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RESEARCHES AND EVALUATIONS

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CONTENTS

CHAPTER 1

USE OF DIGITAL TOOLS IN DAMAGE ASSESSMENT METHODS OF EARTHQUAKES IN TÜRKIYE

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1. Introduction

Approximately 90% of earthquake-related deaths occur in developing countries. More than 80% of deaths from earthquakes in the past century occurred in nine countries, including Türkiye, Armenia, Chile, China, Guatemala, Iran, Italy, Japan, and Peru (Ozdemir et al., 2021). Since Türkiye is located on active fault lines, it frequently encounters devastating earthquakes and tremors. These earthquakes cause serious loss of life and property in various parts of the country and cause great destruction, especially in the built environment. Türkiye's neotectonic pattern is mainly controlled by the convergence of the African, Arabian, and Eurasian plates, which started in the Middle Miocene and resulted in the westward migration of the Anatolian plate. Large tectonic plates, including the Northern Anatolia, Eastern Anatolia, and Western Anatolia fault lines, are important parts of the country's geological structure (Figure 1). Earthquakes along these fault lines cause great loss of life and property and require effective damage assessment and disaster management methods. Major earthquakes experienced in recent years show that Türkiye is under serious threat from earthquake risk (Bayrak et al., 2015). Post-earthquake damage assessment is a critical stage that directly affects the efficiency of disaster management and reconstruction processes. Fast and accurate damage assessment increases the effectiveness of emergency aid and rescue efforts and enables planning long-term recovery processes (Li et al., 2023).

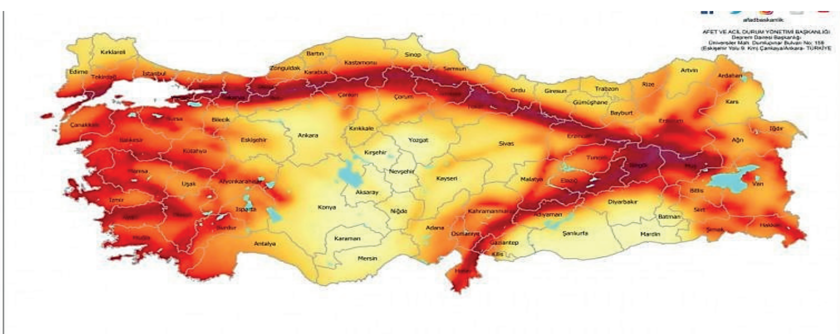


Figure 1. *Türkiye's earthquake risk rating map (AFAD, 2018)*

Field inspections and manual assessments are traditionally used in damage assessment after earthquakes. However, the inadequacy and time-consuming nature of these methods have made the integration of digital technologies mandatory (Kaplan & Kaplan, 2021). Digital technologies have brought radical changes in damage assessment processes. Tools such as remote sensing, artificial intelligence, flying robots (drones), mobile applications, and digital twin technology, which come to the fore in building construction processes and the construction industry, have significantly increased speed, accuracy and efficiency (Takva & İlerisoy, 2023; Zhang et al., 2018). These digital tools, which are also used in damage assessment methods, started with the use of aerial photographs and satellite images and developed with drones and high-resolution satellite images. Additionally, artificial intelligence and machine learning algorithms have begun to be used to automatically detect damage from these images (Figure 2). Digital transformation has been effective at all stages of disaster management. The use of digital tools in data collection, analysis, sharing, and coordination processes has provided field teams with access to real-time information and accelerated decision-making processes (Sajan et al., 2023). Mobile applications and social media have played an important role in citizens' communication of damage and assistance requests, making the processes more transparent (Eksi et al., 2014). The use of digital technologies is important in structure analysis, structural deformations, risk assessment of post-earthquake disasters, and wear of materials (Goksen et al., 2024; Takva et al., 2023). By integrating this technology into damage assessment studies, efficient results are obtained in multidisciplinary studies (Cimellaro et al., 2014).

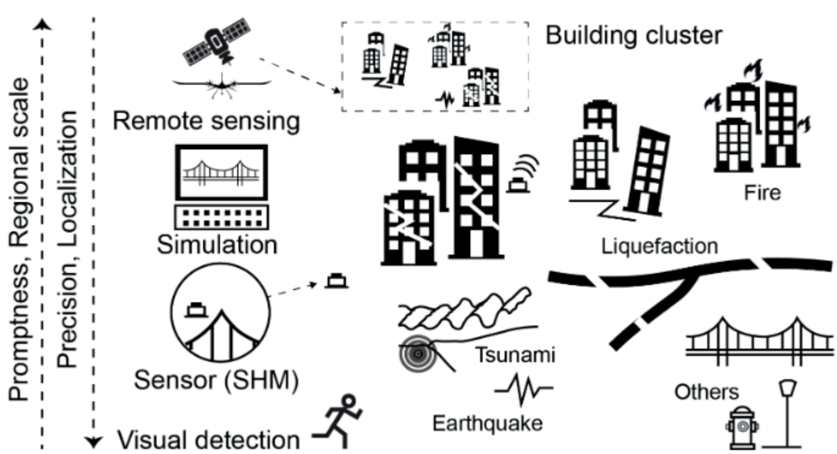


Figure 2. *Digital technologies used in damage assessment of earthquakes and post-disasters (Gu et al., 2024)*

Based on the data obtained, the effectiveness of post-earthquake damage assessment methods and the integration of digital technologies into these processes are of vital importance in the disciplines of architecture and urban planning. This study aims to examine the evolution of methods applied for damage assessment after major earthquakes in Türkiye and the impact of digital transformation on these processes. By comparing the damage detection methods used in the 1999 İzmit and Düzce earthquakes, 2003 Bingöl earthquake, 2011 Van earthquakes, 2020 Elazığ and İzmir earthquakes, and 2023 Kahramanmaraş earthquakes, the effect of digital transformation on these processes was analyzed. Literature review and case analysis methods were used in the study. The evolution of digital technologies in damage assessment and disaster management has provided important findings on how they increase the speed, accuracy, and efficiency of processes. As a result, the innovations and advantages brought by the integration of traditional methods used in damage assessment and digital technologies are discussed, and the critical role of digital transformation is emphasized by comparing the methods used after earthquakes in different periods.

2. Major Earthquakes in Türkiye

Türkiye's location in the Eastern Mediterranean is among the most active earthquake regions in the world. According to Türkiye's updated active fault maps, there are 326 separate faults, fault zones or combined systems. The longest observed fault zones are divided into separate sections according to earthquake areas. In 2020, 485 separate fault sections were identified across Türkiye that were assessed to have the potential to create seismic ground motion (Yön et al., 2020). Large earthquakes, in addition to their destructive effects, also cause air pollution. Improper disposal of debris and construction materials leads to the release of hazardous substances into the environment, posing a danger to both human health and ecological systems. Demolition vehicles (excavators, etc.) sent to the region after the earthquake also play an active role in releasing chemical substances such as dust and fuel into the air. The United Nations estimates that the 2023 Kahramanmaraş earthquakes produced at least 10 times more debris than the Izmit and Düzce earthquakes of 1999. This situation also shows the extent of air pollution (Zanoletti & Bontempi, 2024). Additionally, when the effects on public health, infrastructure, and environmental monitoring are investigated, the negative aspects of earthquakes are seen.

2.1. 1999 İzmit and Düzce Earthquakes

The 1999 İzmit (Mw 7.4) and Düzce (Mw 7.2) earthquakes are an important turning point in Türkiye's earthquake history. These earthquakes caused widespread loss of life and property and created great destruction. Post-earthquake damage assessment studies have largely relied on field surveys and manual assessments. Engineers and technical teams working in the field tried to determine the damage levels by evaluating the structural integrity of the buildings. This process has been a time-consuming and labor-intensive method (Demir et al., 2024). During field inspections, cracks in the load-bearing systems of the buildings, damage to columns and beams, collapses in walls, and floor deformations were carefully documented. In addition, infrastructure damage and road collapses formed an important part of the field investigations. These inspections are critical for quickly assessing damage and preparing emergency response plans (Dogan & Kalaylı, 2024).

Since remote sensing technologies were still in the development stage at that time, a confirmatory and complementary approach was mainly followed in damage assessment studies. The use of remote sensing techniques has been quite limited. Aerial photographs and low-resolution satellite images were used to provide an overall assessment of damage in some areas. Remote sensing techniques used in this period were generally based on comparison of pre- and post-earthquake images. With this method, it was possible to detect structural changes and destruction, especially in large areas. However, the low resolution and limited accuracy of these techniques have not been effective enough in detailed damage detection (Saatcioglu et al., 2001). Figure 3 shows the devastating effects of the 1999 earthquakes.

(a) (b)

Figure 3. *1999 İzmit earthquake; (a) top view, (b) damage to the building structure (Scawthorn & Johnson, 2000)*

2.2. 2003 Bingöl Earthquake

The 2003 Bingöl Earthquake (Mw 6.4) was an important turning point in the digitalization process of damage assessment methods in Türkiye. In this earthquake, aerial photographs and satellite images were used more widely and effectively compared to previous periods. After the Bingöl earthquake, especially high-resolution aerial photographs and satellite images played a critical role in damage assessment and assessment studies (Işık et al., 2021). Aerial photographs were used to provide an overview of structural damage in post-earthquake areas. These photographs facilitated rapid inspection of large areas and determination of the general distribution of damage (Adams & Huyck, 2006). Figure 4 shows the effect of the earthquake.

