Method of applying Unmanned Aerial Vehicle (UAV) for landslides identification in the Dominican Republic

Hamlet Reynoso Vanderhorst (h.d.reynosovanderhorst@wlv.ac.uk)
University of Wolverhampton https://orcid.org/0000-0002-6253-5743

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Abstract

Unmanned Aerial Vehicle (UAV) are tools for site recognition, 3D reconstruction, and inspections in risky areas. As manufacturers identify their multiple applications, significant improvements in hardware and software are made, transforming traditional workflows into a digital one. These workflows support the pre- and post-construction of buildings, houses, and infrastructures against the inflictions of natural or human-made disasters. In the Dominican Republic, the construction and maintenance of infrastructure projects are a continuous tasks carried out before natural events. However, the knowledge of "how", the context, and effectiveness of the tool are still under development, generating techniques and approaches to solve problems easily and faster. Therefore, the aim of this paper is to develop a case in which a human made landslide is evaluated utilising a UAV in contrast to complex site explorations. Three approaches were taken: (1) Images with GPS coordinates for infrastructure location, (2) 3D reconstruction for landslide site measurements and slope recognitions with contour lines, then, (3) videos of the site with 360° approach. 5 elements at risk were identified: houses, road, landslide zone, infrastructure proximity and school. The element evaluated was the landslide zone for identification of the cause. The findings showed that construction works of a bridge in the surroundings was the most remarkable factor that influenced the occurrence of a 60.82° and 52% slope in an average of the steep in the rotational landslide. Furthermore, the UAV was a useful tool for data acquisition.

1. Background Section

The concept of aerial photogrammetry begun since the Second World War. It was used doves, aerostatic balloons, and airplanes. After several decades, the civilians started to use Remotely Piloted Aircraft System (RPAS), Unmanned Aerial Vehicle (UAV), or Drone for commercial purpose related to photography and later UAV photogrammetry. The RPAS has different names according to its context, weight, and country of application. Nevertheless, RPAS are tended to be used against satellite imaging by the high resolution, real-time image, and low-cost of acquisition (Agüera-Vega, Carvajal-Ramírez, & Martínez-Carricondo, 2017). Furthermore, these tools for surveys and inspection have commonly RGB cameras with resolution between 12–20 MP and others, more sophisticated, may have LiDAR technology (Chiang, Tsai, Li, & El-Sheimy, 2017), thermal imaging (Yahyanejad & Rinner, 2015), chemical pollution(Qiu, Chen, Zhu, Wang, & Qiu, 2017) and acoustic measurements (Zhang, 2017). The actual market quadcopter RPAS have a battery life between 15–30 min depending on its operations (Greenwood, Lynch, & Zekkos, 2019). However, the criterial of UAV selection relies on the task to accomplish. In the context of smart cities, the application of UAVs is found in monitoring construction projects, carrying out inspections on infrastructure, cargo internet and medical samples, monitoring and spreading fertilizers in agricultural farms, supporting the police in law enforcement procedures, and providing situational awareness along with damage quantification in disaster management. As the contribution of UAV is tagged under "Drones for Good", the literature implies that relevant number of investigations in the topic have been carried out, but the rapid pace of the UAV industry provokes several updates to this field yearly.

There are 4 different natural events that influence the application of UAV in the literature: earthquakes, floods, landslide, and wildfires as presented in Table 1. Most of the tasks in these events are related to situational awareness and damage quantification related to the build environment. It is used images and videos to understand the site conditions and later it is quantified the damages utilizing the technique of photogrammetry and processing the data within a photogrammetry software. The outcomes are adjusted for the next software interaction that could be for Geographic Information Systems (GIS), or a specialized software that address a specific analysis. The RGB sensor have provided the possibilities of multiple applications by just understanding the methods and techniques of data collection. Other sensors are predominately used but the financial, case specific, and risk implications within them may influence the amount of manuscripts describing operations with them.

