Unmanned Aerial System Integration for Monitoring and Management of Landslide: A Case of Dominican Republic

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Abstract

The Unmanned Aerial System (UAS), Aerial Robot or Drone has been a multi-purpose tool for professionals, especially for its unknown versatile applications and regardless of its challenges in adoption. In the built environment and the current global situation, the topic of disaster management has grabbed attention from the scientific community, raising questions of cyberspace linking the COVID-19. As a result, the case study shows how UAS is used to evaluate the landslide provoked as cascading effect of a bridge site construction and the digital data required to feed in 2D and 3D a database of urban planning development. The findings reveal that the application of UAS reduced physical inspections, allowed professionals to obtain inaccessible data, and helped to overview the site conditions identifying the cause of the phenomenon. A safety design factor of the critical building of the school in the community to mitigate the landslide hazards at Santa Maria, Dominican Republic was recommended. Future works in 360°evaluation for similar cases in construction are recommended.

Keywords –

UAS; GIS; Disaster Management; Urban Planning; Landslide; Santa Maria; Communities

1 Introduction

Disasters are defined by the degree of damage caused to alive and living entities.

In a philosophical sense, disaster may mean molecular and structural arrangements of matter welcoming experiences, opportunities, and invitations to understand and teach knowledge and wisdom to humans regarding their capabilities of transcendence with and without a technology base.

Engineers, in their various ramifications, have used science to fabricate biological and non-biological technological solutions to address the threats of humankind. Consequently, each timeline and space country contain unique settlements of threats and solutions for risk reduction and recovery of disasters.

According to their technological integration, the solution could be called “intelligent”, “digital” or “smart”.

The dimension in which the solution is applied indicates the field and variables to consider, for example: “construction”, “infrastructure” or the combination of both adding human interactions in “cities”.

The approach of evaluating the effectiveness of the cities interactions with technologies relies on the allocation and provisions of the design of the cities rather than the adaptation of the cities to the technological evolution [1]. In other words, the meaning of a “smart city” can refer to a city that integrates technologies to improve the lives of its citizens as well as other social techniques and practices.

In rural and undeveloped emerging communities in developing countries, this concept could be referred to as a design for its use or a later integration. In any case, disasters concerned about construction, as landslides, may happen by different causes and mitigation plans of the cascading effects and recovery phase are imperious and necessary to develop.

The team of geologists and engineers attempt to assess the phenomenon and describe possible solutions in case that the landslide would imminently collapse the school structure. Because of the lack of knowledge by contractors and limitations of the site, the UAS allowed the data gathering process to assure quality and data preservation of the study.

Therefore, the aim of this paper is to illustrate a framework that integrates the UAS outcomes for risk evaluation in the Dominican Republic undertaking a UAS approach of data collection of a landslide near a primary school in a small town in the Dominican Republic in 2018. The following section revised the literature regarding operations of UAS in landslides and developed a conceptual framework for future cases on this matter.

2 Literature Review

Landslides are originated from high rainfall saturation, subterranean aquifer expansion, water infiltration via porous rocks, and soil surface erosion. They can also be generated as a cascading effect of earthquakes, hurricanes, floods, deforestation, and earthworks (drillings, blasting, excavation, soil consolidation, etc.).

Landslides are phenomena interconnected to the restructuring of minuscule solid particles and the displacement of the particles into a low altitude state, provoking alterations and changes to the underground and surface of the earth.

The demand for methods and assessments before construction works in urban areas are enormous after several disasters occurred in recent years. Nevertheless, old and unsupervised urban and rural constructions made before these upgrades require agile mitigation and technological disaster recovery plans.

Modern professionals in the field of planning and construction of urban areas from public, private or non-profit sectors have been implementing sophisticated tools such as robots, sensors, and software to address quality assurance, data storage, long-term cost reduction, and other tasks to their projects [2]. However, the adaptation and acceptance of sophisticated tools present the barriers of the learning curve, knowledge transfer, viability from some professionals and organisations [3]. Hence, the application of robots, sensors, and software oriented to urban planning and construction should be diversified and standardised with the actual best practices and regulations in force.