Satellite images were used for more detailed analysis and were effective in detecting damages, especially in rural areas. During the 2003 Bingöl Earthquake, the use of Geographic Information Systems (GIS) technology also increased significantly (Doğangün, 2004). GIS has been used as a powerful tool to analyze, map, and visualize post-earthquake data. Within the scope of damage assessment studies, various data such as building damages, infrastructure damages, and ground deformations were combined and analyzed on the GIS platform (Aydın et al., 2024). GIS technology has increased the speed and accuracy of damage assessment studies and also facilitated data sharing and coordination. Thanks to this technology, data sharing between different institutions and teams has been carried out more effectively and it has been possible to obtain damage assessment results more quickly (Korkmaz, 2010).

(a) (b)

Figure 4. *2003 Bingöl earthquake; (a) the appearance resulting from the collapse of buildings, (b) the damage left on the building structure (Doğangün, 2004)*

2.3. 2011 Van Earthquakes

The earthquakes (Mw 7.2 and Mw 5.6) that occurred in Van province in 2011 represent an important stage in the digital transformation of damage assessment methods in Türkiye. During this period, digital data collection and analysis methods were at the center of damage assessment studies. Damage data was collected and analyzed quickly and accurately, especially by using digital data collection tools and software during field inspections (Eksi et al., 2014). Field teams collected data through digital forms and GPS-based applications, using mobile devices such as tablets and smartphones to assess damage. This method enabled data to be instantly transmitted to a central database and analyzed, thus significantly increasing the speed and accuracy of damage detection (Işık et al., 2018). Figure 5 shows the size of the earthquake.

During the 2011 Van earthquakes, social media platforms also played an important role in damage assessment and disaster management processes. Social media was used as an effective communication tool for the public to quickly communicate their situation and needs after the earthquake. Information shared through platforms such as Twitter and Facebook has helped disaster management teams respond quickly and effectively (Kadak et al., 2013). Social media data has played an integral role in damage assessment and needs analysis. Photos and videos shared by citizens contributed to the visual documentation of the damage, and these data supported official damage assessment efforts. In addition, information collected via social media allowed instant monitoring of the situation in the field and updating of intervention plans (Damcı et al., 2015).

(a) (b)

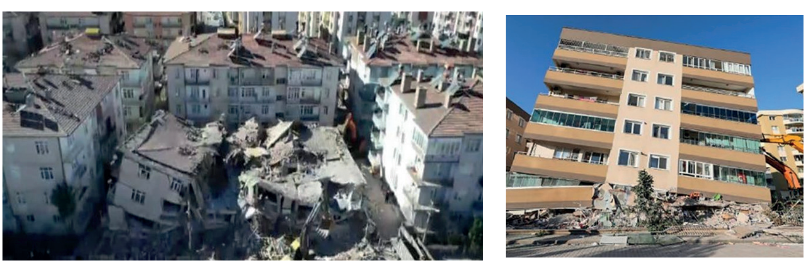
Figure 5. *2011 Van earthquakes; (a) soft storey irregularity, (b) inability of the building structure to withstand earthquake loads (Damcı et al., 2015)*

2.4. 2020 Elazığ and İzmir Earthquakes

The Elazığ (Mw 6.8) and İzmir (Mw 6.9) earthquakes that occurred in 2020 showed that digital technologies are further developed and disseminated in damage assessment processes in Türkiye (Caglar et al., 2023; Yakut et al., 2021). During these earthquakes, advanced digital technologies and innovative methods were used in damage assessment. In particular, high-resolution satellite images, drones and artificial intelligence-supported analyses have played an important role in damage assessment studies. Drones have emerged as a revolutionary innovation in post-earthquake damage assessment. During the Elazığ and İzmir earthquakes, drones were used to visualize the damaged areas quickly and in detail. This method allowed data to be collected quickly and safely, especially in hard-to-reach areas and areas where major destruction occurred (Karakas et al., 2021).

High-resolution satellite images also played a critical role in damage assessment. Satellite images enabled rapid assessment of large areas and determination of the general distribution of damage. These images have been analyzed with artificial intelligence and machine learning algorithms, allowing automatic damage detection and increasing the speed and accuracy of these processes (Saralioglu, 2022). These technologies have significantly increased the speed of damage detection and minimized human errors. In particular, artificial intelligence algorithms have determined the structural conditions and damage levels of buildings by quickly analyzing large data sets. This has helped field teams make accurate and rapid decisions and prepare emergency response plans effectively (Sünbül & Soyluk, 2024).

During the Elazığ and İzmir earthquakes, mobile applications and social media platforms played an important role in damage assessment and disaster management processes. Citizens reported damage via mobile applications and this information was transmitted to central databases and analyzed. This method enabled teams in the field to quickly access information and organize response plans accordingly. Social media has been used as an effective communication tool for citizens to quickly communicate their situation and needs, which has helped disaster management teams respond more effectively (Ağrali et al., 2022). Figure 6 shows the effects of earthquakes on buildings.



(a) (b)

Figure 6. *Earthquakes in 2020; (a) Elazığ earthquake (Dogan et al., 2021), (b) İzmir earthquake (Demirci et al., 2022)*

2.5. 2023 Kahramanmaraş Earthquakes

The earthquakes (Mw 7.7 and Mw 7.6) that occurred in Kahramanmaraş in 2023 were an important example of how digital technologies can be used further in damage assessment and disaster management. During these earthquakes, damage assessment processes were carried out using the latest digital technologies and methods, in the light of information obtained from previous experiences. In particular, Unmanned Aerial Vehicles (UAVs), artificial intelligence and machine learning algorithms, high-resolution satellite images, and internet-based data collection platforms have played important roles (Ersoz et al., 2024).

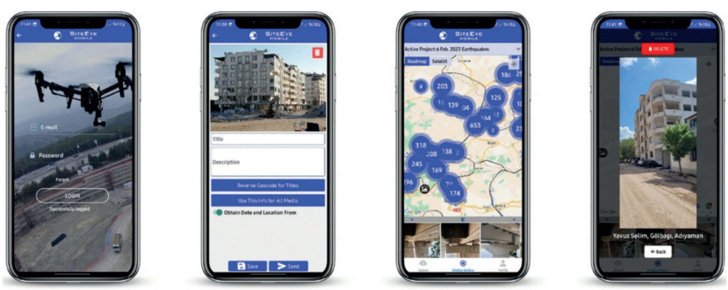
UAVs have enabled rapid and detailed mapping of damaged areas after the earthquake. These devices have been used to determine the extent and extent of damage by taking high-resolution images. Thanks to UAVs, data can be collected quickly and safely even in areas where field teams cannot reach or in dangerous areas. The use of artificial intelligence and machine learning algorithms has brought great innovations in damage detection processes. Algorithm-based systems have enabled automatic detection and classification of damage by analyzing data obtained from satellite images and UAVs. These systems used image processing techniques to determine the extent of damage, thus minimizing human errors (Ekmen & Avci, 2024).

In the 2023 Kahramanmaraş earthquakes, internet-based data collection platforms and mobile applications also became important components of damage assessment processes. Citizens reported damage through these platforms and this information was transmitted to central databases and analyzed. This method allowed field teams to collect damage data in a standard format and correlate it with GPS coordinates. In this way, it has become easier to geographically map and analyze the collected data. Additionally, these technologies have increased the speed and accuracy of data collection and sharing processes (Ayso et al., 2024). Figure 7 shows the magnitude of the earthquake.

Figure 7. *Collapse of a building as a result of the 2023 Kahramanmaraş earthquakes (Mertol et al., 2023)*

3. The Effect of Digital Transformation on Damage Detection Methods and Comparison of Damage Detection Methods

The rapid development of digital technologies in recent years has led to major changes in damage detection methods. Digital transformation has made significant contributions by providing faster, accurate and effective solutions in disaster management and damage assessment processes. In particular, the integration of technologies such as big data analytics, artificial intelligence, machine learning, unmanned aerial vehicles, high-resolution satellite images, and social media has made it possible for these processes to become more efficient (Ersoz et al., 2024). Big data analytics allows large data sets to be analyzed quickly and effectively, providing detailed information about the extent and extent of damage. Artificial intelligence and machine learning algorithms analyze data obtained from satellite images and unmanned aerial vehicles, making it possible to automatically detect and classify damage. These technologies help prepare response plans effectively by increasing the speed and accuracy of the damage assessment process and minimizing human errors. Mobile applications and internet-based data collection platforms are also important components of damage assessment processes (Figure 8). Photos and videos shared by citizens contribute to the visual documentation of damage, and this data allows instant monitoring of the situation on the field and updating response plans (Calantropio et al., 2021).



(a) Login Screen (b) Data Upload (c) Interactive Map (d) Data Visualization

Figure 8. *Use of mobile applications in damage detection applications (Ersoz et al., 2024)*

Comparison of damage assessment methods is important to understand the effectiveness of the methods applied after various earthquakes and the innovations brought by digital technologies. During the 1999 İzmit and Düzce earthquakes, damage assessment largely relied on traditional methods. Site surveys were carried out manually by engineers and experts, and data took time to collect and analyze (Dogan & Kalaylı, 2024). Traditional methods were also used in the 2003 Bingöl earthquake, but computer-based data analysis systems began to come into play. This allowed the data to be processed in a more systematic way (Aydın et al., 2024). During the 2011 Van earthquakes, the use of mobile technologies and GPS increased, data collection processes for damage assessment accelerated and the use of GIS became widespread. The use of digital mapping techniques also began in this period (Işık et al., 2018).