Table 1
Peer-review Literature of the Application of UAV in Disaster Management

No.	Tasks	Journals	Citations	Task				Sensor
				Situational Awareness	**Damage Assessments**	**Software Analysis**	**Cargo**	
1	Earthquake	11	(Chuang, Rau, Lai, & Shih, 2019) (Samad, Iqbal, Malik, Arif, & Bloodsworth, 2018) (Kakooei & Baleghi, 2017) (Yasuhara, Murakami, & Mimura, 2015) (Saffarzadeh, et al., 2017) (Nedjati, Vizvari, & Izbirak, 2016) (Montgomery, 2016) (Xu, et al., 2014) (Xue, Zhang, Zhao, Guo, & Ma, 2012) (Lega, d'Antonio, & Napoli, 2010) (Li Y., Gong, Hong, & Song, 2009)	Monitoring Inspection Visualisation Real Time Video Visualisation	3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying	Disaster Site Model in GAMA Photogrammetry Software GIS Software		Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG, 360, Infrared Camera RBG

No.	Tasks	Journals	Citations	Task				Sensor
2	Flood	11	(Nadeem & Chandna, 2018) (Wang, Zhang, Zhang, Huang, & Feng, 2019) (Duo, Trembanis, Dohner, Grottoli, & Ciavola, 2018) (Hashemi-Beni, Jones, Thompson, Johnson, & Gebrehiwot, 2018) (Torres, A.Pelta, Verdegay, & Torres, 2016) (Murphy, 2016) (Guohua Wu, 2016) (Lai, et al., 2015) (Li Y., et al., 2012) (Guo, Huang, & Y.P.Li, 2010) (Sharma, Kumar, Desai, & Gujraty, 2008)	Surveillance Visualisation Visualisation	2D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying	River-Flow Simulation GIS and Inundation Simulation Flood Simulation Azimuth Processing		Camera RBG Camera RBG Camera RBG LiDAR Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG Camera RBG
3	Fire	7	(Tuna, Nefzi, & Conte, 2014) (Hwang, Yu, & Choi, 2018) (Ristorto, D'Incalci, Gallo, Mazzetto, & Guglieri, 2017) (Maza, Caballero, Capitan, Martinez-de-Dios, & Ollero, 2011) (Ambrosia, Sullivan, & Buechel, 2011) (Quaritsch, Kruggl, Wischounig-Strucl, Bhattacharya, & Rinner, 2010) (Reusen, 2008)	Real Time Video Real Time Video Real time video, Monitoring Visualisation Real Time video, Images Real Time video, Images	2D Surveying 2D Surveying		Cargo Network	Video Camera RBG Video Camera RBG Camera RBG Camera RBG and Infrared Camera RBG and Multispectral Camera RBG Camera RBG

No.	Tasks	Journals	Citations	Task				Sensor
4	Landslide	6	(García-Delgado, Machuca, & Medina, 2019) (Usman, Murakami, & Bisri, 2018) (Casagli, et al., 2017) (Nikolakopoulos, et al., 2017) (Al-Rawabdeh, He, Mousaa, El-Sheimy, & Habib, 2016) (Liu, Chen, Matsuo, & Chen, 2015)	Visualisation Visualisation Monitoring Visualisation	3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying 3D Surveying	GIS Software GIS Software GIS Software GIS Software		Camera RBG Camera RBG Camera RBG, Laser Scanning, Thermography & Interferometric Camera RBG, Laser Scanning, LiDAR & Interferometric Camera RBG Camera RBG
	Total	35		18	21	11	1	32 Camera, 8 LiDAR-Thermography, 2 Radar

However, in this research was contemplated that landslide events are not wide investigated as other phenomena. The few investigations in the application of UAV for landslide and, even more, in developing countries as the Dominican Republic required an in-depth investigation in order to gather the impressions and best practices in the sector.