The one that applies to this study is the Unmanned Aerial Systems (UAS) for human-made construction pits or natural landslides.

In the literature, the methods to address evaluations of landslides with UAS are commonly implemented by applying photogrammetry techniques and reconstructing the surface and terrain models in the cyberspace. A complete description of a case was made in [4]. This case describes the types of UAS (fixed wings and quadcopters) utilised for the assessment; modes of operations (autonomous or manual); adequate parameters of accuracy in regard to the height, type of sensors, ground control points, software, and essential data to reconstruct the digital terrain model of the area of study. However, the challenge of accuracy remains in the study when a generalisation case is willing to be addressed. [5] explain and demonstrate that the biggest challenge of UAS photogrammetry with vegetation can be defeated by including LiDAR sensors for accurate terrain models. Despite the combination of these sensors and techniques, post-processing software has advanced enough to reduce, automate, and facilitate the dependency of LiDAR and discrepancies of the photogrammetry according to the level of detail required for the operation.

Going forward through time, a study by [6] contributes with a framework for UAS landslide monitoring expressing the relevancy of regularly assessing the landslide sites. The UAS used was more advanced, similar to the models used nowadays; and explained the principle of ground sample distance or the equivalency pixel/cm. This approach shows the manual system carried out to produce desired outcomes. Nevertheless, the reconstruction process represents a time-consuming and specialised skill set to learn that the data collection process may not look as it is according to [7]. However, recent studies present a global view of data collection with UAS appearing as a standard as [8].

Furthermore, [9] shared a framework for adoption in the Dominican Republic but did not cover details of the cases to acquire data with UAS and the technical parameters to apply them.

The adoption process of UAS within the construction of urban areas relies on the technological tools to find solutions and approaches to erect projects. The most used technologies for these purposes are the 2D multi-layers of Geographic Information System (GIS) for land project distribution and the CAD software for building designs (Revit, ArchiCAD, Vector Works, Civil 3D, and others).

This software accepts a variety of file formats to enable representations of the blueprints or current site conditions. In the same manner, the UAS and their workflows permit feeding the digital part or cyberspace of the project with realistic site conditions for better interpretation and representation of the dynamics involved. An example of the explanation can be seen in Diagram 1, showing how the current workflows are updated with the UAS implementation and a possible definition of smart city. The diagram illustrates the process of risk evaluation in the workflow of disaster management according to the literature.

In the aspect of extending the UAS implementation, the UAS future could be understood by the adoption and merging of multiple technologies of the 4th industrial revolution such as the benefits of cloud computing [10], virtual reality training, 6G internet of things [11], visual-spatial information in real-time with Building Information Modelling (BIM) & GIS [12] for autonomous monitoring tasks with artificial intelligence (AI) in the definition of a data-driven smart city.

Future trends would also allow another range of tools and applications to be involved, such as apps and wearables technologies. Examples of the applications can be forecasting of COVID-19 propagations with AI, anxiety levels after a disaster, emotional experiences of buildings and infrastructure usages through heart bits vibration, body temperature, and other mediums.

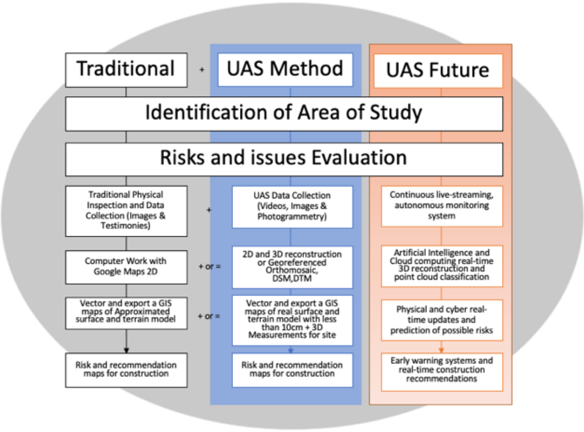

Diagram 1. The framework of UAS Data Collection and trends

Diagram 1 describes the traditional methodology of data collection for multidimensional risk evaluation. In blue is defined the when and where the UAS outcome could be used during the traditional method approach. Finally, in orange are the trends of UAS with other technologies and possible implications in the workflow in a scenario that indicates the applicability of the smart city concept.

