technology-based innovative startups which, typically, find their inceptions based on such technologies.

Building Construction and Disruptive Technologies – Learnings from Case Applications

Construction industry has a lot of room for integrating disruptive technologies and innovations in their business. These include (but not limited to); Building Information Modelling (BIM), Extended Reality (VR/MR/AR), smart automation, Artificial Intelligence (AI), image processing, cloud technologies, Unmanned Aerial Vehicles (UAVs), and Internet of Things (IoT) applications etc. Another area is "SMART" technologies whereas SMART here refers to "self-monitoring, analysis, and reporting technology." These technologies depend on use of IoT, AI, and smart devices as the operational core. In construction, application of such technologies can result in better project management, control, learning curve and better facilities management. Following sections discuss overview of selected research's example case applications as done by the author in different researches, in order to showcase the vindication of disruptive technologies' potential for ensuring digital transformation in building construction.

Research Case Application 1: Smart Productivity Tracking

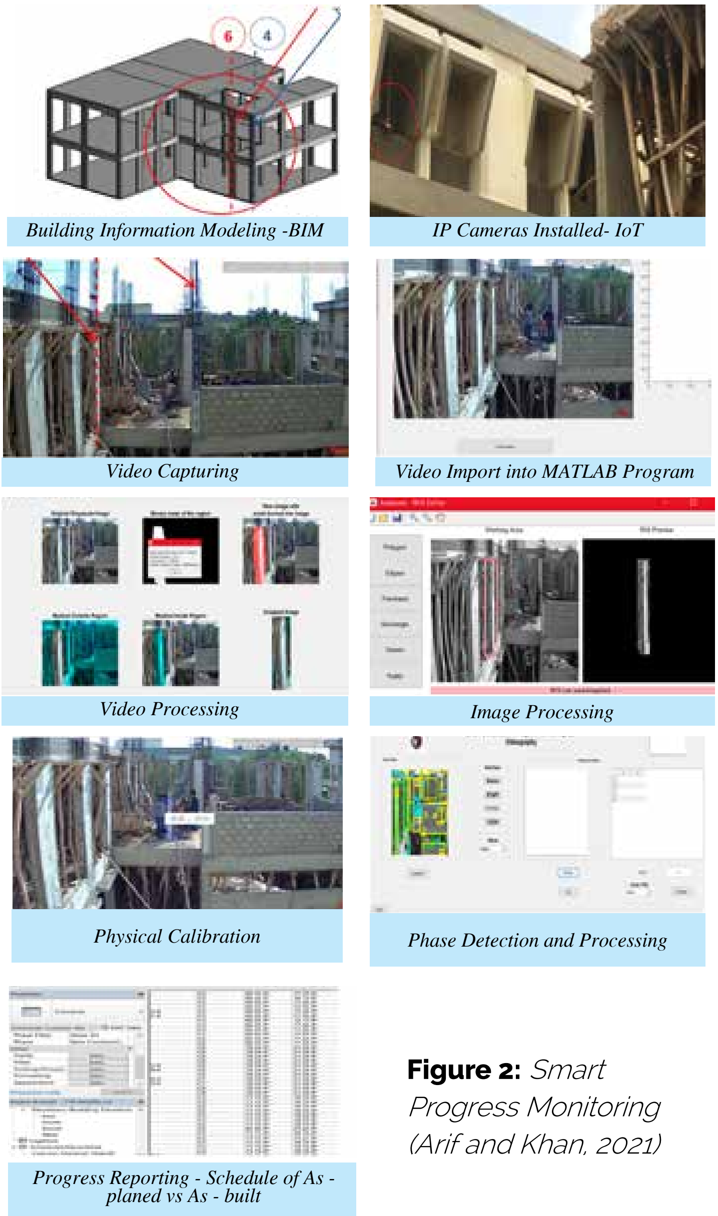
In another study, regarding Smart Productivity Tracking at Construction Site, Arif and Khan (2020) introduced a real-time productivity tracking framework that integrates survey data, cloud computing, and Building Information Modeling (BIM). The framework combines data collected through on-site surveys with cloud-based platforms to create a seamless flow of real-time information. By integrating BIM, the system allows for continuous tracking of construction productivity, offering insights into project performance and resource utilization. This approach enhances project management by providing immediate feedback on progress, helping stakeholders make data-driven decisions. The framework aims to improve efficiency, reduce delays, and optimize construction processes, offering a modern solution for productivity monitoring in the construction industry. It highlights the transformative potential of combining digital technologies for effective project oversight. Figure 1 illustrates the use