2. Landslides And Unmanned Aerial Vehicle (Uav)

Landslides are geophysical events caused by nature or human-made events. There are plenty of definitions and types of landslides (Highland L., 2018) that in a philosophical sense, the landslide is defined by the displacement of particles from a high altitude to a lower one and they receive typification according to their order in a cascading effect and the created soil arrangement deformations. The damages, losses, fatalities, and infrastructures represent a plethora of threats for the development of communities. Landslides occur after heavy rainfall, droughts, telluric movements, and natural and human-made explosions. Landslide are classified according to the flow and movement type (Hungr, et al., 2014). Landslides provoked by earthquakes rely on geological formations. Well-endured overhanging rocky slopes to 1° soft slopes with sediments are the range of altitude flows in line with the soil structure. Moreover, the preeminent material that responds to earthquake in a landslide include rocks, colluvial sand, cemented soils, granular alluvium, granular deltaic deposit, and loess. The most common behaviour of landslides before earthquakes are normally triggered by materials that have not previously faced a hit (Keefer, 1984). Furthermore, a recent study shows the typology of landslide in Ganzhou City, China, referring to (15°- 35°) as gentle steep, (35° – 55°) moderately steep and (60°-70°) steep or rotational landslide in subtropical areas. Visual models of their typical landslides are presented in the paper (Zhan, et al., 2021; Hungr, et al., 2014). Typologies of steeps are mentioned as the city has multiple landslides as a consequence of the construction works. Other typologies are based on the degree of collapsing by identifying the volume and shape of mass movement evaluated. For example, in Latin America, Nicaragua, rockfalls and slides occur abruptly as a single mass or group of rock detachment. They can be cause by steep human-made or natural like in the craters. This type of landslide is triggered by earthquakes, rainfalls and human activities close to urban areas along roads or inside mines (Devoli, et al., 2008). These studies reflect the practices of typifying the landslide visually and by the volume of mass moved but they do not contain information of methodological assessment with UAV and there is a lack of studies in the Caribbean Region related to landslide, especially in the Dominican Republic.

There are more than 40 cases of the landslides reported in the scientific community making Japan, Slovenia, China and Canada the most active ones (Abolmasov, et al., 2017; Gariano & Guzzetti, 2016). Furthermore, assessing a systematic literature research of 513 documents utilising the keywords of Landslide and UAV with Scopus data base, the countries of China and Taiwan seems to be presenting findings regarding the application of UAV for landslide. The strategies and operations of these countries may be different against these type of events in contrast to countries in Latin American Region (Moncada & Yamagishi, 2018; Carrera, et al., 2021). Currently, the development of UAV application still undocumented and in the beginning stages in the region. Each country may address their own typification of landslides, methodologies and mitigations plan against the disaster as the event may have different behaviours and materials that make then unique from different contexts. A recent literature in the Dominican Republic regarding landslide typology were not found as may be possible that the country may not face this kind of event recurrently or landslide have been a cascading effect of another event. Furthermore, the application of UAV for landslide in this context were not reported. Nevertheless, according to the literature search, the most recent fields of investigations are related to landslide and UAV are involved in slope, rainfalls, proximity to rivers, earthquake occurrence, volume of mass moved, velocity of landslide, identification of the failure mechanism in early warning in villages and houses, elevations, and stability of the mass near to houses.

Table 2
Top 12 Journals in Landslide and UAV Scopus Data Base

Journals	**Number**
Landslides	50
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives	43
Remote Sensing	33
IOP Conference Series: Earth and Environmental Science	21
Proceedings of SPIE - The International Society for Optical Engineering	18
Engineering Geology	16
Journal of Mountain Science	11
Geomorphology	10
Journal of Chinese Soil and Water Conservation	9
Geosciences (Switzerland)	8
International Geoscience and Remote Sensing Symposium (IGARSS)	7

The demands of novel methodologies for data collection are imminent as risks, accuracy and time are critical in investigations regarding landslides. The useful outcomes of the UAV are suitable for: (i) Measuring the cross-sections of the landslide, (ii) Analysing volume and slope, (iii) Recording the magnitude of the event, (iv) instructing the early warning systems with the orthomosaics, Digital Terrain Model (DTM), obliques images, 3D point cloud and mesh for measuring elements and presentation purpose. Some of the outcomes complement and supplement the satellites and Geographic Information System (GIS) workflows offering precise, real-time, and more accurate data than the high-resolution satellites imaging. Despite the UAV in the literature is based on RGB sensors and other sensors such as LiDAR, it represents a significant improvement in DTM extractions by the extend of area that the UAV is capable to cover. Around 300,000 m^2 utilising one quadcopter is an example of these approaches (Vanderhorst, et al., 2021). The design and models of UAV influence the data type, quality, and time of acquisition by the initial investment involved. According to (Vanderhorst, et al., 2021) there is a workflow that led the implementation of the UAVs in disaster management but did not provide technical explanations. However, it was updated with the prices for understanding in the first step of UAV applications.

