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360-DEGREE POINT CLOUD TECHNOLOGY FOR BUILDING MANAGEMENT

Prepared by Barritt Lovelace, P.E.
Collins Engineers, Inc.

Introduction

The ability to collect and utilize large amounts of data is transforming our world.   Industries like healthcare, finance, energy, communication and transportation are finding ways to utilize data to improve people's lives. The Minnesota Department of Transportation (MnDOT) and Collins Engineers, Inc. (Collins) have been utilizing drones and other imaging equipment to collect and process large amounts of data during asset inspections with the goal of improving the quality and ability of asset owners to make risk-based, data driven decisions. Processing software and inspection specific asset management platforms are giving asset owners the ability to utilize this data to accelerate their ability to effectively manage these important assets. MnDOT and Collins have become leaders not only in drone technology, but more specifically in creating and utilizing 3D modeling to communicate inventory and inspection data.

Overview

The Building Services Section (BSS) owns and operates 888 individual buildings at 269 sites throughout Minnesota. BSS is exploring ways collect, process and communicate as-built data for their sites and buildings with imaging and scanning technology. The data can be collected with spherical cameras, handheld cameras, laser scanners and drones or any combination of these technologies. This research phase gathered information on the capabilities available to help MnDOT move into implementation. This Transportation Research Synthesis documents the state of the industry, identifies previous research and implementation regarding 360-degree point cloud and reality modeling technology for building management.

Technical Advisory Panel (TAP)

Barritt Lovelace P.E., Regional Manager, Principal Investigator
Collins Engineers, Inc.

Christopher Bjork, Building Process Coordinator, Technical Liaison
Minnesota Department of Transportation

Lisa Jansen, State Planning & Research Project Coordinator, Project Coordinator
Minnesota Department of Transportation

Christopher Moates
Minnesota Department of Transportation, Technical Advisory Panel Member

David Schilling
Minnesota Department of Transportation, Technical Advisory Panel Member

Michael Ligday
Minnesota Department of Transportation, Technical Advisory Panel Member

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT, Implementation, and the Local Road Research Board. This TRS does not represent the conclusions of the authors, MnDOT or LRRB.

Executive Summary

This project includes reviewing existing research and technologies and also leveraging relationships with technology companies and other Department of Transportations (DOTs) to determine the state of the industry. A survey was sent to agencies that own buildings to gather information on how building owners are utilizing and/or planning to utilize scanning technology to document existing facilities. This technology can be used to digitally document both building sites and exteriors, and also building interiors. The technologies include hardware such as drones, cameras, lidar, and lasers. Software is available to process the data into deliverables and cloud platforms exist to share this information across project teams. This report reviewed the existing state of technologies and identified possible solutions that can be implemented into project workflows. The technology review and literature review revealed a relatively new, but tested technologies to meet MnDOT's goals of improving data reliability and saving project costs. A survey of other agencies suggests the technology has not been widely adopted but, that there is interest in implementation.

Literature Review

A literature review was performed to determine past recent research, articles and relevant case studies.

3D Modeling of Building Indoor Spaces and Closed Doors from Imagery and Point Clouds

https://www.ncbi.nlm.nih.gov/pubmed/25654723

Díaz-Vilariño L, Khoshelham K, Martínez-Sánchez J, and Arias P present a pipeline of techniques used for the reconstruction and interpretation of building interiors based on point clouds and images. The methodology analyses the visibility problem of indoor environments and goes in depth with door candidate detection. The presented approach is tested in real data sets showing its potential with a high door detection rate and applicability for robust and efficient envelope reconstruction.

Enhanced RGB-D Mapping Method for Detailed 3D Indoor and Outdoor Modeling

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5087378/

Shengjun Tang, Qing Zhu, Wu Chen, Walid Darwish, Bo Wu, Han Hu and Min Chen present a novel approach to geometrically integrate the depth scene and RGB scene to enlarge the measurement distance of RGB-D sensors and enrich the details of model generated from depth images.

BIM for Existing Buildings (A Study of Terrestrial Laser Scanning and Conventional Measurement Technique)

https://www.theseus.fi/handle/10024/134598

This thesis by Musa Raza contributes to the knowledge of TLS by presenting a real-time example of how BIM and TLS be integrated for the existing buildings for any required purpose. This provides a development idea and model for the future users and researchers to undertake the process improvement by using this example as a practical guide for understanding the feasibility of TLS and BIM for different existing buildings.

Indoor Scene Point Cloud Registration Algorithm Based on RGB-D Camera Calibration

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5579576/

In this paper by Chi-Yi Tsai and Chih-Hung Huang, an automatic point cloud registration algorithm is proposed to efficiently handle the task of 3D indoor scene reconstruction using pan-tilt platforms on a fixed position. The proposed algorithm aims to align multiple point clouds using extrinsic parameters of the RGB-D camera obtained from every preset pan-tilt control point.