Figure 1: *Smart Productivity Tracking (Arif and Khan, 2020)*

of disruptive technology in different steps of framework implementation.

Research Case Application 2: Smart Progress Monitoring

In a study, Arif and Khan (2021) presented a novel Smart Progress Monitoring Framework (SPMF) that integrates videography, MATLAB, and Building Information Modeling (BIM) to monitor the progress of building construction elements. The framework leverages video footage captured on-site, which is processed using MATLAB for image analysis, and BIM for accurate modeling and data visualization. This integration allows real-time tracking of construction progress, offering an automated and efficient solution to compare actual site conditions against planned timelines. By combining these technologies, the framework improves project management, enhances decision-making, and reduces human error, ultimately contributing to more efficient construction processes and better resource allocation. The approach represents a significant advancement in construction monitoring using digital tools. Figure 2 illustrates the use of disruptive technology in different steps of framework implementation.


Building Information Modeling -BIM

IP Cameras Installed- IoT

Video Capturing

Video Import into MATLAB Program

Video Processing

Image Processing

Physical Calibration

Phase Detection and Processing

Progress Reporting - Schedule of As - planed vs As - built

Figure 2: *Smart Progress Monitoring (Arif and Khan, 2021)*

Figure 3: *Virtual Reality for Structural Health Digitization (Arif et. al, 2025)*

Research Case Application 3: Virtual Reality for Structural Health Digitization

Arif, Khan, and Khan (2025) conducted a study regarding use of Virtual Reality for Structural Health Digitization. It explored the integration of LiDAR (Light Detection and Ranging) technology with UAVs (Unmanned Aerial Vehicles) for digitizing civil infrastructure. This method allows for the precise capture of detailed 3D models of infrastructure, aiding in the assessment of physical conditions. The integration of UAVs and LiDAR enhances the accuracy and efficiency of data collection, enabling detailed visualization of infrastructure that would otherwise be time-consuming and costly to obtain. LiDAR, UAV, and AI were used to create a 3D reconstructed model of a high-rise water tank for accurate condition assessment. Unlike traditional visual inspections, this method quantifies structural deflections, detects cracks, and integrates point cloud models with as-planned designs in Navisworks, improving the precision of maintenance decisions. Figure 3 illustrates the use of disruptive technology in different steps of framework implementation.

Research Case Application 4: Mixed Reality for Construction Progress Visualization

Construction progress monitoring often faces errors due to subjective reporting and lack of integrated visualization. Digitizing construction activities and comparing them to the planned schedule can aid decision-making. Mixed reality (MR) allows overlaying remaining project work onto ongoing construction in 3D. When integrated with platforms like Building Information Modeling (BIM), MR enables dynamic visualization and real-time updates on construction progress. This study introduces an MR-IM workflow using Unity3D to create an application for immersive project visualization and accurate measurements. Implemented on a real-world project, the MR-IM application showed less than 5% error compared to manual measurements, offering a precise, real-time tracking solution. Figure 4 illustrates the use of disruptive technology in different steps of framework implementation.