For disaster in construction and urban areas, the dimensions and methodologies that the UAS provides, currently, are visual information useful for assessment in the dimension of social, infrastructure and environmental aspects for urban planning development in mitigation and post disaster plans [13].

To identify the most compromised dimensions, it is required to evaluate the total risk (Rt) of the elements in investigation with Equation 1:

$$Rt = E \times H \times V \qquad (1)$$

Equation 1 describes how the total risk is estimated calculating the expression of E as element (School or Small homes), H as hazard (Landslide, or earthquake) and V as vulnerability (weakness). These values are categorised between 1 to 10 according to the level of relevancy and the risk of a specific aspect of the city.

The values of the Equation 1 can be assigned through visual data collection in urban areas as in orthomosaics and GIS identification. The threats against communities, houses or environment evaluation of the structural weakness or vulnerability that may face the element can be assessed for strength, transfer, or disesteem easily [14].

However, beyond the future of these new methodologies assisted with aerial robots and other technologies, there are challenges in their adoption that make the future trends reachable in a distant time from now.

The challenges are classified by the inconsistencies in sensors in size, software for data processing, energy source, and interoperability of the software. The adoption and insertion of the UAS files to their full potential —applicability of the outcomes for the investigation— can be stressful if employees and contractors for not communicate appropriately the implications of UAS for the organisation in this matter.

For this reason, the following illustration is presented to provide ideas of how construction organisation may address their due diligence in risky areas, councils may get awareness of another method of communication between departments, researchers can assess their duties faster, and trust in the development and application of robots [15].

3 Case of Study

The Caribbean country of the Dominican Republic shares the island territory with the Republic of Haiti. The geographical location of the country determines its risks before earthquakes such as 2003 Dominican Republic Earthquake [16], 2010 Haiti Earthquake [17]; hurricanes, and floods recurrently every year [9]. The school buildings, infrastructures, policies regarding the safety factor of construction, urban development, and education systems before disasters require several improvements [18]. An example of these issues is the community of Santa Maria at San Cristóbal providence in the Dominican Republic. This hamlet, with a cathedral, is in a zone composed of alluvium and lower terrace of the Nigua River, with a general composition between sand, silt, and gravel. The composition of the soil is sensitive to the cascading effects of erosions, ground saturation, telluric movements natural or by drillings, blasting, and raw material production from the river as a landslide. Since 2017 the community has experienced land cracks with more than 15cm of expansion and spontaneous landslides that attempt the safety of houses, schools, and the route of land communication of the highway 6 of November as Figure 1 and Figure 2 respectively presents [19].

Figure 1. Community site near landslide effects

Figure 2. Highway affected by landslide

The primary school serves as a safe centre for the citizens in the event of a hurricane; therefore, the integrity of the building is compromised to an imminent risk of collapsing and diverse methods were utilised to verify the security design factor of the building foundations in which the UAS photogrammetry was applied to identify the site conditions and risks involved in the area.

4 Methodology

The case study was developed by collecting documents, reports, historical data, and interviews in a public institution in the Dominican Republic. The National Geological Service (SGN acronym in Spanish) is the institution responsible for carrying out investigations related to environmental detriment, adequate practices of urban planning and sustainability of natural resources and more. Then, the Nvivo 2020 software was used to identify the fields inside construction that the UAS were applicable as the following case is.

The landslide site was recorded with videos and images. Later, a 3D reconstructed utilising a UAS Phantom 3 professional with 4000x3000 resolution, FOV 94° 20 mm - f/2.8 focus at ∞, 1280g weight in deployment moment and an average of 65m (215 ft) height from the starting point according to the Exif files with the Pix4D software were carried out. For the site reconstruction, 203 images were taken with the sensor in zenith position (90°) between 12:40-13:20 hours to avoid hard shadows in the model. Then, images in specific points were taken to collect the GPS position and compute them into the GIS system for risk analysis. The regulations in the country in 2018 were not restrictive for UAS less than 2 kg and operations should take the basic safety measurements for the deployment. In addition to the UAS assessment a caution walking assessment was made to assure the quality of the works.