City Wide Scanning Helps with ADA Compliance

https://read.nxtbook.com/bnp/point_of_beginning/january_2019/city_wide_scanning_helps_ada_.html

This article by Larry Trojak describes the successful effort to use 3D scanning to help the City of Tulsa with ADA compliance.

Incredible 3D Laser Scans Saved in 2015 Could Help Rebuild the Notre Dame

https://www.sciencealert.com/before-the-fire-an-art-historian-had-taken-amazing-3d-scans-of-notre-dame

This article by Natalie Coleman documents the scanning of Notre Dame Cathedral before the fire in 2019 and how the scanning will play an important role in rebuilding the historic church.

Conclusion

The literature review discovered previous research related to the technology available to perform indoor and outdoor scanning. Previous research that identifies the application and implementation of scanning was not found suggesting that while the technology has matured enough to make scanning feasible there has not been adoption of the technology in the public sector and no studies were available that demonstrate implementation of scanning for buildings.

Industry Survey

A survey was sent to 130 building professionals throughout Minnesota and the United States to help understand the state of the industry when it comes to building management and 3D scanning. The survey included 10 questions and was fully answered by 20 agencies. The survey was sent to both public and private building owners but no responses from private agencies were received. The following questions were included in the survey along with the results. The survey was available and open for entry for 6 weeks.

Question 1

Please enter the name of your organization.

Responses

Minnesota State Historic Preservation Office

Florida Department of Transportation

MN DNR

South Dakota DOT

South Carolina Department of Transportation

Arizona Department of Transportation

NJDOT

State of VT Highway Division

Louisiana Department of Transportation and Development

Connecticut Dept of Transportation

Mississippi Department of Transportation

Kansas Department of Transportation

Minnesota Department of Administration

Louisiana Department of Transportation and Development

CT DOT - Highway Facilities

New Mexico Department of Transportation

Dakota County

Tennessee Department of Transportation TDOT

CA Dept of Transportation

Georgia Department of Transportation

90%
of survey correspondences
are from state DOT's.

Figure 1: Map of Survey Responses Nationally

Question 2

How many buildings does your organization own and manage?

1-10 buildings 1.00%

61%
Over 61% of respondents are managing over 500 buildings.

100-500 buildings 21.98%

Over 500 buildings 61.04%
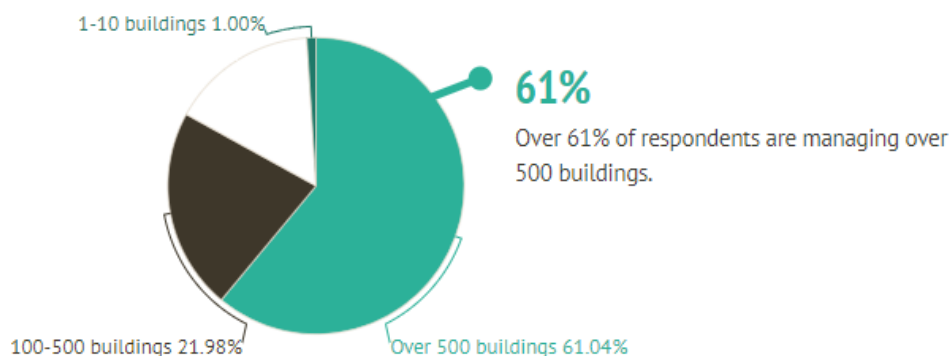
Figure 2: Number of buildings managed and owned by respondents.

Question 3

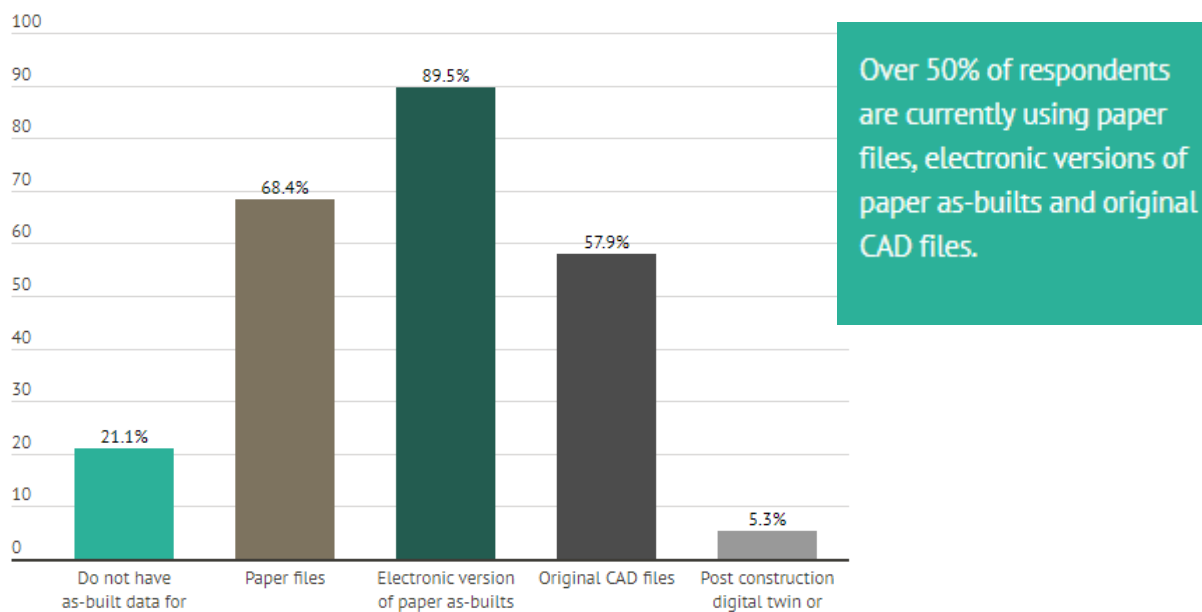How does your organization store as built data? (Choose more than one if necessary)