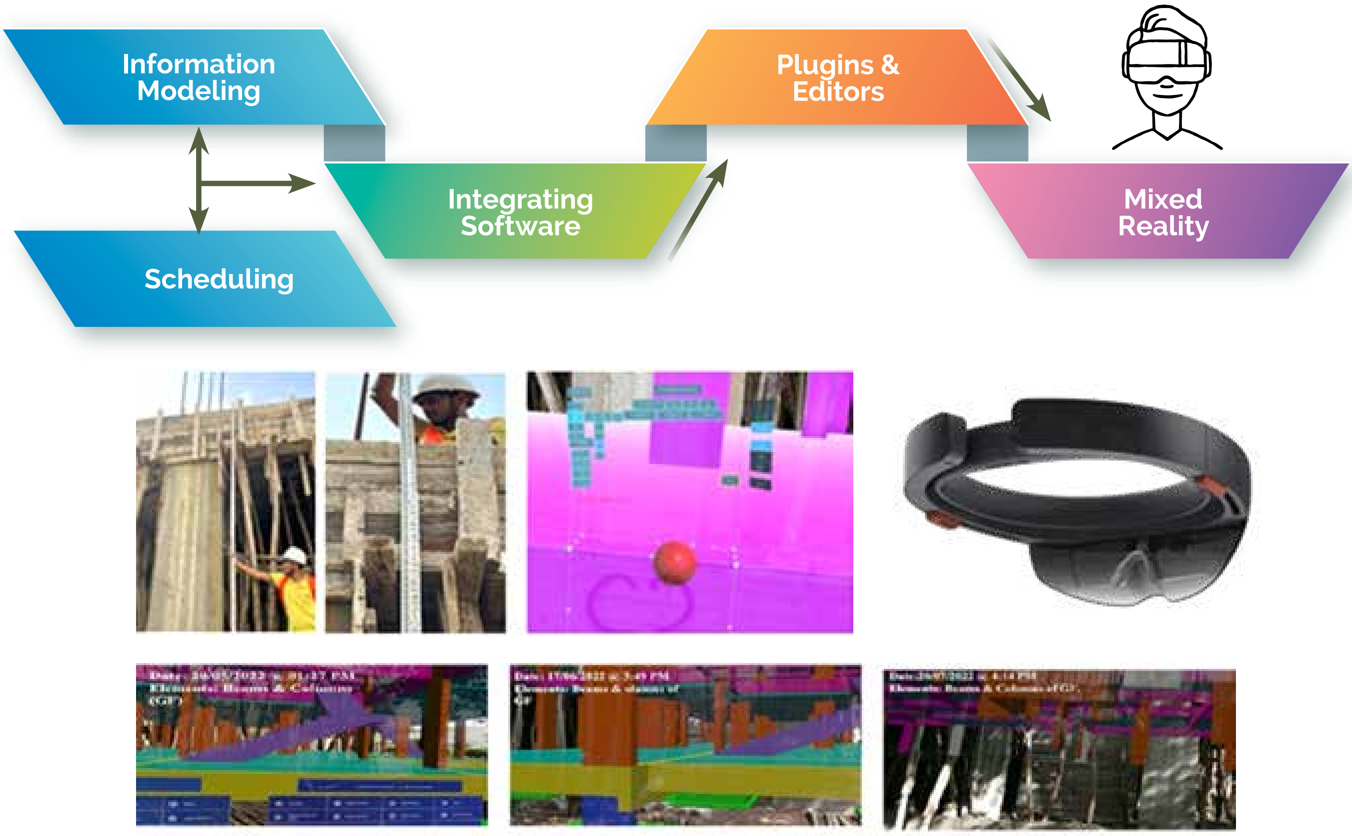


Figure 4: *Mixed Reality for Construction Progress Visualization (Arif and Khan, 2024)*

Research Case Application 5: BIM-Living Lab and VR for Energy Efficient Housing Design

This research aimed to develop an energy-efficient housing design strategy and corresponding designs using a hybrid methodology combining analytical modeling, simulation, and audited data to ensure realistic Building Information Modeling (BIM) at LOD 500. The study utilized a Living Lab setup, integrating IoT-based sensing technology to collect real-time data on parameters like occupancy, daylighting, lighting, and air conditioning (Azhar et. al 2023). This data was analyzed alongside simulation results to identify energy inefficiencies. If discrepancies were found, energy efficiency guidelines were proposed. The design review was conducted in a virtual reality (VR) environment, allowing stakeholders to collaborate seamlessly. This VR-based approach disrupted traditional design processes, enhancing the integration and efficiency of the energy-efficient design process (Arif and Azhar, 2025).