The operations took place outside of the city centre, where the most significant landslide effects were felt and seen. Some areas were dangerous to access and difficult to obtain measurements physically of the cracks. The landslide impacted negative 2 families drastically breaking the foundations of the house as shown in Figure 3. The UAS video was utilised to examine the surroundings of the community and determine the potential threats involved, such as a falling of high-tension electrical lines.

Figure 3. House foundation cracks

The high-tension electrical lines that were not visible on the GIS maps of the organisation were located using images with GPS coordinates encoded in them. Therefore, a multidimensional risk assessment of the site was made evaluating the critical infrastructures with Equation 1. After the assessment the reconstruction of this first site, utilising the photogrammetry technique and Pix4D, was made to measure the inaccessible landslide cracks deformation and make estimations of the landslide slopes as shown in Figures 4 & 5. Furthermore, some of the results are based on the experience shared and the interpretation of the data acquired by the authors.

Figure 4. Identification 3D and 2D of the Landslides

Figure 5. 3D measurement of the Landslides 1 and 2

5 Results and Discussion

The outcome of the data gathered was divided into three aspects: (i) Recover trust from previews UAS application that resulted in low quality works in other projects; (ii) Overview of the site conditions and landslide effect to the community and the school; (iii) an upgrade of the actual GIS maps of the organisation and provide guidance for further research in terms of foundation factors of the school.

A major concern from the organisation was the question of opening a new position for UAS operations would be cost-effective or hire them according to the requirements of projects alternatively? According to [7] the UAS is a cost-effective solution for data collection. However, due to the lack of personnel qualified and the access to the UAS, the institution has adopted the position to integrate UAS outcomes in their projects by utilising contractors externally by agreements, commercially or from another government organisation. Furthermore, this approach did not assure the adequacy of the outcomes for the purposes of the investigations.

After the data was presented in 2D, the most challenging outcome to share, understand, and navigate was the 3D model with measurements due to the capability of the computers to open a cloud platform. The limitation was surpassed by utilising a computer with higher video ram memory (16GB) allowing to measure the height and the visible extension of the landslide as in Figure 5. The information permit to estimate the type and root of the landslide along with the contour lines. The surface was irregular and an estimated shape was taken for the purpose of identifying the type of landslide. The benefit of this approach involved the risk reduction of the personnel and suitable estimations with up to 30 cm of accuracy for the calculations against visit the site and make the analyses.

However, the trees represent an issue for the 3D model but the software was able to produce a 2D and 3D Digital Terrain Model (DTM) from the 2D and 3D Digital Surface Model (DSM) or orthomosaic georeferenced. This information provided the contour lines to assess the slope of the different landslides and identify their type. Moreover, the 3D models were printed and attached with the other 2D data for better interpretation and shareability.

Despite the effectiveness of visual assessments for the community, the 3D reconstruction made for estimating the length of the fissure was difficult to compare physically and some fissures were unavailable to measure utilising the method by the vegetation. For this reason, LiDAR would be preferable to mix with the photogrammetry for more accurate observation as mentioned before by [6].

Furthermore, the limitations that this method could bring around the urban area is related to safety and privacy. The UAS operation should comply with specific standards of piloting, UAS danger operation perception, aircraft airworthiness (noise reduction tools and obstacle avoidance), and specific height requirements to restrict cases of privacy disruption. Furthermore, the community may be notified the day of flying to avoid issues.

The advantage of a monitoring system or maintenance system after construction phases such as this, permit to prevent disasters in the future such as bridge failures during floods or electrical infrastructure explosion.

The conclusions of the study were that the extraction of raw materials and erosion at the edge of the River Nigua were the key factors of the landslide by the type of landslide in sequence in the same area. In the video, it was appreciated the overview of site conditions in a 360° view and recordings were made in specific points. The UAS operation to overfly the sector in a circular trajectory allowed the investigators to understand the influence of external factors on the community, for example, a bridge construction and other elements that were assumed as a main factor of the landslide as shown in Figure 6 and 7. Further applications of BIM and UAS could prevent this kind of circumstance.