Over 50% of respondents are currently using paper files, electronic versions of paper as-builts and original CAD files.

89.5%

68.4%

57.9%

21.1%

5.3%

Do not have as-built data for | Paper files | Electronic version of paper as-builts | Original CAD files | Post construction digital twin or

Figure 3: Data Storage of Organizations

Question 4

What software is your organization using to manage their buildings?
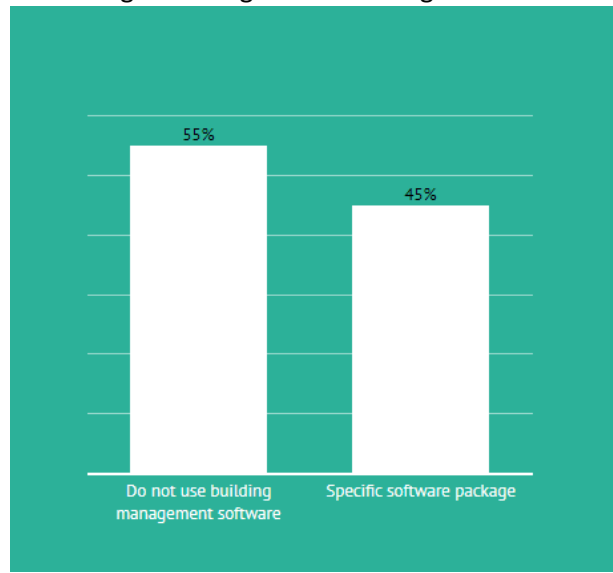
Figure 4: Data Storage of Organizations & Software Types

Summary of Specific Software Types Used by Survey Participants	
Software	State/Agency
CADD	Florida Department of Transportation
VFA Facility	Georgia Department of Transportation
Inspection	Connecticut Department of Transportation
SAP	Louisiana Department of Transportation and Development
Archibus	Minnesota Department of Administration - State Historic Preservation Office
Bentley InspectTech	Connecticut Department of Transportation
Audit Mate	South Dakota Department of Transportation
Archibus	Minnesota Department of Natural Resources

Figure 5: Specific Software Types by Respondents

Question 5

What method is your organization using to document your buildings exteriors after construction? (Choose more than one answer if necessary)
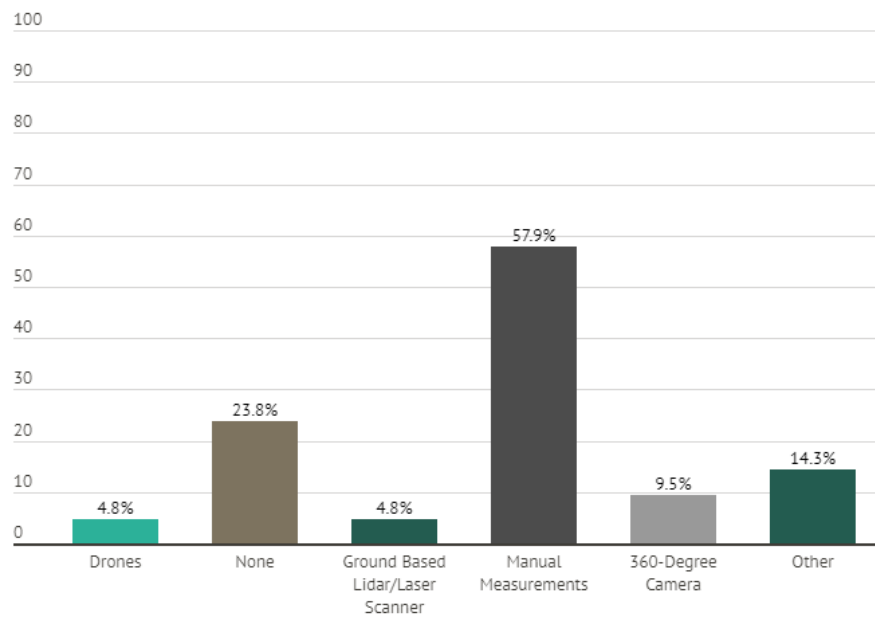