However, in disaster management context time is the most valuable asset that UAV, in any professional model, provide indisputably (Álvares, et al., 2018; Vanderhorst, et al., 2020). There are operations with RGB cameras and LiDAR that have been carried out in the literature to understand the accuracy of the works (Wang, et al., 2021). Another study in applying the UAV methodology for pavement damaged by landslide propose 2D and 3D reconstruction of the road and then, utilise the data obtained for damage typology and risk evaluation (Nappo, et al., 2021) The study identified cracks wider than 1 cm, the 3D models were used to locate anomalies, rapid detection of damages and road distress. In disaster from landslides accuracy depends on the UAV used, internet connection and surface conditions (Mao, Hu, Wang, & Long, 2021) Nevertheless, the methodologies of UAV operations for landslide are contrasted in Fig. 2 in a summarized aspect. The walking distance is substituted with the UAV operations, but certain qualitative data remains in the process.

3. Methodology Of The Uav Approach For Landslide Recognition

In the Dominican Republic, there are entities that carry out investigations regarding geological effects before disaster. A methodology was reported as a part of open-ended questions related to the application of UAV in the institution and experiences from the author. The institution has applied the UAV for disaster management, mining, risk evaluations of underground water, generation of data base for urban planning and amenity characterisation, geology systems, etc. The UAVs used in the organisation are from the contractors. Then, they face the issue of inaccuracy in the details of site data acquisition. Therefore, the UAV used for this assessment was the DJI phantom 3 professional with 12MP. The operation was carried out in different locations near and at the community. Two locations were selected to make the deployment following the steps:

(1st) Identify the area of study in google earth assessing their routes of communication to the community. It was important to document any anomaly in the surroundings as construction sites, infrastructure development, alternative routes, building arrangement, rivers, mountains, etc. for general site descriptions.

(2nd) Appoint deployment sites for the UAV aligned with safety and regulations requirements. These points allowed to deploy the UAV in a low-risk urban environment.

(3rd) Evaluate weather conditions for optimal sunlight time, wind speed, and functioning of the UAV.

(4th) Program the photogrammetry path according to the UAV specifications of the manufacturer and tolerable accuracy for the reconstruction.

(5th) On site, it is crucial to take all the necessary safety measurements against information that might have not been shown on google maps as in satellites may take time to update their maps. Furthermore, conversations on site were required with the locals and the teams of professionals from geologists, engineers and topographers fields to understand the purpose of the assessment. In terms of UAV deployment, it was strongly recommended to explain the type of operations to the locals as fear of death after a natural event may rise. In some cases, locals may perceive the UAV operations as an attempt for their life or an object to shoot as maybe flight around properties in urban areas.

(6th) Oblique, on zenith and panoramic images that can capture the description of the site. Images on zenith position were utilised for obtaining the GPS coordinates of the infrastructures and houses for updating the GIS maps of the entity investigating the case. Then, videos in different trajectories were required to understand the overview of the emerging community. As a quadcopter was available for acquiring the data, videos were utilised to feed the limitations on mapping the community area. A 360° video on adequate heights according to the regulations and permissions in place were made.

(7th) Then, finally, the data acquired was processed utilising photogrammetry software for Digital Terrain Model and contour lines extraction. This information allowed the professionals to identify the type and cause of landslide in the zone.

The seven steps led the UAV assessment, and the information extracted support the digital workflow of the organisations. The workflow presented can be visualised in the following perspective:

Figure 3 is a workflow that described the steps to consider before operating UAV. The ideas with red shadow represent the case requirements.