In the 2020 Elazığ and İzmir earthquakes, digital technologies were applied more widely. Drones and high-resolution satellite images have been used in damage assessment studies, and artificial intelligence and machine learning algorithms have been developed. Mobile applications and social media have made it easier for the public to report damage, enabling disaster management teams to respond quickly (Sünbül & Soyluk, 2024). Advanced digital technologies were used in the 2023 Kahramanmaraş Earthquakes. UAVs, high-resolution satellite images and artificial intelligence algorithms have played an important role in damage detection. Internet-based data collection platforms, mobile applications and social media have also been effective in disaster management (Ersoz et al., 2024).

Digital transformation has greatly changed damage detection methods. While traditional methods were time-consuming and error-prone, digital technologies have accelerated processes and increased accuracy. Digital technologies have enabled rapid collection and analysis of data. Artificial intelligence and machine learning algorithms have minimized human errors and reduced error bias in damage detection. Digital platforms have enabled disaster management teams to work more effectively by facilitating data sharing and coordination. Social media and mobile applications have increased awareness and accelerated feedback processes. Key advantages provided by digital technologies include rapid data collection and analysis, high accuracy and reliability, data sharing and coordination, public participation, and feedback. Table 1 shows the damage assessment methods applied after the earthquakes that occurred in 1999, 2003, 2011, 2020, and 2023.

Table 1. *Damage detection methods applied in earthquakes*

Earthquake	Damage Detection Method	Use of Digital Technologies	Advantage	Disadvantage
1999-İzmit and Düzce	Traditional field surveys, manual data collection	None	Real data collection	Slow and error prone, limited scope
2003-Bingöl	Traditional methods, computer-based data analysis systems	With manual control	Systematic data processing	Slow, limited digital integration
2011-Van	Mobile technologies, GPS, GIS	With manual control	Rapid data collection, digital mapping	Limited technology infrastructure, data processing problems
2020-Elazığ ve İzmir	Drones, satellite images, artificial intelligence and machine learning algorithms, mobile applications, social media	With manual and automatic control	Fast and accurate analysis, wide coverage	Data management challenges, high cost
2023-Kahramanmaraş	UAVs, high-resolution satellite images, artificial intelligence and machine learning algorithms, internet-based platforms, social media	With manual and automatic control	Very fast and accurate analysis, extensive data sharing, and coordination	Data security and privacy concerns, high technology addiction

4. Conclusion

In this study, the development of methods used for damage assessment after major earthquakes in Türkiye, from the 1999 İzmit and Düzce earthquakes to the 2023 Kahramanmaraş earthquakes, and the effect of digital transformation on these processes were examined. The analyses reveal that with the integration of digital technologies, significant improvements have been made in damage detection processes. The time-consuming and error-prone nature of traditional methods has been replaced by faster, more accurate, and more effective systems with digital transformation.

In the future, wider and more effective use of digital technologies in damage assessment and disaster management will play a critical role in increasing social awareness. In this context, the development of artificial intelligence and machine learning applications and the integration of these technologies into damage assessment processes and the effective use of unmanned aerial vehicles and satellite images are important. In addition, it is necessary to disseminate mobile applications and internet-based data collection methods, increase social media and public participation, intensify education and awareness activities, and strengthen the technological infrastructure. Further development of artificial intelligence and machine learning algorithms will increase the accuracy and speed of data analysis. The ability of these technologies to perform real-time data analysis will help disaster response teams make fast and accurate decisions and significantly improve response processes.

However, in order to use digital technologies effectively, disaster management teams and relevant personnel must receive training on these technologies. Regular training programs and awareness-raising activities will ensure the correct and efficient use of technological developments. To successfully implement digital transformation, it is important to strengthen and constantly update the necessary technological infrastructure. This will contribute to more effective damage assessment and disaster management processes. Additionally, public and private sector collaborations and encouraging international collaborations will support digital technologies to provide innovative solutions in disaster management. As a result, artificial intelligence and machine learning applications, unmanned aerial vehicles and satellite images, mobile applications and internet-based data collection, social media and public participation, education and awareness-raising activities, and strengthening of technological infrastructure are recommended. These recommendations offer strategies for more effective use of digital technologies in post-earthquake detection studies.

References

Adams, B. J., & Huyck, C. K. (2006). The emerging role of remote sensing technology in emergency management. *Infrastructure Risk Management Processes: Natural, Accidental, and Deliberate Hazards*, *1*, 95.

AFAD. (2018). Türkiye's earthquake risk rating map, https://en.afad.gov.tr/turkeys-new-earthquake-hazard-map-is-published, Last Accessed Date: 17.11.2024.

Ağrali, Ö., Sökün, H., & Karaarslan, E. (2022). Twitter data analysis: Izmir earthquake case. *Journal of Emerging Computer Technologies*, *2*(2), 36-41.

Aydın, M. C., Birincioğlu, E. S., Büyüksaraç, A., & Işık, E. (2024). Earthquake Risk Assessment Using GIS-Based Analytical Hierarchy Process (AHP): The Case of Bitlis Province (Türkiye). *International Journal of Environment and Geoinformatics*, *11*(1), 1-9.

Ayso, E., Köz, İ., Doğanalp, S., Aslan, M., Tuşat, E., Kahveci, M., & Taşpınar, C. (2024). Assessing the impact of the 2023 Kahramanmaraş and Hatay earthquakes on cadastre and property data using GPS and GIS. *Bulletin of Earthquake Engineering*, 1-19.

Bayrak, E., Yılmaz, Ş., Softa, M., Türker, T., & Bayrak, Y. (2015). Earthquake hazard analysis for East Anatolian fault zone, Turkey. *Natural Hazards*, *76*, 1063-1077.

Caglar, N., Vural, I., Kirtel, O., Saribiyik, A., & Sumer, Y. (2023). Structural damages observed in buildings after the January 24, 2020 Elazığ-Sivrice earthquake in Türkiye. *Case Studies in Construction Materials*, *18*, e01886.

Calantropio, A., Chiabrando, F., Codastefano, M., & Bourke, E. (2021). Deep learning for automatic building damage assessment: application in post-disaster scenarios using UAV data. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *1*, 113-120.

Cimellaro, G. P., Scura, G., Renschler, C. S., Reinhorn, A. M., & Kim, H. U. (2014). Rapid building damage assessment system using mobile phone technology. *Earthquake Engineering and Engineering Vibration*, *13*, 519-533.

Damcı, E., Temur, R., Bekdaş, G., & Sayin, B. (2015). Damages and causes on the structures during the October 23, 2011 Van earthquake in Turkey. *Case Studies in Construction Materials*, *3*, 112-131.

Demir, A., Günay, S., Marinković, M., Dilsiz, A., Bektaş, N., Khalil, Z., ... & Sezen, H. (2024). 2022 Düzce, Türkiye earthquake: advances in the past 2 decades, lessons learned, and future projections. *Bulletin of Earthquake Engineering*, 1-28.

Demirci, H. E., Karaman, M., & Bhattacharya, S. (2022). A survey of damage observed in Izmir due to 2020 Samos-Izmir earthquake. *Natural Haz-*

ards, *111*(1), 1047-1064.

Dogan, G., Ecemis, A. S., Korkmaz, S. Z., Arslan, M. H., & Korkmaz, H. H. (2021). Buildings damages after Elazığ, Turkey earthquake on January 24, 2020. *Natural hazards*, *109*(1), 161-200.

Dogan, O., & Kalaylı, M. A. (2024). 17 Ağustos 1999 Kocaeli Depreminde Adapazarı Şehir Merkezinde Devrilen Binaların Devrilmeye Karşı Optimum Yükseklik/Genişlik Oranının Belirlenmesi. *Politeknik Dergisi*, *27*(1), 59-68.

Doğangün, A. (2004). Performance of reinforced concrete buildings during the May 1, 2003 Bingöl Earthquake in Turkey. *Engineering Structures*, *26*(6), 841-856.

Eksi, A., Çelikli, S., & Kiyan, G. S. (2014). The effects of social networking on disaster communication used by the emergency medical and rescue staff-the case of the Van Earthquake. *Eurasian Journal of Emergency Medicine*, *13*(2), 58.

Ersoz, A. B., Pekcan, O., Altun, M., Teke, T., & Aydogmus, O. (2024). Utilizing digital technologies for rapid damage assessment and reconnaissance: the February 6, 2023 Kahramanmaraş-Türkiye earthquakes (Mw 7.7 and Mw 7.6). *Bulletin of Earthquake Engineering*, 1-19.

Goksen, F., Takva, C., Takva, Y., & Ilerisoy, Z. Y. (2024). Post-earthquake fires: risk assessment and precautions. *Mehran University Research Journal Of Engineering & Technology*, *43*(1), 1-16.

Gu, J., Xie, Z., Zhang, J., & He, X. (2024). Advances in Rapid Damage Identification Methods for Post-Disaster Regional Buildings Based on Remote Sensing Images: A Survey. *Buildings*, *14*(4), 898.

Işık, E., Harirchian, E., Büyüksaraç, A., & Levent Ekinci, Y. (2021). Seismic and structural analyses of the eastern anatolian region (Turkey) using different probabilities of exceedance. *Applied System Innovation*, *4*(4), 89.

Işık, M. F., Işık, E., Bülbül, M. A. (2018). Application of iOS/Android based assessment and monitoring system for building inventory under seismic impact. *Gradjevinar*, *70*(12), 1043-1056.

Kadak, M. T., Nasıroğlu, S., Boysan, M., & Aydın, A. (2013). Risk factors predicting posttraumatic stress reactions in adolescents after 2011 Van earthquake. *Comprehensive psychiatry*, *54*(7), 982-990.

Kaplan, O., & Kaplan, G. (2021). Response spectra-based post-earthquake rapid structural damage estimation approach aided with remote sensing data: 2020 samos earthquake. *Buildings*, *12*(1), 14.