Figure 6: Methods of Documentation of Building Exteriors after Construction:

Other responses included:

- We document the exterior finishes during physical inspections; building assets are located via google earth mapping built into InspectTech
- As-builts
- Pictures, personal assessment

Question 6

What method is your organization using to document your buildings interiors after construction?
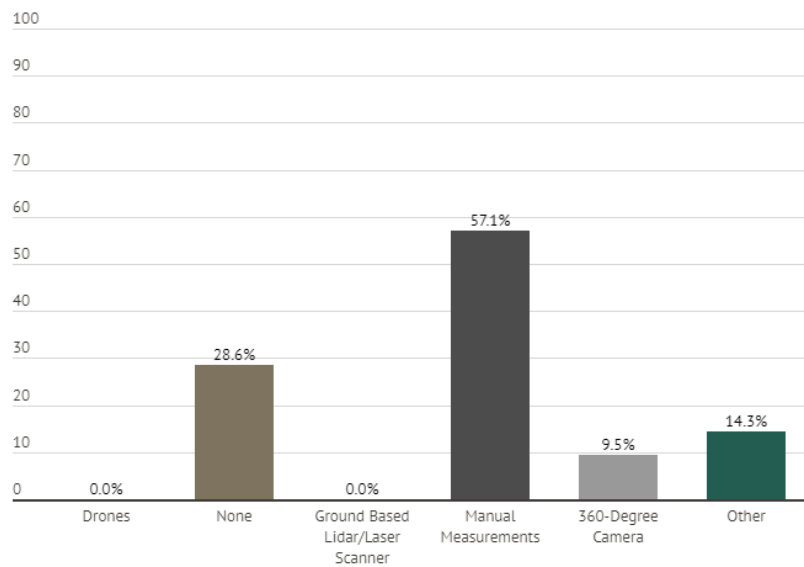
Figure 7: Methods of Documentation of Building Interiors after Construction

Other responses included:
- Building Interiors are documented during physical inspections
- As-builts
- Drawing provided by contractor

Question 7

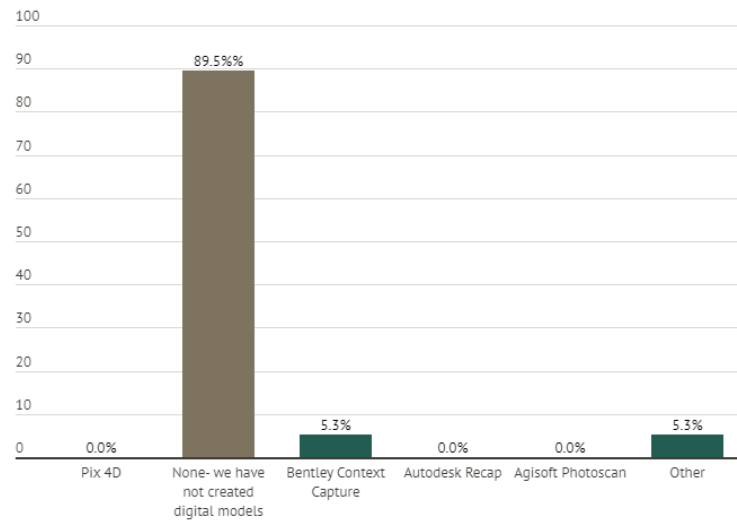What software does your organization use to create digital twins of your buildings?

Figure 8: Software Used to Create a Digital Twin of Buildings

Other responses included:

- AutoCAD

Question 8

If your organization is not currently using technology to scan your buildings do you plan on using in the future?
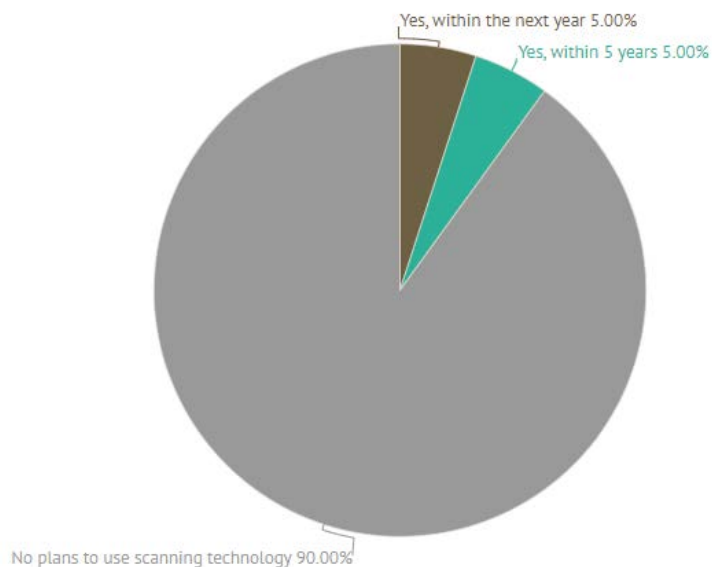

Figure 9: Percentage of Organizations that Plan on Using Technology to Scan Buildings