Furthermore, these type of approach and workflows allow researchers to map the components towards UAV operations from a decentralised system perspective. Councils may have their own early warning program and data base that along with other robots significantly can mitigate and address challenges related to this nature. However, the sensors play an important role in quality assurance of the assessment according to the terrain surveyed. Normally, technology of photogrammetry shall be used for description and LiDAR for accurate surface model. In addition, the type of data acquired should be connected with workflows within digital twin, geographic and city information systems, smart contracts or metaverse experiences in order to maximize the data usability. Virtual training on landslide management and identification of structural damages for future reconstruction of cities. Nevertheless, there are some barriers in operating these types of tools. They are regarding safety, privacy and accuracy by the elements that covers the terrain. Furthermore, the costs of these tools should be evaluated previous the flight to understand the impact of the study.

4. Site Identification Of The Landslide

In the Dominican Republic landslides are phenomena less faced as hurricanes (LeBlanc, et al., 2017). The literature in landslide at the country is not documented in the research domain. Rockfalls and landfalls are events that occurs as a consequence of heavy rainfall in highways between mountains, at the north of the country and other places, and are managed by the entities in charge of maintenance.

Furthermore, in cases of settlements near to rivers, floods are the leading in devastating communities as the case of Jimani (Gomez-Valenzuela, et al., 2021). Earthquakes are a concern in the country and investigations to regulate the urban planning around high probability of damages are considered (Novelo-Casanova, et al., 2020). Therefore, the landslide phenomena may have different reasons according to the area of manifestation.

The coordinates (18.4600247; -70.1071018) identified the emerging community of Santa Maria near to the river Nigua. This community is connected through 2 ways: Carretera Medina and a route connected to the 6 of November highway. The community has a small population around 700 people in a 350,000 m^2 and disperse houses. The access of the community was limited by the river flows for the Carretera Medina and alternative route was made in place during the bridge construction as in Fig. 4.

Some images have been taken from: (Vanderhorst, 2021)

Figure 4 is described the site of the landslide. (A) is the panoramic view from the river to the community in which the school and the deployment site were located. (B) is the landslide crown observed close to the 2 houses inflicted. (C) is the panoramic view from the school to the landslide site and river observing the electrical towers. (D) is the location 1 of the first deployment in front of the 2 houses damaged. (E) Cracks perpendicular to the main road. (F) Alternative road and bridge construction. (G) Map that locates all the points and connection with principal highways.

The soil of the community of Santa Maria at San Cristóbal providence is in a zone composed by alluvium and lower terrace of the Nigua River, with a general composition between sand, silt, and gravel. The composition of the soil is sensible to the cascading effects of telluric movements, erosions, ground saturation and raw material production from the River Nigua. Since 2017 the community has experienced land cracks with more than 15cm of expansion and spontaneous landslide that attempt the safety of houses, schools, and the route of land communication of the routes that connect to the principal highway 6 of November (Moya, et al., 2018). The area presents a landfall of more than 10m in a surrounding. The conversations with the locals' inhabitants produce the story of the landslide in the zone. In a land next to the River Nigua 2 families were affected by the sudden land cracks that later were expanding into a fissure. Concrete house was damaged in their slab debilitating their structure. The other house suffers less impact has their construction were less solid with zinc. As the zone did not represent a critical area for earthquake, or previous landfalls without heavy rains were not reported, assessment of the different elements were carried out. Then, the engineers started to evaluate different infrastructures, buildings and soil structure that could indicate a future risk for the congested site of the hamlet with a church.

Figure 5 shows the 5 points of risks identified during the visit at the site. In red is the landslide site in investigation.

The elements of electrical tower and schools area were not possible to evaluate from google earth and images with the UAV were taken to acquire their coordinates and observe the geological structures of the zone. The images were captured in an average altitude of 105m from the sea level. The images that contain information of the cracks and fissure visually provided an understanding of the type of landslide in questions. The size and the damages occurred seemed to be provoked by an abrupt vibration of the soil rather than a water saturation. Furthermore, in the second deployment site, was reconstructed landslide area for measurements as it was difficult to access the main fissures. Several of them were found at different heights of the hillside. Robust trees were cut in half by the fissures. The UAV was programmed to carried out a semi-autonomous operation in a low-risk area at 65m height. The software pilot made easy was supporting the operation. 200 pictures were taken surveying approximately 120,000m^2. The photogrammetry images captured perpendicularly to the surface were processed utilising the software Pix4D. The area of interest was around 36,000 m^2 that included the houses, the road and the landslide effects.