Karakas, G., Nefeslioglu, H. A., Kocaman, S., Buyukdemircioglu, M., Yurur, T., & Gokceoglu, C. (2021). Derivation of earthquake-induced landslide distribution using aerial photogrammetry: the January 24, 2020, Elazig (Turkey) earthquake. *Landslides*, *18*(6), 2193-2209.

Korkmaz, K. A. (2010). Integrated seismic hazard evaluation and disaster management approach for Turkey. *Environmental Earth Sciences*, *61*, 467-476.

Li, S., Wang, X., Tao, T., Zhu, Y., Qu, X., Li, Z., ... & Song, S. (2023). Source model of the 2023 Turkey earthquake sequence imaged by Sentinel-1 and GPS measurements: Implications for heterogeneous fault behavior along the East Anatolian Fault Zone. *Remote Sensing*, *15*(10), 2618.

Mertol, H. C., Tunç, G., Akış, T., Kantekin, Y., & Aydın, İ. C. (2023). Investigation of RC buildings after 6 February 2023, Kahramanmaraş, Türkiye earthquakes. *Buildings*, *13*(7), 1789.

Ozdemir, R., Demir, C., & Catak, B. (2021). Faculty members' earthquake preparedness levels and their related factors: a cross-sectional study from a university in a high-risk earthquake zone in Turkey. *Journal of injury and violence research*, *13*(2), 151.

Saatcioglu, M., Mitchell, D., Tinawi, R., Gardner, N. J., Gillies, A. G., Ghobarah, A., ... & Lau, D. (2001). The August 17, 1999, Kocaeli (Turkey) earthquake damage to structures. *Canadian Journal of Civil Engineering*, *28*(4), 715-737.

Scawthorn, C., & Johnson, G. S. (2000). preliminary report: Kocaeli (Izmit) earthquake of 17 August 1999. *Engineering Structures*, *22*(7), 727-745.

Sajan, K. C., Bhusal, A., Gautam, D., & Rupakhety, R. (2023). Earthquake damage and rehabilitation intervention prediction using machine learning. *Engineering Failure Analysis*, *144*, 106949.

Saralioglu, E. (2022). Mapping surface deformation using SNAP-StaMPS after Seferhisar-Izmir earthquake. *Natural Hazards*, *111*(1), 687-708.

Sünbül, G., & Soyluk, A. (2024). A review of using deep learning technology in the built environment of disaster management phases. *Journal of Architectural Sciences and Applications*, *9*(Special Issue), 201-218.

Takva, Ç., & İlerisoy, Z. Y. (2023). Flying Robot Technology (Drone) Trends: A Review in the Building and Construction Industry. *Architecture, Civil Engineering, Environment*, *16*(1), 47-68.

Takva, Y., Takva, C., & Goksen, F. (2023). A Contemporary House Proposal: Structural Analysis of Wood and Steel Bungalows. *Engineering, Technology & Applied Science Research*, *13*(3), 11032-11035.

Yakut, A., Sucuoğlu, H., Binici, B., Canbay, E., Donmez, C., İlki, A., ... & Ay, B. Ö. (2021). Performance of structures in İzmir after the Samos island earthquake. *Bulletin of Earthquake Engineering*, 1-26.

Yön, B., Onat, O., Öncü, M. E., & Karaşin, A. (2020). Failures of masonry dwelling triggered by East Anatolian Fault earthquakes in Turkey. *Soil Dynamics and Earthquake Engineering*, *133*, 106126.

Zanoletti, A., & Bontempi, E. (2024). The impacts of earthquakes on air pollution and strategies for mitigation: a case study of Turkey. *Environmental Sci-*

ence and Pollution Research, *31*(16), 24662-24672.

Zhang, Y., Burton, H. V., Sun, H., & Shokrabadi, M. (2018). A machine learning framework for assessing post-earthquake structural safety. *Structural safety*, *72*, 1-16.

CHAPTER 2

INVESTIGATION OF THE USE OF LOCAL MATERIALS IN HISTORICAL BUILDINGS: THE CASE OF AYVALIK

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1. Introduction

Dating back to the 19th century and later, Ayvalık, together with the settlements of Cunda (Alibey), Küçükköy and Altınova, has a significant built environment and cultural heritage potential. It became one of the prominent port and industrial settlements of Western Anatolia in the 19th century with its economic activities such as olive oil industry and maritime trade. Many new buildings were constructed in parallel with this development. Many types of buildings such as residences, schools, churches, factories, hotels, shops, casinos and banks have survived from that period. Almost all of the masonry buildings were constructed using stone materials extracted from the region. Considering their authenticity and historical document value, it is clear that these buildings should be preserved.

In the Nara Document on Authenticity published by the International Council on Monuments and Sites (ICOMOS) in 1994, the authenticity of a monument is linked to its incorporation of various sources of information. These sources of information are defined as *'design and form, materials and objects, use and function, traditions and techniques, location and setting, spirit and expression, and historical evolution'.* (ICOMOS, 1994). The material that are part of these values contain technological, historical, and artistic information related to the period of the structure in which they are used. Determining the properties of historical building materials and their production technologies is essential not only for documenting the structure as cultural heritage but also for its preservation. (Uğurlu ve Böke, 2009). In addition, the use of local materials in historical buildings stands out as one of the factors that determine the identity of historical buildings and increase their sustainability.

To date, scientific studies conducted on Ayvalık in the fields of architecture and related disciplines have primarily focused on the architectural features of these historical structures and the region's tourism potential. However, it is noteworthy that there are few studies on building materials that add aesthetic integrity to the physical environment created by historical buildings. The main problem of this study is that the structural features and the reasons for the preference of *'sarımsak taşı'*, which is a local building material, are insufficiently addressed in the studies. In this study, the use of *'sarımsak taşı'* the traditional residences, religious-monumental buildings and commercial buildings that constitute the historical texture of Ayvalık was investigated.

2. Ayvalık ve Historical Buildings

Ayvalık, a district of Balıkesir Province in the Marmara and Aegean Regions of Turkey, is located at the southern end of the Edremit Gulf and on the Aegean Sea Coast (Figure 1) (Altıner ve Kelkit, 2020). Ayvalık appears as an agricultural and coastal settlement in its historical process. The old name of Ayvalık, which was the agricultural inland region of the city-state of Lesbos in the Ancient Period, is Kydonies. Until the 1770s, the settlement of Ayvalık was considered a small coastal town, but it experienced rapid development in the last quarter of the 18th century (Arıkan, 1988). This development occurred due to the increasing demand for olive oil in Istanbul and European countries during the 18th century (Erim, 1948). After this date, economic activities and population movements began to increase, and a new urban fabric started to emerge in the settlement with its civil and religious architectural content (Bayraktar, 2002). The movement of the social structure in the historical process has left traces on the city skyline. Documents from the period after the 1850s, when the settlement began to strengthen economically, reveal that the urban fabric of the settlement includes industrial and commercial buildings, residential architecture, religious buildings, consulates, and institutional buildings such as hospitals and schools, as well as architecture with different functions and forms (Figure 2) (Yorulmaz, 1994).

Figure 1: *Location of Ayvalık (Google earth, e.t. 21.11.2024)*

Figure 2: *Ayvalık in 1904 (İBB archive, e.t: 21.11.2024)*

Traditional Houses

19th century traditional residences, which have an important place in the urban fabric, were shaped by the economic, political, social and cultural background of the period (Tekeli, 1992). When they were first built, the houses were inhabited by citizens of Greek origin, and although the users changed after the exchange in the second half of the 19th century, they continued to be the carrier elements of the urban fabric. The traditional houses, which have an important place in the formation of the historical identity of the city, have survived to the present day and still maintain their potential for use. The other reason why they have been preserved and survived to the present day is that the boundaries of the urban protected area of Ayvalık urban fabric have been determined. With the decision of the *Gayrimenkul Eski Eserler ve Anıtlar Yüksek Kurulu* (GEEAYK) dated 19.06.1976 and numbered 160, Ayvalık was given legal protection status as a natural and historical area in need of protection (Balıkesir KTVKBK archive).

Traditional houses are generally built in adjoining order, with one or two storeys above ground, using masonry construction system and stone material. The use of backyard-courtyard is common in houses with entrances directly from the street. Houses located on corner plots can open to the street on both sides. There are types with and without overhangs in the façade layout (Figure 3). When the façade layout is examined in detail, it can be said that the fact that the first users of the houses were non-Muslims or Levantines has an effect on the façade layout, design and ornamentation programme. It is understood that the plans of the residential buildings were designed according to the needs and lifestyle. Based on the fact that the common architectural language can be read throughout the city, it is possible to say that there is a regular construction in the settlement.

Figure 3: Ayvalık traditional houses

Religious- Monumental Buildings

The monumental religious buildings of the city are the churches built by non-Muslims, the users of the city, after the 18th century in locations dominating the silhouette of the city and playing an active role in the formation of the historical texture. Some of the churches, monasteries and chapels that have survived to the present day are as follows. Taxiarchis Church, Kato Panayia Church (Hayrettin Pasha Mosque), Hagios Goannes Church (Clock Mosque), Hagios Georgios Church (Çınarlı Mosque), Hagia Triada Church, Faneromeni (Ayazma) Church and Portaitissa Church (Figure 4). This builgdings in Ayvalık City centre. These monumental structures, which exhibit the architectural features of the neo-classical style as a reflection of the art environment of the 18th and 19th centuries, are considered as the continuation of the Byzantine Churches, but they also create their own architectural style by being influenced by the local architecture (Güney ve Uçar, 2010). It is observed that most of these buildings were used for functions different from their original functions after the exchange and some of them were left empty. The Church of Taxiarchis is currently functioned as a memorial museum. The inscription at the entrance of the church, which is thought to have 3 different construction periods, states that the construction was completed in 1844. The church has a simple mass and plan organisation and draws attention with its spatial character and Greek Period decorations decorating the interior. (Uçar, 2013). Kato Panayia Church, Hagios Goannes Church and Hagios Georgios Church function as mosques. Today, Faneromeni (Ayazma) Church is also exhibited as a museum with its original plan scheme. Hagia Triada Church is in ruins and restoration works have been started. In addition to the Greek-Orthodox churches, the Hamidiye Mosque, the only mosque built in Ayvalık during the Ottoman period, was built by Sultan Abdülhamit for the Muslims living in Ayvalık and is a special building that attracts attention with its different architecture.