Conclusions and Recommendations

Following Table summarizes the use of disruptive technologies in the discussed case applications.

Table: Use of Digital technologies in Case Studies

Case Application	BIM	XR (VR/AR/MR)	UAVs	LiDAR	AI	IoT	Automation Process	Cloud Technology	Image Processing
Smart Productivity Tracking	✓	-	-	-	-	-	✓	✓	-
Smart Progress Monitoring	✓	-	-	-	-	✓	✓	-	✓
Virtual Reality for Structural Health Digitization	-	✓	✓	✓	✓	-	-	-	✓
Mixed Reality for Construction Progress Visualization	✓	✓	-	-	-	-	-	✓	✓
Energy Efficient Housing	✓	✓	-	-	-	✓	-	-	-

It can be observed and concluded that in the discussed applications, the integrative use of disruptive technologies has resulted in providing solutions for digital transformation for all phases of building construction i.e. design, construction, maintenance, and efficient operations. Hence, it can be easily said that use of such (and other) disruptive technologies can pave the way for quick digital transformation at the industrial level as well.

However, Industry-level response for adoption of disruptive technologies should emphasize the need for capacity building and human resource development to increase awareness and adaptability. There should be strong calls for developing indigenous solutions that are cost-effective and resource-efficient. Investments in research and development should prioritize these homegrown solutions. A stronger industry-academia partnership is essential, where academia provides innovative solutions in response to industry identified needs. The industry must also assess its readiness for disruptive technologies while adapting to innovation. Academia must update curricula to focus on solution-oriented, problem-based learning. Additionally, professionals with technical expertise and a focus on R&D should play key roles in policy-making at regulatory forums.

References

Disruptive Innovation Theory (https://www.christenseninstitute.org/theory/disruptive-innovation/#:~:text=Definition,upmarket%2C%20eventually%20displacing%20established%20competitors.)

Arif, F., & Khan, W. A. (2020). "A Real-Time Productivity Tracking Framework Using Survey-Cloud-BIM Integration." Arabian Journal for Science and Engineering, 45(10), 8699-871.

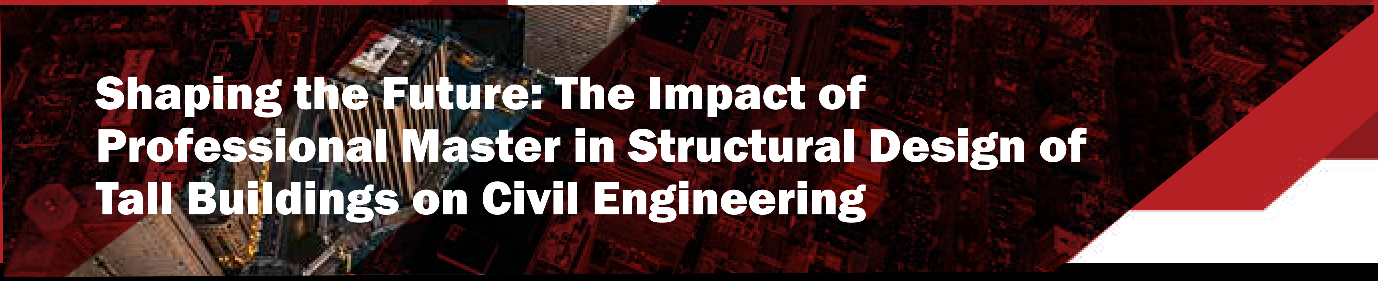
Arif, F., Khan, W.A. (2021). "Smart Progress Monitoring Framework for Building Construction Elements Using Videography–MATLAB–BIM Integration." Int J Civ Eng 19, 717–732 (2021). https://doi.org/10.1007/s40999-021-00601-3

Azhar, N., Arif, F., & Khan, A. B. (2023). Framework for Energy Performance Measurement of Residential Buildings Considering Occupants' Energy Use Behavior. Engineering Proceedings, 44(1), 15. https://doi.org/10.3390/engproc2023044015