Question 9

What is your organization's main goal for using digital scanning for buildings? (Choose more than one answer if necessary)

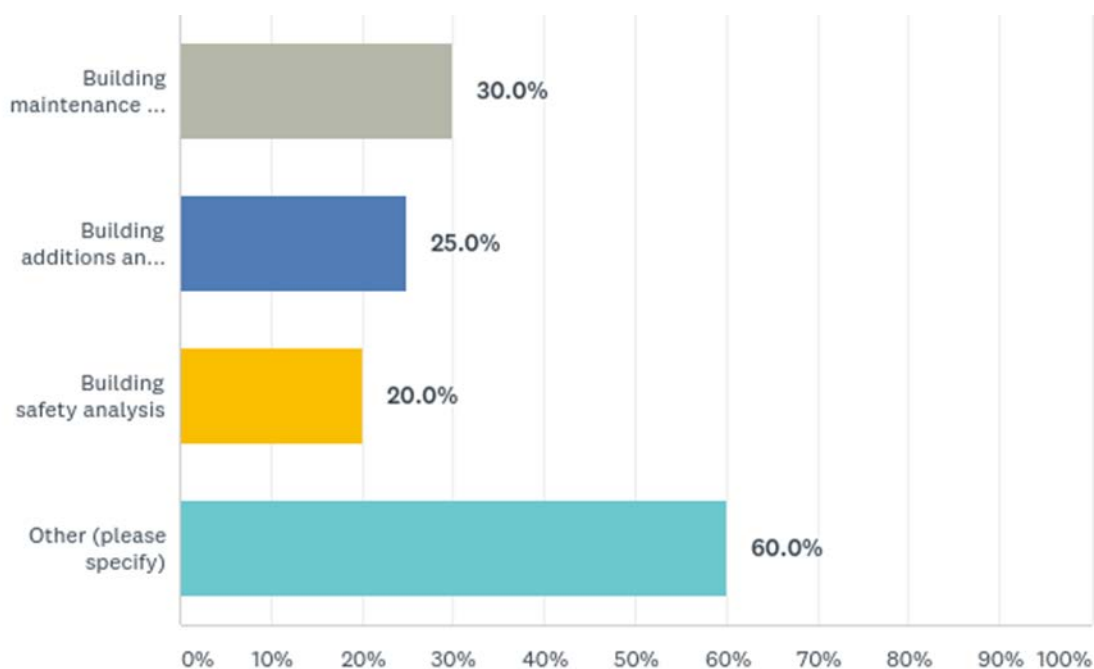| ANSWER CHOICES	RESPONSES	
Building maintenance and repair planning	30.0%	6
Building additions and modifications	25.0%	5
Building safety analysis	20.0%	4
Other (please specify)	60.0%	12
Total Respondents: 20		

Figure 10: Organization's Main Goal for Using Digital Scanning for Buildings

Other responses included:

- N/A
- No plans
- we aren't utilizing digital scanning of buildings
- existing conditions documentation
- N/A
- We do not use digital scanning of buildings but I'm curious what benefits you hope to achieve from them. Although expensive, I'm an advocate for physical inspections so CTDOT has been contracting out our building inspection assignments to the consultant community.

- Not currently panning to use digital scanning
- No current plans
- no plans for this technology
- Unaware of us moving this direction
- assessing climate controls and effect on employee environment
- N/A

Question 10

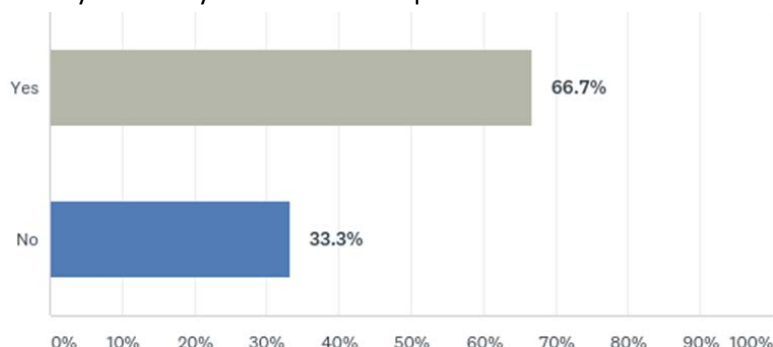Would you like to receive the survey results by email when complete?

Figure 11: Percentage of Survey Participates who want to Receive Survey Results.

Survey Conclusions

The survey respondents consisted mostly of State DOTs of which the majority manage over 500 buildings. While the technology itself has matured making implementation possible there are very few respondents using the technology and few have plans to use it in the future. Survey participants that are planning to use the technology state maintenance, repair, additions and building modifications repair as the most common goals for the technology.

Technology Review

Currently there are many technologies available to collect, process and communicate information on assets including buildings and building sites. This technology is transforming the way we manage these assets and is giving building owners the information they need to make better decisions on how to maintain, manage and improve their assets. The technology is generally hardware for collection, software for processing collected data and web-based platforms to communicate information. Below is a summary of some of the more popular technologies available.