Figure 4: (a) Taxiarchis Church - (b) Kato Panayia Church (Hayrettin Pasha Mosque) - (c) Hagios Goannes Church (Saatli Mosque) - (d) Hagios Georgios Church (Çınarlı Mosque) - (e) Hagia Triada Church - (f) Faneromeni (Ayazma) Church

Commercial and Industrial Buildings

In 19th century Ayvalık, an important commercial and educational centre, Greeks built olive oil factories, soap factories, schools, shops and warehouses reflecting their social, economic and cultural level. In addition, flour mills and tanneries built on the seafront are among the buildings constructed for commercial purposes. The shops, which constitute the most crowded building group in the urban fabric after the residential architecture, have made ayvalık one of the bustling harbour settlements with its industrial and commercial activities. these buildings allow the evaluation of the trade potential and the architectural identity of the city to be read (Akın Akbüber, 2020). The fact that the shops were taken under protection together with the houses has enabled them to survive until today. However, most of these buildings were abandoned because they could not meet the comfort demands of the new users. Restoration works have recently started for many of the abandoned shops (Figure 5).

The most intensive trade in the region during the period was olive oil and soap production. In this context, the previously small enterprises were replaced by factories where industrial production would be carried out to a large extent with the introduction of steam power. The machines operated by steam boilers increased the production capacity and accelerated imports. At the same time, locally small enterprises continued to produce. Ayvalık's commercial building stock, which incorporates a wide range of commercial buildings ranging from undivided, square or rectangular shops to olive oil factories, which are the smallest unit of the bazaar texture, is considered as industrial heritage (Fig 6)

Figure 5: *Typical non-used shop examples (Akın Akbüber, 2020).*

Figure 6: *Olive oil production facilities of different scales*

3. Geology of Ayvalık and Local Material Resources

Western Anatolia is a geography with rich natural stone reserves due to the fact that it is located in a region where different geological belts are located and these belts contain different rocks (Sayar ve Erguvanlı, 1955). Ayvalık is located between the Biga Peninsula and the Menderes Massif (Ercan vd.,1986). Yuntdağ volcanites, the most widely distributed unit in the study area, consist of andesite, tuff, silicified tuff, lahar, agglomerate, and to a lesser extent basalt (Akyürek ve Soysal, 1981; Akgün, 2007).

It is known that the rocks forming the ground of Ayvalık urban protected area are of volcanic origin (Ercan vd., 1986) (Figure 7). Volcanic tuff / tuffites formed as a result of the accumulation of volcanic ashes on the slopes, lakes and seas during volcanic eruptions vary according to the geological formation in the region where they are located (Taşlıgil ve Şahin, 2016; Şener vd, 2013).

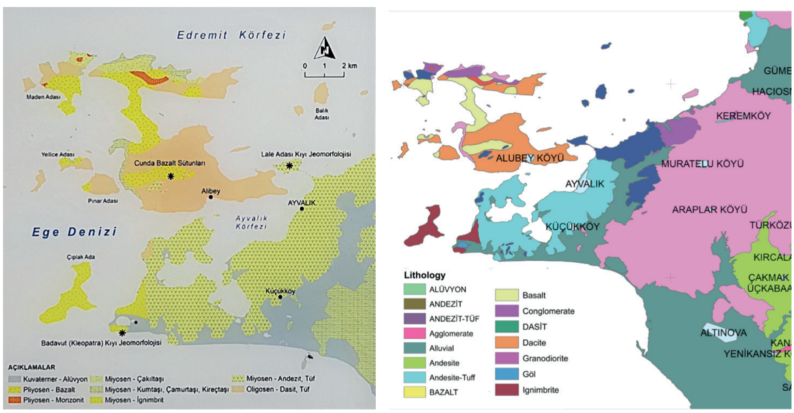

Figure 7: *Geological map of the region (left- Akgün, 2007 / rihgt- developed from MTA 1/100000 scale map, developed by S. Berber)*

The most frequently used material in Ayvalık historical buildings is 'Sarımsak Taşı'. The stone is pinkish in colour and of volcanic origin (Figure 8)(Altunkaynak, 1997). Due to its durability, easy workability, long life span and colour (rose dry, pink), it was used as the most important local building material source in the region in the past. The stone is found in the pinkish-coloured, abundantly fiamme-structured and pumice-rich Ayvalık ignimbrites of Lower Miocene age. It is extracted from quarries located in Badavut, south of the Salt Lake, at the southwestern end of the Sarımsaklı Peninsula. Ignimbrite tuffs are dense in the quarry and its surroundings (Akyürek, 1978).

Figure 8: *Ignimbrite stone-Sarımsak Taşı (Özmürüt, 2008; Efe ve İnan, 2023)*

Sarımsak taşı, was used as a building material in almost every period of the traditional and monumental architecture of Ayvalık and its neighbourhood. Badavut Quarry (Figure 9), which is the most used local material source of the region, was declared a Grade I Natural Protected Area in 1989, preventing the supply of stone from here, and in 1995 it was taken under protection by being included within the borders of Ayvalık Nature Park. The quarrying of stone from the quarry is now subject to the special permission of the General Directorate of Nature Conservation and National Parks.

Figure 9: *Badavut stone quarry (Özmürüt, 2008; Efe ve İnan, 2023)*

4. Use of Local Material Source *Sarımsak Taşı* in Historical Buildings

From the past to the present, stone has been used in many forms as a building material. Stone, which served the function of shelter directly by carving rocks in early periods, has developed and transformed over time. Stone can be used in load-bearing structures such as columns, piers, lintels, architraves, non-load-bearing structural elements such as jambs and stairs, as a covering material on walls and floors, in decorative elements such as column-pilaster capitals, floor moldings, and as aggregate in binding mortar mixtures.

In this part of the study, the use of sarımsak taşı, which is a local material source in traditional houses, monumental structures and commercial buildings in Ayvalık settlement, was examined. The use of volcanic garlic stone, called ignimbrite, as a carrier in walls, columns, lintels and architraves is common in structures (Figure 10).

Figure 10: *Use of sarımsak taşı in load-bearing elements*

When the facade elements are examined; it is seen that this stone is used in door-window jambs, pilasters as facade decoration, floor and eaves molding. (Figure 11). In some of the buildings where projections or balconies are used in the facade organization, stone is also used in the buttresses carrying the projection.[1] The use of sarımsak taşı has also been detected in the bell towers of religious buildings and in the minarets added to mosques converted from churches.

Figure 11: *Using sarımsak taşı on house doors and windows*

1 Iron load-bearing elements were mostly used under the projections and balconies on the upper floors of Ayvalık traditional houses.

Figure 12: *Using sarımsak taşı on minarets (Çınarlı Mosque-Saatli Mosque)*

Ticaret Commercial buildings are no different from residential buildings and monumental buildings. While the shops, which are smaller in scale than other buildings, use stone as a building material in the entire construction process, it was determined that bricks were used together with stone in the construction of structures such as olive oil factories, soap houses, etc., which are industrial heritage. Garlic stone was used in the stairs and flooring of almost every historical building in Ayvalık. It is also seen that garlic stone and yellowish colored andesite stone quarried from the region is used in the wall construction of Ayvalık historical buildings (Figure 13).

Figure 13: *Another local stone used in the region is yellowish andesite (Taxiarchis Church)*

5. Evaluation and Results

The preservation and sustainable existence of historical buildings is directly related to the use of appropriate materials. Stone material, which is important in terms of structural durability, has been used in all types of building construction from past to present. Historically, local material resources were often used to reduce transportation and processing costs during the construction of a building. The suitability of local materials to the climatic conditions, geographical characteristics and cultural heritage of the region ensures the longevity of the building and preserves its historical context.

Stone, which can be used in every layer and element of buildings from the floor to the roof, can also have locally characteristic features. *Sarımsak taşı* analyzed in this study is a local material. It has been used in the structural system elements, facades, floors and stairs, ornamentation and decoration elements of buildings of various scales from traditional houses to religious buildings, from soap houses to olive oil factories.

Sarımsak Taşı extracted from the quarries in the Sarımsaklı-Badavut area has a wide range of uses. The reason for the preference of garlic stone, which is used in almost every building in Ayvalık, is its easy workability and accessibility. It has also created the architectural identity of the region with its color and texture. When considered as a local building material, it also has a positive impact on environmental sustainability.

References

Akgün, A. (2007). *Ayvalık ve yakın çevresinin erozyon ve heyelan duyarlılığının coğrafi bilgi sistemleri tabanlı incelenmesi*. [Yayımlanmamış doktora tezi]. Dokuz Eylül Üniversitesi.

Akın, B. (2015). Ayvalık evleri'nin cephe karakterinin oluşumuna etki eden faktörlerin değerlendirilmesi. *Sanat Tarihi Dergisi*, XXIV (2), 121-136.