Arif, F. Azhar N (2025). Development of Energy Efficient Housing Design for Karachi using living lab- virtual reality integration, SHECSRSP 168. https://www.youtube.com/watch?v=mmwQdVwLmzg

Arif, F., Khan, W. A., & Khan, A. U. R. (2025). LiDAR-UAV Integrated Digitization of Civil Infrastructure for Visualization of Physical Condition. Construction Technologies and Architecture, 15, 11-18. https://www.scientific.net/CTA.15.11

PMTB
PROFESSIONAL MASTER DEGREE IN
STRUCTURAL DESIGN OF TALL BUILDINGS



Shaping the Future: The Impact of Professional Master in Structural Design of Tall Buildings on Civil Engineering

In the ever-evolving field of civil engineering, the construction landscape is reaching new heights – quite literally. With the increasing demand for skyscrapers and tall structures, the role of structural engineers has become more crucial than ever. To meet this demand and equip civil engineers with specialized skills, Professional Master in Structural Design of Tall Buildings (PMTB) is shaping the future of civil engineering.

Professional Master in Structural Design of Tall Buildings

PMTB is a response to this growing demand for specialized expertise. These programs go beyond the foundational principles taught in traditional civil engineering education, delving into the complexities of tall building design, including structural systems, seismic considerations, and wind dynamics. The curriculum is designed to provide students with a holistic understanding of the challenges and innovations inherent in tall building design and construction.

The Rise of Tall Buildings

In recent decades, the global skyline has been transformed by towering structures that defy traditional engineering norms. Tall buildings are not merely symbols of architectural prowess; they represent the intersection of art, science, and functionality. As cities expand vertically, there is a pressing need for engineers who possess a deep understanding of the unique challenges associated with designing and constructing tall buildings.

Specialized Knowledge

One of the keyways in which these programs shape the future of civil engineers is by offering specialized knowledge. Students are exposed to advanced topics such as performance-based seismic design, and wind engineering and structural health monitoring. This specialized knowledge equips graduates with a competitive edge, making them sought-after professionals in the field of structural engineering.

Interdisciplinary Approach

The design and construction of tall buildings require a multidisciplinary approach. PMTB encourages collaboration between engineers, architects, and other professionals. This interdisciplinary approach mirrors the real-world challenges faced by civil engineers working on complex projects, fostering teamwork and effective communication skills.

Real-World Application

Theoretical knowledge is valuable, but its real worth is realized when applied to practical scenarios. PMTB includes hands-on projects that allow students to apply their learning to real-world situations. This practical experience is invaluable in preparing civil engineers for the challenges they will face in their careers.

Recommendation

The Professional Master in Structural Design of Tall Buildings is playing a pivotal role in shaping the future of civil engineering. By providing specialized knowledge, fostering an interdisciplinary approach, promoting real-world application, this program prepares engineers to tackle the complexities of designing and constructing the skyscrapers that define our modern cities. As the demand for tall buildings continues to rise, the graduates of these programs are well-positioned to lead the way in creating the structures that will shape our urban landscapes for generations to come.

PMTB
PROFESSIONAL MASTER DEGREE IN
STRUCTURAL DESIGN OF TALL BUILDINGS

PROFESSIONAL MASTER IN STRUCTURAL DESIGN OF TALL BUILDINGS

Click or Scan QR for more info

Offered by

School of Engineering & Technology (SET)

Be a part of Global Network of fellow Professionals & Alumni from over 50 countries through self-paced blended learning (online + in-class) approach

ENROLL NOW FOR August 2025 INTAKE

PROGRAM HIGHLIGHTS

- Aligned with industry trends
- Applied Learning
- Flexible learning
- Experience Campus Life
- World-class Faculty
- Flexi-payment

in www.linkedin.com/in/aitpmtb
f www.facebook.com/aitpmtb
✉ pmtb@ait.ac.th
🌐 www.solutions.ait.ac.th/pmtb