Data Collection Hardware

There are many types of hardware available to collect building data including drones, lidar, 360 cameras, and other imaging equipment.

Drones

The use of drones to collect exterior building information has evolved quickly in recent years. The technology is well established and is underutilized but, growing in use. Purpose-built commercial drones are available that can collect data manually or with pre-programmed autonomous flights. The collected data is typically in the form of high-resolution images, but drone payloads can also include lidar. Information collected can be processed into 3D point clouds and triangular meshes that are dimensionally correct.
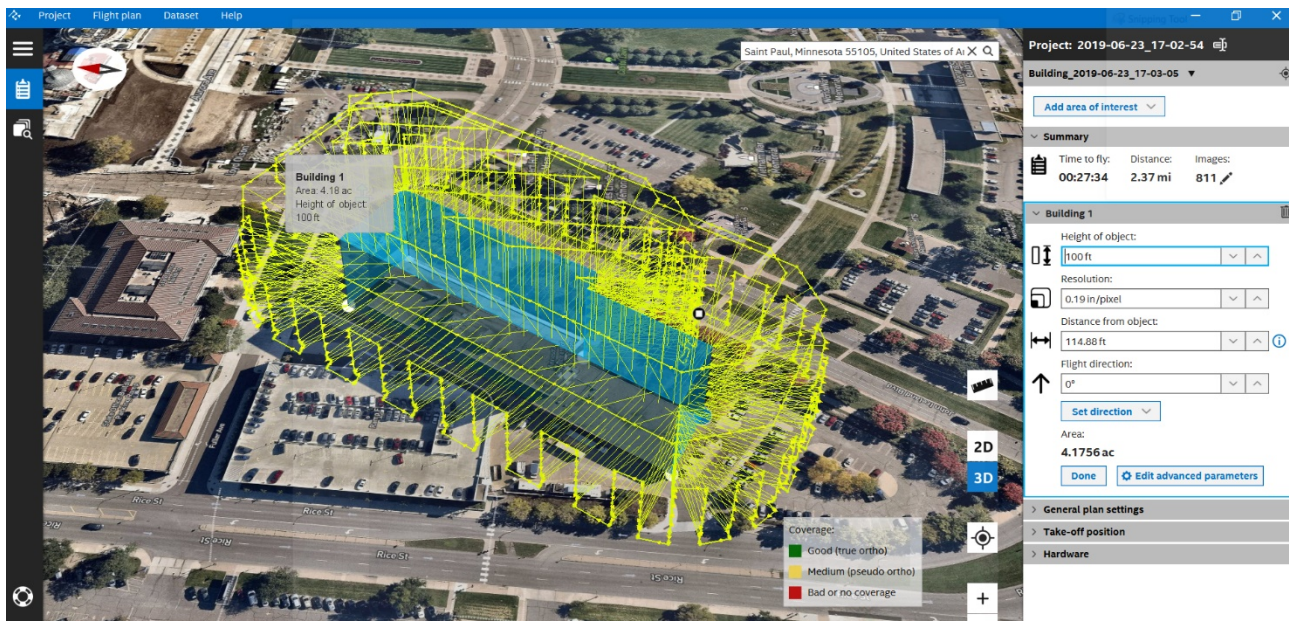