Akın Akbüber, B. (2020). Ayvalık Kent Dokusunda 19. Yüzyıl Ticari Faaliyetlerinin Mekânsal İzleri 'Dükkânlar'. *Sanat Tarihi Dergisi*, 29 (2), 807-829.

Akyürek, B. ve Soysal, Y. (1978). Kırkağaç-Soma (Manisa) Savaştepe-Korucu-Ayvalık (Balıkesir)-Bergama (İzmir) civarının jeolojisi. *Maden Tetkik ve Arama Enst. Rap.,* [Yayımlanmamış rapor]. 6432.

Akyürek, B. ve Soysal, Y. (1981). Biga yarımadası güneyinin (Savaştepe-Kırkağaç-Bergama-Ayvalık) temel jeolojik özellikleri. *M.T.A. Dergisi,* (95-96), 1-13.

Altıner, F., Kelkit, A. (2021) Land use cover change analysis (1985-2020) of Ayvalık district Balikesır Turkey using geographic information systems and remote sensing. *Fresenius Environmental Bulletin*, 30 (7), 8275-8283.

Altunkaynak, Ş (1997). *Bergama-Ayvalık dolayında genç volkanizma plutonizma ilişkilerinin jeolojik ve petrolojik araştırılması*. [Yayımlanmamış doktora tezi]. İstanbul Teknik Üniversitesi.

Arıkan, Z. (1988). 1821 Ayvalık İsyanı. *Belleten*, (LII), 571-601.

Balıkesir Kültür ve Tabiat Varlıkları Koruma Bölge Müdürlüğü Arşivi.

Bayraktar, B. (2002). *Osmanlı'dan Cumhuriyet'e Ayvalık Tarihi.* Atatürk Araştırma Merkezi.

Ercan, T., Satır, M., Türkecan, A., Akyürel, B., Çevikbaş, A., Günay, E., Ateş, M. ve Can, B. (1986). Ayvalık çevresinin jeolojisi ve volkanik kayaların petrolojisi. *Jeoloji Mühendisliği Dergisi,* (27), 11-19.

Erim, H. (1948). Ayvalık Tarihi. Güney Yayıncılık ve Gazetecilik.

Efe, R. ve İnan, F. (2023). İda madre jeoparkı. *Yerel Kimlik Dergisi*, (74), 29-35.

Güney, Y. ve Uçar, H. (2010). XIX. yüzyıl ayvalık kiliselerinde ahşap konstrüksiyon teknikleri. *Güzel Sanatlar Enstitüsü Dergisi,* (10), 165-183.

IBB digital archive of Atatürk's library. (2024). *Ayvalık.* https://katalog.ibb.gov.tr/yordam/ayvalik

ICOMOS. (1994). The Nara Document on Authenticity (Nara Conference on Authenticity in Relation to the World Heritage Convention, held at Nara, Japan, from 1-6 November 1994).

Özmürüt, Y. (2008)**.** *Küçükköy (Ayvalık) Ovası'nın hidrojeolojisi ve deniz suyu girişimi.* [Yayımlanmamış yüksek tezi]. Dokuz Eylül Üniversitesi.

Uğurlu, E., ve Böke, H. (2009). Tarihi yapıların özgün değerleri ile korunması, *Restorasyon Konservasyon Çalışmalar Dergisi.* (1), 17-19.

Tekeli, İ. (1992). Ege Bölgesindeki Yerleşme Sisteminin 19. Yüzyıldaki Dönüşümü, *Ege Mimarlık* . (3-4), 78-83.

Uçar, H. (2013) Taksiarhis Kilisesi'nin Mimari Özellikleri. *Ege Mimarlık*, (84), 58-64.

Yorulmaz, A. (1994). *Ayvalık'ı Gezerken*. Geylan Kitabevi.

CHAPTER 3

A RESEARCH ON THE USE OF ROBOTIC SYSTEMS IN CLEANING CURTAIN WALLS OF HIGH-RISE BUILDINGS

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1. Introduction

Increasing building heights in the construction industry and choosing different geometric forms on building façades in the context of architectural design have become possible in the light of technological developments. Such changes affect many aspects throughout the building function, from design to construction and beyond (Goksen et al., 2024; Gökşen and Ayçam, 2023; Takva et al., 2023a; Takva, et al., 2023b). One of these is the façade cleaning process. As high-rise buildings develop not only in height but also in variety of forms and functions, exterior maintenance is becoming increasingly difficult. At the same time, the fact that high-rise buildings sometimes have different form features makes the design of façade access equipment more complex. However, user-friendly designs and ensuring operational safety are the most important issues. Façade cleaning, which is dangerous due to height, is a job that requires the necessary precautions to be taken in terms of working rules and occupational safety. With the developing and changing conditions, façade cleaning process, which is done manually by human power, can now be carried out with robotic systems.

With the use of glass material in large-scale structures, the need for access to the façade began. While façade cleaning is simple enough for single-storey buildings, access to façades and exterior surfaces has become difficult in buildings of increasing height. Although stairs were used in the first stage for façade cleaning, when the façades reached heights that could no longer be reached safely, various systems began to be used to facilitate access (Weismantle et al., 2018).

Façade cleaning of high-rise buildings built as a result of developments in the construction industry is both a troublesome and dangerous job. For this reason, robotic systems that can climb vertical surfaces and roofs are expected to replace manual labor in façade cleaning works (Nansai and Mohan, 2016).

Today, façade cleaning of high-rise buildings is generally based on crane, basket or climber cleaning techniques under the supervision of human operators (Figure 1). Since these methods depend on manpower, they cause socioeconomic losses due to work accidents. In Germany, the USA, France, and other countries, various façade robots have been developed for building façade maintenance and cleaning (Lee et al., 2018). Robotic systems can make it possible to clean the façades of high-rise buildings without risking the life safety of employees. In addition, it can increase technological level and productivity (Zhang et al., 2007).

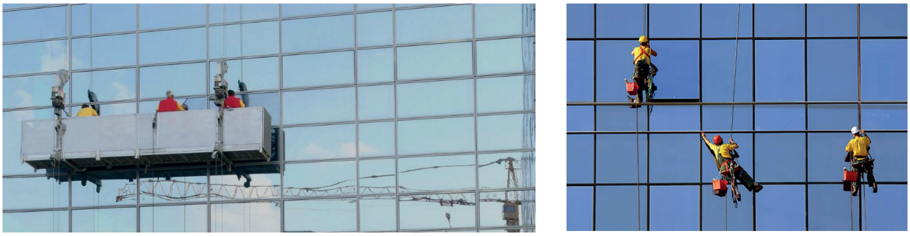


Figure 1. *Cleaning of high-rise building façades with traditional methods (URL-1; URL-2)*

A cleaning robot often needs to clean the entire surface of the curtain wall in high-rise buildings. For this reason, it is important for robots to have the ability to pass between surfaces. When the existing glass surface cleaning is completed, boundaries and obstacles must be overcome to enable passage to the surface on one side. Therefore, curtain wall geometry and window size come to the fore in the cleaning process (Li et al., 2021).

In the last thirty years, robotic developments have been advancing rapidly in industrial areas, services and especially in all areas intertwined with people's social lives (Nansai et al., 2017). Nowadays, robots are being developed to facilitate the workload in many areas such as manufacturing, security inspection, and construction industry. Robots are expected to be used in façade cleaning and adapt to different conditions in order to provide a better working and living environment (Li et al., 2021). Considering the building aesthetics and the comfort of the building occupants, the façades need to be cleaned regularly. In a study, in interviews with building residents, management companies and companies operating in exterior cleaning, it was stated that façade exterior surfaces should be cleaned once or twice a year (Yeom et al.,2022).

The aim of this study is to examine and systematically compare the functions of façade cleaning robots used in high-rise buildings. Façade cleaning robots, which are crawler, vacuum, magnetic or drone-shaped, have advantages such as safety, efficiency, quality, and environmental impact, as well as disadvantages such as adaptation, cost, storage space, and technical difficulties. Within the scope of this study, information about the features of robotic façade systems, the factors affecting their design, and different robotic systems were obtained. In line with this information, it is aimed to compare different types of robotic systems in terms of usage flexibility, possibilities and features in glass façade cleaning of high-rise buildings.

2. Robotic Systems Used on Façades

Façade cleaning in high-rise buildings provides important opportunities for the use of robots. As a result of the advancement of construction technologies and facilities in recent years, high-rise buildings have been built. Even in the latest new skyscrapers, façade cleaning is generally done by human power. In some skyscrapers, including the Burj Khalifa, people clean the façades by hanging from a rope. Carrying out these operations with manual labor carries the risk of falling from heights and causing injury or death. The use of robotic system solutions in façade cleaning works has a serious potential to increase efficiency and reduce risks to people (Nansai et al., 2018). In this context, extensive studies have been carried out on façade cleaning robots. A series of Skycleaners, operated entirely by pneumatic actuators, were developed in Germany to clean the façade by moving on the glass surface thanks to its vacuum suction cups (Zhang, et al., 2006a; Zhang, et al., 2006b). Developed by Serbot AG, an industrial company in Switzerland, the GEKKO cleaning robot is designed to clean with horizontally rotating vacuum suction cups (URL-3). Tito 500 is a façade cleaning robot developed by RATIOFOREM in the USA. With the wheel mechanism placed inside the robot and acting as a damper, it cleans by moving up and down on the façade of the building along the vertical wires (Akinfiev et al., 2009).