Figure 6. Construction site of the Bridge

Figure 7. Opposite side of the Landslide and Community

The effects of the landslide have a focalised damages categorised as minor by the assessment of the highway and 2 families in contrast to the rest of the community taking the Equation 1. Furthermore, the community were confident that after the termination of the construction works side effects of the landslide would stop. Furthermore, the maps were updated with the visual data and further research was carried out regarding the school design factor by a local university.

It is recommended that if an active monitoring of vulnerable zones is desired, an integration of the city council is required to reduce time in sharing technical information and avoiding delays on physical inspections. As mentioned in the literature, the Diagram 1 showed the process, considerations, and future trends that would bring adopting UAS in their workflow.

The risk analysis utilising Equation 1 allowed the professionals to identify the critical structural elements in the community at risk and safeguard them against threats such as the school and the cascading effects as in Table 1 is shown according to the information provided by the citizens of the town. The engineering explanations of the landslide was concerned with seismic waves provoked by the material extraction and the erosion.

Table 1. Cascading Effects. The order of events describes the types of actions that provoked the disaster and school risk evaluation.

Order	Event	Type
1	Flood	Natural
2	Bridge Destruction	Natural
3	Community without access	Human Made
4	Earth Works	Human Made
5	Landslide	Natural
6	Collapsing Houses	Natural
7	School Threats	Natural

Another future technical solution that could emerge from UAS data integrating the concept of smart city or digital city is the use of apps. For example: apps for alert risks in the community or an alert that describe the risks involved in certain areas of the community or the country visiting in case of investors and citizens. However, the penetration of smart devices and technological platforms should be enhanced in the country to make it fully operable. The 5G and 6G internet platforms, BIM and AI could be a step forward for the future of smart communities in developing countries such as the Dominican Republic and others.

6 Conclusion

In conclusion, the adoption into the investigation allowed the engineering team to understand and communicate clearly the problem and identify the source of the landslides, provide recommendations for the citizens, and evaluate the construction factors of the school in their foundations. The Diagram 1 was useful to identify the role of UAS for these activities. Despite the digital challenges and low capabilities that the adoption of 3D modelling from the UAS, images, videos and orthomosaic encountered, the workflow supports the update of the 2D GIS maps, provides an overview of the risks, and facilitates the situational awareness of the zone. Trust in the technology was gained and as a result of the study only 2 families were impacted negatively by the cascading effects of the constructions. Furthermore, the smart city concept could be integrated after the penetration of technologies of the 4th industrial revolution and applications are the common platform for living in comfort. As nowadays computers and smartphones are an imposing need, the adoption allowed different platforms to build under these foundations such as Twitter, Whatsapp and Wechat. Furthermore, the delivery and use of 3D representation for this type of assessment should incorporate LiDAR.

Further works were carried out regarding the school safety but the implications of 360°images, videos, virtual reality, and 3D reconstruction with UAS for similar cases related to construction are suggested with frameworks and studies to preserve the security of these buildings. Exploration of the quality factors and BIM integration are also recommended.

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References

[1] V. S. Barletta, D. Caivano, G. Dimauro, A. Nannavecchia and a. M. Scalera, "Managing a Smart City Integrated Model through Smart Program Management," *Applied Sciences,* 10(714):1-23, 2020.

[2] J. Wu, L. Peng, J. Li, X. Zhou, J. Zhong, C. Wang and J. Sun, "Rapid safety monitoring and analysis of foundation pit construction using unmanned aerial vehicle images," *Automation in Construction,* 128:103706, 2021.

[3] S. M. Sepasgozar, S. Hawken, S. Sargolzaei and M. Foroozanfa, "Implementing citizen centric technology in developing smart cities: A model T for predicting the acceptance of urban technologies," *Technological Forecasting & Social Change,* 142:105-116, 2019.

[4] U. Niethammer, M. James, S. Rothmund, J. Travelletti and M. Joswig, "UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results," *Engineering Geology,* 128:2-11, 2012.