Figure 12: Intel Falcon 8+ Commercial Drone

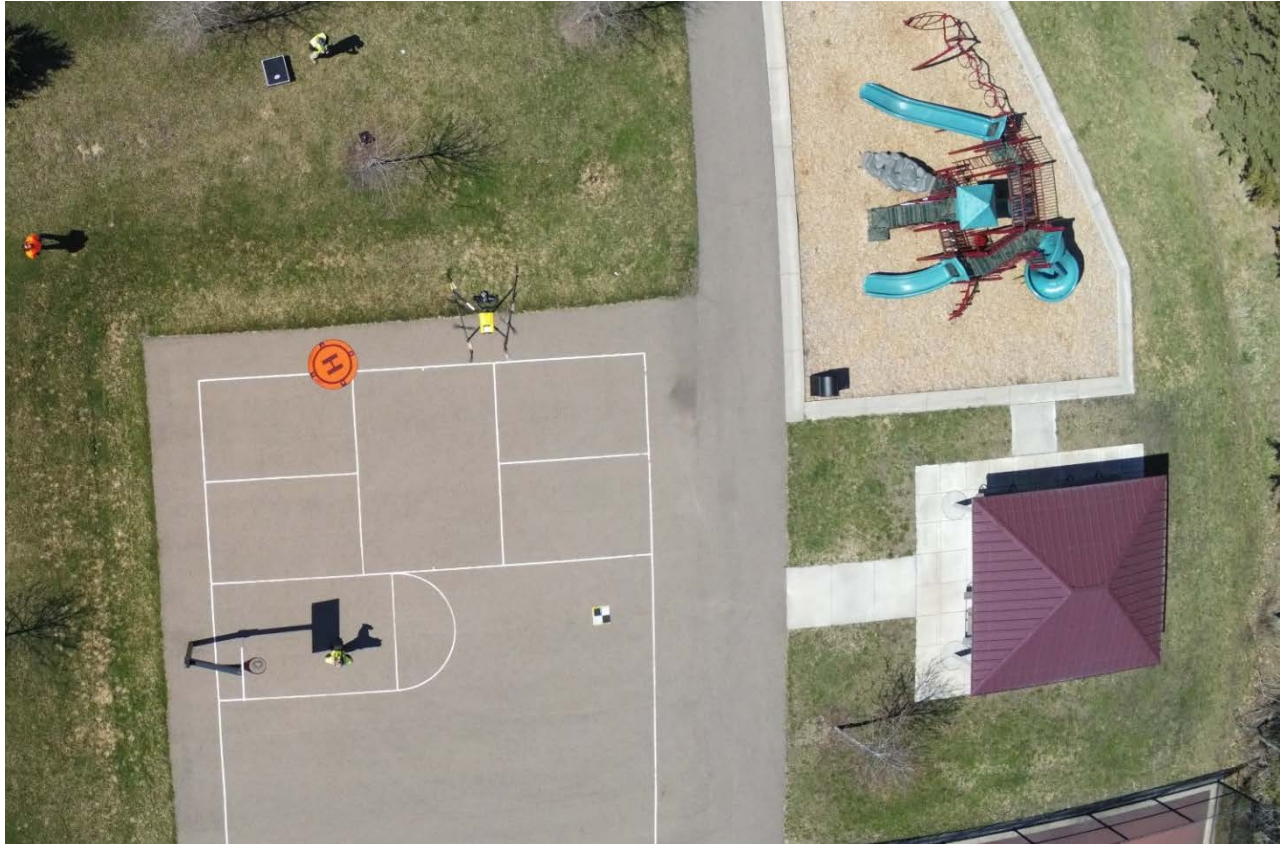*Figure 13: Autonomous Drone Flight Plan of MnDOT Central Office*

Figure 14: Commercial Drone Collecting Site Data

360 Cameras and Imaging Equipment

Consumer Grade Cameras

There are numerous 360-degree cameras on the market that can capture 360 video and images of interior spaces. These cameras can be used simply to create imagery for reference or can take images to be processed into 3D models. These cameras are generally cheap and easy to use and implement.

Professional 360 Degree Cameras

Professional level 360 imaging equipment also exists that can scan interior spaces into 3D models. Matterport is one example and the technology is popular in both the real estate industry and commercial type applications. With professional level equipment, measurements can be made, and floor plans extracted.

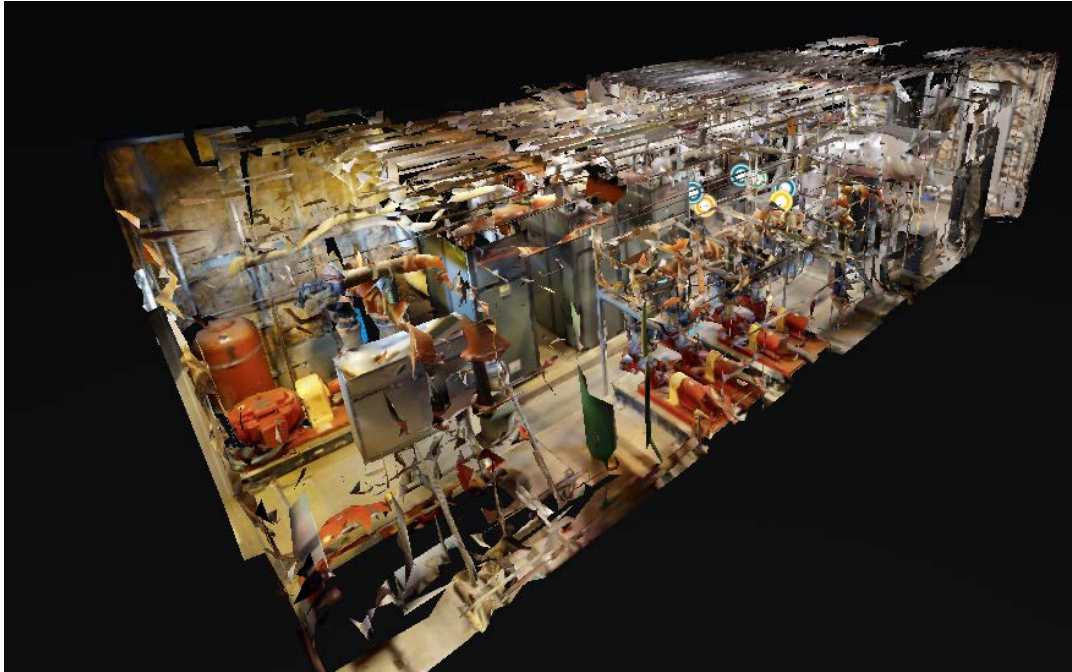*Figure 15: Ricoh Theta Z1 360 Camera*

Figure 16: Matterport 3D Scan of Interior Space

Lidar/Laser Scanning

Lidar and laser scanning are additional popular technologies that can be used to scan and model exterior and interior spaces. These technologies tend to be more expensive but produce quality professional level results.