2.1. SIRIUSc

SIRIUSc is the world's first façade cleaning robot for high-rise buildings, combining all the necessary components such as robot engineering, cleaning engineering, fall arrest system and so on in a single system (Figure 2). The robot does not need any device such as guide rails to move on the façade. In addition, it can also perform the cleaning function in situations that prevent manual cleaning, such as wind conditions in high-rise buildings. Cleaning performance, continuous availability and minimum operating costs are among the features that qualify SIRIUSc as the ideal façade cleaning robot (URL-4).

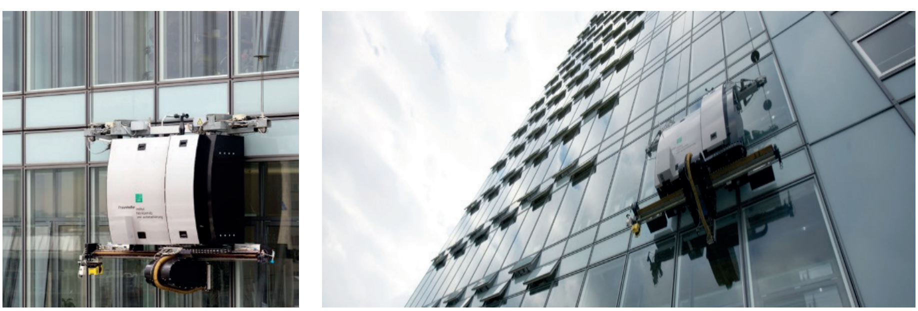


Figure 2. *SIRIUS façade cleaning robot (URL-5)*

This façade cleaning robot system is not just a robot. A crane system is placed on the roof at the top of the façade, in the trajectory of movement for each glass to be cleaned (Figure 3). The robot then descends vertically from the façade and performs the cleaning task when it comes up. Four cables attached to the crane at the top of the building protect the robot from falling. In order for the robot to move safely, the cables must be in sufficient tension. In addition to enabling robot movement, cables also provide power and data transmission. The robot weighs 450 kg and the gantry weighs 5,000 kg (Elkmann et al., 2008).

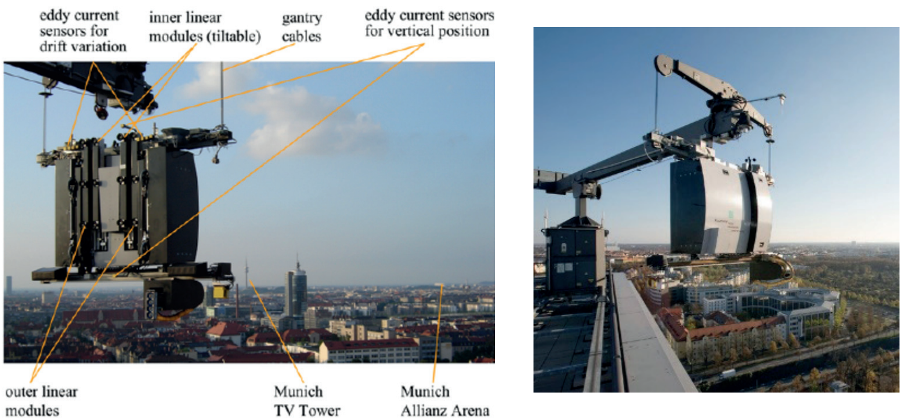


Figure 3. *SIRIUSc façade cleaning robot and system (Elkmann et al., 2008; URL-5)*

The main components of SIRIUSc, developed for vertical façades; robots mechanics and kinematics, rooftop gantry, sensor systems to detect face shape, frames, and obstacles, control technology, and navigation, power supply and integrated cleaning unit (Elkmann et al., 2008).

2.2. Sky Cleaner 3

Sky Cleaner 3 was designed in 2001 to clean the complex façade surfaces of the Shanghai Museum of Science and Technology (Figure 4). The robot has a similar structure to its two previous prototypes (Sky Cleaner 1 and Sky Cleaner 2) (Zhang et al., 2007).

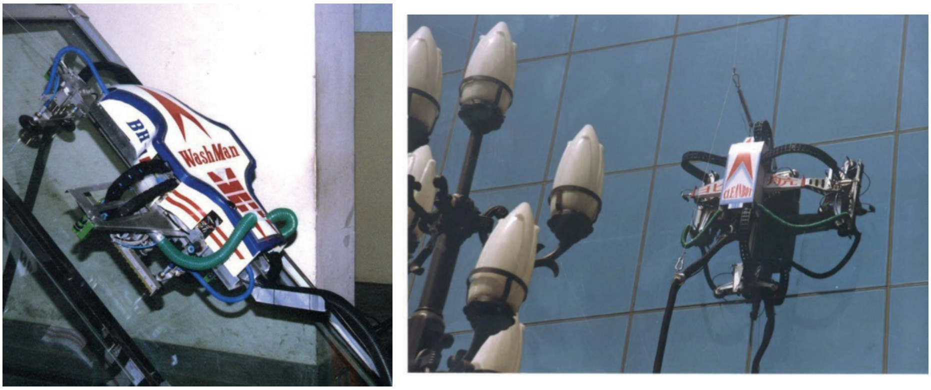


Figure 4. *Sky Cleaner 1 and Sky Cleaner 2 (URL-6)*

A turning waist joint actuated by a pendulum cylinder connects the X and Y cylinders (Figure 5). On opposite ends in the Y direction there are also four brush cylinders. An adaptable cleaning head has been designed to perform the cleaning process efficiently. While cleaning the glass façade surface, water is prevented from dripping down. This process is carried out through the vacuum pump on the robot. In this way, the water flows down and is collected on the supporting vehicle on the ground. At last the drainage is filtered, and then reused for cleaning (Zhang et al., 2007).

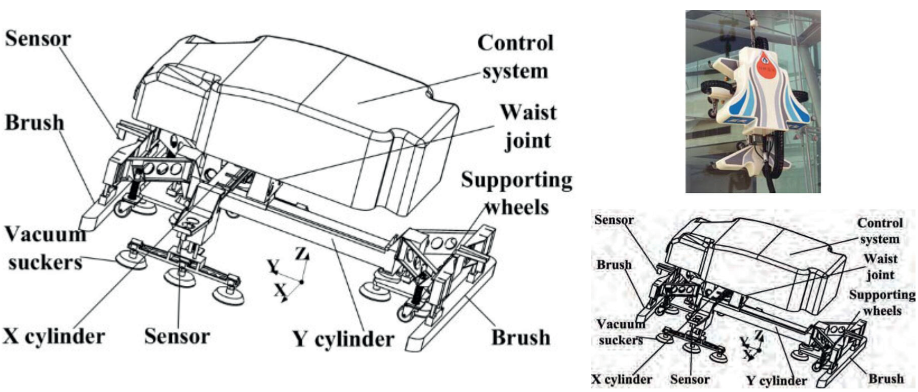


Figure 5. *Sky cleaner 3 prototype (Zhang et al., 2007)*

Sky cleaner 3 can move autonomously on the glass façade. Control and monitoring of the robot is carried out through a graphical interface. A specific cleaning trajectory is essential so that the cleaning movement covers the entire façade surface. Area covering is a common and useful type of planning that requires the robot's motion trajectory to cover every part of the façade area. If Sky Cleaner 3 makes its front cleaning target in the left-right direction, it needs to pass two-degree angled edges several times. However, it can operate and clean unhindered in the vertical direction, because in this way the glasses are considered to form a plane. As a result, the robot begins to clean the glass wall from the upper left point, and hen works its way down (Figure 6). When the first glass column is finished cleaning, move on to the next column. Due to the eaves protrusion at the top and some parts near the floor at the bottom cannot be cleaned due to robot operation safety. The coverage percentage on this small working area is over 93 percent and the cleaning efficiency is $125m^2/h$ (Zhang et al., 2007).

Figure 6. *Glass façade cleaning with Sky cleaner (Zhang et al., 2007)*

2.3. GEKKO Façade Cleaning Robot

GEKKO façade cleaning robot was developed by Serbot. It is the first commercial robot to climb a vertical surface. It can clean well thanks to pure water and rotating brushes. It can be integrated into almost all building façade forms with its mechanism (Figure 7). The advantages of this façade cleaning robot can be listed as follows;

- It offers a suitable system for cleaning hard-to-reach façade surfaces.
- It provides a faster solution compared to manual cleaning.
- Cleaning can be done without the need for extra personnel.
- It offers the opportunity to work automatically. Only the person using the robot needs to direct it.

Figure 7. *GEKKO façade cleaning robot (URL-7; URL-8)*

2.4. TITO 500

Tito 500, the façade cleaning robot developed by RATIOFOREM, is used with a crane that can be mounted on a high-rise building to keep it in a vertical position (Figure 8). This crane can move around the outer surface of the building roof. This method is used when the robots to be used in cleaning operations are bulky and thus allows increasing cleaning efficiency. The wheel mechanism inside the robot acts as a damper at one point. The robot performs the cleaning process by moving up and down on the building façade along the vertical wires (Akinfiev et al., 2009).

Figure 8. *Tito 500 façade cleaning robot (Akinfiev et al., 2009)*

2.5. Sky Pro

It is a façade cleaning robot that uses a rope mechanism to move on the façade surface and includes a brush system for the cleaning process (Figure 9). The robot, which can clean up to 60 times, has removable rotating wheels at the bottom for easy transportation (URL-9).