[5] K.-J. Chang, C.-W. Tseng, C.-M. Tseng, T.-C. Liao and C.-J. Yang, "Application of Unmanned Aerial Vehicle (UAV)-Acquired Topography for Quantifying Typhoon-Driven Landslide Volume and Its Potential Topographic Impact on Rivers in Mountainous Catchments," *Applied Science,* 10(6102) 1-16, 2020.

[6] A. Al-Rawabdeh, F. He, A. Moussa, N. El-Sheimy and A. Habib, "Using an Unmanned Aerial Vehicle-Based Digital Imaging System to Derive a 3D Point Cloud for Landslide Scarp Recognition," *Remote Sensing,* 8(95):1-32, 2016

[7] H. R. Vanderhorst, D. Heesom, S. Suresh, S. Renukappa and K. Burnham, "Application of UAS and Revit for Pipeline Design," in *Creative Construction e-Conference 2020,* Opatia, Croatia, 2020.

[8] L. Xu-gang, L. Zou-jun, Y. Hong-yan, L. Ji-bo, Z. Yan-jun, L. Xiao-yu and W. Yan-ru, "Rapid identification of landslide, collapse and crack based on low-altitude remote sensing image of UAV," *Journal of Mountain Science,* 17 (12):2915-1928, 2020.

[9] H. R. Vanderhorst, S. Suresh, S. Renukappa and D. Heesom, "Strategic Framework of Unmanned Aerial Systems integration in the disaster management public organisations of the Dominican Republic," *International Journal of Disaster Risk Reduction,* 56: 102088, 2021.

[10] S. A. Bello, L. O. Oyedele, O. O. Akinade, M. Bilal, J. M. D. Delgado, L. A. Akanbi, A. O. Ajayi and H. A. Owolabi, "Cloud computing in construction industry: Use cases, benefits and challenges," *Automation in Construction,* 122:103441, 2021.

[11] A. Kumari, R. Gupta and S. Tanwar, "Amalgamation of blockchain and IoT for smart cities underlying 6G communication: A comprehensive review," *Computer Communications,* 172:102-118, 2021.

[12] B. Dave, A. Buda, A. Nurminen and K. Främling, "A framework for integrating BIM and IoT through open standards," *Automation in Construction,* 95: 35-45, 2018.

[13] E. Parodi, R. Kahhat and I. Vázquez-Rowe, "Multidimensional damage assessment (MDDA): A case study of El Niño flood disasters in Peru," *Climate Risk Management,* 33:100329, 2021.

[14] H. R. Vanderhorst, S. Suresh, S. Renukappa and D. Heesom, "UAS application for urban planning development," in *2021 European Conference on Computing in Construction*, Online, 2021.

[15] Q. Chen, B. G. d. Soto and B. T. Adeya, "Construction automation: Research areas, industry concerns and suggestions for advancement," *Automation in Construction,* 94: 22-38, 2018.

[16] N. J. Rojas-Mercedes, L. D. Sarno, A. L. Simonelli and A. Penna, "Seismic risk of critical facilities in the Dominican Republic: case study of school buildings," *Soft Computing,* 1-17, 2019.

[17] S. Voigt, A. T. Tobias Schneiderham, E. S. Monika Gähler and H. Mehl, "Rapid Damage Assessment and Situation Mapping: Learning from the 2010 Haiti Earthquake," *Photogrammetric Engineering & remote Sensing,* 77(9):923-931, 2011.

[18] V. A. Muñoz, B. Carby, E. C. Abella, O. D. Cardona, T. López-Marrero, V. Marchezini, L. Meyreles, D. Olivato, R. Trajber and b. Wisner, "Success, innovation and challenge: School

safety and disaster education in South America and the Caribbean," *International Journal of Disaster Risk Reduction,* 44:101395, 2020.

[19] M. M. P. D. Moya, B. M. Feliz, A. V. E. Feliu, Á. R. M. D. Jesús, R. C. F. Almonte, E. L. F. Peña, R. O. S. Castillo and J. A. P. Reyes, "Análisis de la estabilidad del talud y estudio de vulnerabilidad del plantel "Escuela Básica Santa María" en la provincia San Cristóbal de la República Dominicana 2018.," Instituto Tecnológico de Santo Domingo, Santo Domingo, Distrito Nacional, República Dominicana, 2018.