Figure 17: Stationary and Mobile Scanners

Figure 18: Laser Scan of Building Interior

Data Processing Software

Data collection is the first step in the workflow with data processing being the next step. Data that is collected in the field generally needs to be processed into deliverables that can include 3D point clouds, 3D textures meshes, orthomosaic maps, and orthoplanes. The software platforms are typically referred to as reality modeling. There are many reality modeling platforms that are designed to process this data including but not limited to:

- Agisoft Photoscan
- Autodesk Recap
- Bentley Context Capture
- Pix4D

Figure 19: Pix4D Waikiki Natatorium Reality Model

Cloud Sharing Platforms

Building scanning is data intensive and one challenge is the ability to effectively share the information gathered in an efficient manner. Cloud hosting and sharing is one method available to quickly and efficiently share this data with stakeholders without the need to transfer large files. These platforms can process data and/or make data available for viewing and annotation.

Reality Modeling Benefits

Reality modeling has many benefits including the following:

- Reduced overall project costs
- Reduction in plan errors due to lack of adequate building information
- Improved life cycle asset management
- Improved ability to communicate asset configurations and conditions
- Decreased site visits by professional staff
- Improved ability to make data driven decisions

Limitations to reality modeling include the following:

- Start up costs for hardware and software
- Learning curve in scanning and data processing
- Increased data management needs

Conclusion

The world is changing, and these changes are being driven by big data and the ability for people to effectively use, share and to make better decisions in a wide range of industries including asset management. 360 Scanning and reality modeling is giving asset owners unprecedented information to improve project outcomes while reducing costs and decreasing errors, omissions and change orders. MnDOT should consider continuing with implementation and should consider the wide range of technologies from low cost consumer level hardware and software to more expensive professional solutions.

Lessons Learned

- There is a wide variety of scanning technologies available from low cost consumer level to higher cost professional level technologies.
- There is evidence that private sector companies are using scanning technology but little documentation is available due to no-public sector entities desire to protect their competitive advantages.
- Drone based outdoor scanning is more developed and established than indoor scanning.
- DOT's have not adopted indoor scanning technologies but have understood the benefits.
- Startup costs are a barrier to adoption for public agencies.
- Indoor scanning has the potential to decrease project costs and increase quality.
- Building scanning technology can extended beyond buildings to other applications including bridges, ancillary structures and transit structures.

Next Steps

- A research or implementation project could confirm the efficiency gains predicted for indoor scanning and could evaluate the following:
    - Hardware Costs
    - Software Costs
    - Cost Savings and Efficiencies
    - Training Requirements
- A research or implementation project would be pioneering among State DOT's and a study would benefit all DOT's and similar public agencies.
- A great deal of work has been completed as part of the MnDOT Bridge Drone Research and much of the items learned can be transferred to building scanning.

Appendix A

MnDOT 360 Degree Point Cloud Technology for Building Management

This survey was sent to state departments of transportation, other state agencies, and private corporations to examine which may have experience and/or interest in digital technology for building management.

1. Please enter the name of your organization.

2. How many buildings does your organization own and manage?
   o 0-10
   o 10-100
   o 100-500
   o Over 500

3. How does your organization store as built data? (Choose more than one if necessary.)
   o Do not have as-built data for buildings
   o Paper files
   o Electronic version of paper as-builts
   o Original CAD files
   o Post construction digital twin or reality model

4. What software is your organization using to manage their buildings?
   o Do not use building management software
   o Specify Software Package

5. What method is your organization using to document your buildings exteriors after construction? (Choose more than one answer if necessary)
   o Drones
   o None
   o Ground Based Lidar/Laser Scanner
   o Manual Measurements
   o 360 Degree Camera
   o Other

6. What method is your organization using to document your buildings interiors after construction?
   o Drones
   o Ground Based Lidar/Laser Scanner
   o None
   o Manual Measurements
   o 360 Degree Camera
   o Other

7. What software does your organization use to create digital twins of your buildings?
   o None, we have not created digital models.
   o Pix4D
   o Bentley Context Capture
   o Autodesk Recap

- o Agisoft Photoscan
- o Other (please specify)

8. If your organization is not currently using technology to scan your buildings do you plan on using in the future?
   - o Yes, within the next year.
   - o Yes, within 5 years.
   - o No plans to use scanning technology.

9. What is your organizations main goal for using digital scanning for buildings? (Choose more than one answer if necessary)
   - o Building maintenance and repair planning.
   - o Building additional and modifications
   - o Building safety analysis
   - o Other (please specify)

10. Would you like to receive the survey results by email when complete?