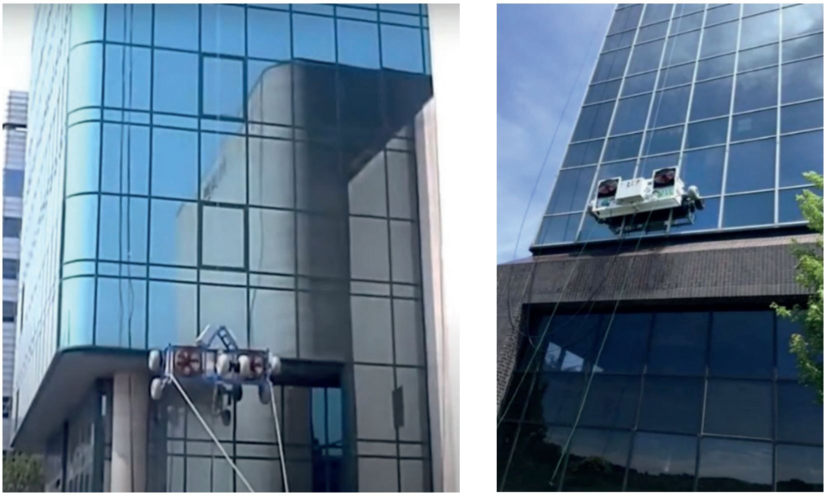


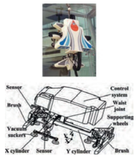
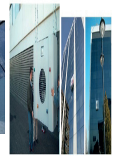
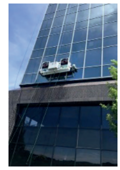
Figure 9. *Sky Pro façade cleaning robot (URL-9)*

The robot, which performs the cleaning function, can move vertically during the façade cleaning process with the help of wires. As a cleaning tool, it has a rotary brush type system.

3. Findings and Evaluation

High-rise buildings are developing day by day in terms of both function and form diversity. There are many issues that should not be ignored from the design phase of the structures to the implementation phase, as well as important points that should be taken into consideration throughout the functional period of the structure. One of these is the exterior maintenance of buildings. Many factors, such as the need to design different façades as the height of the building increases, and the formation of complex façade types as a result of architectural additions, have made exterior maintenance more complex. These operations, which were done manually and with human power in the past, can now be done with the use of robotic façade systems. In line with the information obtained through research in Table 1, 5 different robotic façade systems such as SIRIUSc, Sky Cleaner 3, GEKKO, TITO 500 and Sky Pro are compared in terms of country of origin, direction of movement/locomotion, support devices, cleaning tool and locomotion mechanism features.

Table 1. *Comparison of robotic façade cleaning systems*

Features	Robot Name				
	SIRIUSc	Sky Cleaner 3	GEKKO	TITO 500	Sky Pro
Pictures					
Country of origin	Germany	Germany	Switzerland	The United States	The United States
Direction of movement/ Locomotion	Vertical	Movement in X and Y directions	Moves freely	Vertical and horizontal movements by using a gondola	Vertical
Support devices	Wires/ rooftop gantry	Wires	without using wires	Wires	Wires
Cleaning tool	Rotary brush type	Rotary brush type	Rotary brush type	Rotary brush type	Rotary brush type
Locomotion mechanism	Power is supplied from the gantry/ vacuum suckers	Pneumatic cylinders as well as multiple suctions pads	Adsorption devices	Wheel mechanism	Two rear mounted fans

5 different façade cleaning robots developed by different countries and companies were examined in line with the information obtained. As a result of the comparative analysis in Table 1 in the light of the investigations;

- The direction of movement/locomotion of façade cleaning robots can be movement in X and Y directions or moves freely.
- Support devices are generally provided with wires in the 5 façade cleaning robots examined.
- Rotary brush type is used as a cleaning tool.
- The locomotion mechanism differs in the 5 façade cleaning robots examined as power is supplied from the gantry/vacuum suckers, pneumatic cylinders as well as multiple suctions pads, adsorption devices, wheel mechanism and two rear mounted fans.

4. Conclusion

Façade cleaning, which is dangerous due to height, is a job that requires the necessary precautions to be taken in terms of working rules and occupational safety. With the developing and changing conditions, façade cleaning process, which is done manually by human power, can now be carried out with robotic systems. In the study, 5 different façade cleaning robots that can be used in cleaning the façade systems of high-rise buildings were examined. The cleaning ability and performance results of the robot and the use of robot-assisted solutions in façade cleaning are limited to the target building. Cleaning robots generally require additional tools such as cranes, ropes, and cables. This situation reveals the need to further improve façade integration in cleaning building façades with different geometries. Therefore, adaptability is an element that needs to be improved in this regard. As a result, in addition to the basic common and different features of façade cleaning robots identified within the scope of the study, the development of innovative robots will be more possible thanks to developing technology.

References

Akinfiev, T., Armada, M., & Nabulsi, S. (2009). Climbing cleaning robot for vertical surfaces. *Industrial Robot: An International Journal*, *36*(4), 352-357.

Elkmann, N., Lucke, M., Krüger, T., Kunst, D., Stürze, T., & Hortig, J. (2008). Kinematics, sensors and control of the fully automated façade-cleaning robot SIRIUSc for the Fraunhofer headquarters building, Munich. *Industrial Robot: An International Journal*, *35*(3), 224-227.

Gökşen, F., & Ayçam, İ. (2023). Thermal performance assessment of opaque ventilated façades for residential buildings in hot humid climates. *Građevinar*, *75*(03.), 225-234.

Goksen, F., Takva, C., Takva, Y., & Ilerisoy, Z. Y. (2024). Post-earthquake fires: risk assessment and precautions. *Mehran University Research Journal Of Engineering & Technology*, *43*(1), 1-16.

Lee, Y. S., Kim, S. H., Gil, M. S., Lee, S. H., Kang, M. S., Jang, S. H., ... & Han, C. S. (2018). The study on the integrated control system for curtain wall building façade cleaning robot. *Automation in Construction*, *94*, 39-46.

Li, Z., Xu, Q., & Tam, L. M. (2021). A survey on techniques and applications of window-cleaning robots. *IEEE Access*, *9*, 111518-111532.

Nansai, S., & Mohan, R. E. (2016). A survey of wall climbing robots: recent advances and challenges. *Robotics*, *5*(3), 14.

Nansai, S., Elara, M. R., Tun, T. T., Veerajagadheswar, P., & Pathmakumar, T. (2017). A novel nested reconfigurable approach for a glass façade cleaning robot. *Inventions*, *2*(3), 18.

Nansai, S., Onodera, K., Veerajagadheswar, P., Rajesh Elara, M., & Iwase, M. (2018). Design and experiment of a novel façade cleaning robot with a biped mechanism. *Applied Sciences*, *8*(12), 2398.

Takva, Y., Takva, C., & Goksen, F. (2023a). A Contemporary House Proposal: Structural Analysis of Wood and Steel Bungalows. *Engineering, Technology & Applied Science Research*, *13*(3), 11032-11035.

Takva, Y., Takva, Ç., Gökşen, F., & İlerisoy, Z. (2023b). Examination of Contemporary Additions Made with Adaptive Reuse of Historic Building Heritage. *Online Journal of Art and Design*, *11*(4).

URL-1: Cleaning of high-rise building façades, https://dudutemizlik.com.tr/temizlik-hizmetleri/dis-cephe-cam-temizligi, Last Access Date: 16.11.2024.

URL-2: Cleaning of building façades, http://www.yagmuryonetim.com/bina-cam-temizligi/, Last Access Date: 16.11.2024.

URL-3: GEKKO cleaning robot, https://www.serbot.ch/en/, Last Access Date: 16.11.2024.

URL-4: SIRIUSc cleaning robot, https://www.iff.fraunhofer.de/en/business-units/robotic-systems/facade-cleaning-sirius.html, Last Access Date: 16.11.2024.

URL-5: Façade cleaning robot and system, https://www.iff.fraunhofer.de/en/business-units/robotic-systems/facade-cleaning-sirius.html, Last Access Date: 16.11.2024.

URL-6: Sky Cleaner 1 and 2, https://org.ntnu.no/intelligentsystemslab/robotics/skycleaners.html, Last Access Date: 16.11.2024.

URL-7: GEKKO façade cleaning robot, https://www.serbot.ch/en/facades-surfaces-cleaning/gekko-facade-robot, Last Access Date: 16.11.2024.

URL-8: GEKKO façade cleaning robot, https://www.serbot.ch/en/facades-surfaces-cleaning/gekko-surface-robot, Last Access Date: 16.11.2024.

URL-9: Sky Pro façade cleaning robot, https://www.skypro.com/skypro-brush-machine , Last Access Date: 16.11.2024.

Yeom, D. J., Kim, J. H., Kim, J. S., & Kim, Y. S. (2022). Life cycle cost analysis of a built-in guide-type robot for cleaning the facade of high-rise buildings. *Journal of Asian Architecture and Building Engineering*, *21*(5), 1736-1753.

Weismantle, P., Thompson, K., Torem, E., & Mejorin, A. (2018). *Facade Access & Maintenance for High-Rise Buildings: An output of the CTBUH Facade Access Working Group*. Council on Tall Buildings and Urban Habitat.

Zhang, H., Zhang, J., Zong, G., Wang, W., & Liu, R. (2006a). Sky cleaner 3: A real pneumatic climbing robot for glass-wall cleaning. *IEEE Robotics & Automation Magazine*, *13*(1), 32-41.

Zhang, H., Zhang, J., & Zong, G. (2006b). Effective nonlinear control algorithms for a series of pneumatic climbing robots. In *2006 IEEE International Conference on Robotics and Biomimetics* (pp. 994-999). IEEE.

Zhang, H., Zhang, J., Wang, W., Liu, R., & Zong, G. (2007). A series of pneumatic glass-wall cleaning robots for high-rise buildings. *Industrial Robot: An International Journal*, *34*(2), 150-160.