Figure 6 identifies the photogrammetry grid taken to map the landslide area near to the community of the urban area of Santa Maria. It was utilised a semi-autonomous operation with a Phantom 3.

The software allowed the project to generate the orthomosaic georeferenced and produce contour lines at 1m & 5m in order to understand the slope of the landslide. The 3D object provided an approximate and tolerable length of the mass movement. The cross section of the landslide permitted to utilise trigonometric methods to identify the slope. The first method of measurement was carried out taking polylines and segments of the most prominent landslide crown and estimating its depth and displacement. Different measures were taken as the .obj file have various points of intersections that the measure may vary according to the perspective taken.

Figure 7 shows (A) describe the crown length with and in (B) the distances measured.

Then, the cross-section model was designed to understand the angle and the slope for its classification. The cross section of the landslide crown was draw as an example of trigonometric extraction of the angle and slope by the authors as contour line method was developed for these purposes.

Figure 8 shows the cross section drown for represent the angle of the landslide.

The process followed to identify the angle was:

Equation 1. Slope of the Landslide

$$\theta = \sin^{-1}\left(\frac{5.59}{10.08}\right)$$

$$x = \frac{5.59}{\tan(33.68°)}$$

$$Slope = \tan\left(\frac{(5.59+3.08)}{6.20}\right) \cdot 100$$

In this equation the angle of the first triangle formed. Then, the subsequent equation (x) is extracting the adjacent value of the triangle with the angle found of 33.68 ° to finally identify the Slope utilising the values found from Fig. 8.

Then, the slope of the landslide was visible abrupt that these kinds of slope of 71.51% with an angle of 54.42° are produced by specific kind of event such as earthquake as seen in (Devoli, et al., 2008). However, the engineers and professionals in the study were advocating towards the traditional method of contour lines for assurance purpose and difficulties in extracting the cross-section. The normal workflow of the organisation did not support 3D representation by the computational requirement, understanding of interoperability of the tools within the UAV outcomes and the funding allocation for technologies were limited as qualified personnel in UAV were not available.

Figure 9 describe the superposition of the contour lines over the orthomosaic. The superposition contemplates (A) superposition of contour lines at 1m between them and (B) zoom of the superposition of the contour lines at 5m each one. As in (A) the lines were not clear to count the delta variance, (B) the contour lines at 5m were used.

The contour lines provided a descriptive perspective of the Digital Terrain Model (DTM) by supporting the traditional workflow and validating the results from the 3D reconstruction.
Equation 2. Slope of the Landslide by Contour Lines Methods

$$\text{Slope} = \left| \frac{3 \times 5 \text{ meters}}{6.3 \text{ meters}} \times 100 \right.$$

In this equation is presented the calculation of the slope utilising the contour lines at 5m between them from Fig. 9 (B)

The slope of 42% with 67.22° confirmed the fact that the landslide is a steep abrupt and the cause of its occurrence is around telluric movements. Despite they are from the same data base, the accuracy of the contour lines was less precise than the 3D object. The average of 60.82° with a slope of 56% provided an understanding of the magnitude of the landslide in the specific area shown. The data regarding the steep provided indications of explosions or earth movement has been carried out in the area (Zhan, et al., 2021). Finally, a video was recorded at different heights of the site for volume interpretations and site inspections. In the middle of the meander at 47.5 m of height was located the UAV and turned into several directions to provide a panoramic holistic view of the site conditions. The main area of the landslide was recorded and by visual representation, the type was also identified. The video provided awareness to the engineers about other construction sites as a bridge in the opposite site of the landslide.

Figure 10 is providing the relative location of the UAV and the different views taken to capture the phenomena site conditions. In (A) it is represented the methodology and in (B) is the example of landslide evidence.

5. Discussion

After the 3 assessments of the landslide, different parameters were taken in consideration to provide the final decision regarding the origin of the event. The country is, in a certain degree, active in geological movement and it maybe one insight of the event. However, rainfall and the proximity of the river provoked doubt of the origin as landslide in tropical area may occurs by heavy rainfall. But, in this case, it was the first time happening in this particular area the landslide with a slope of 56% provoking a steep (Devoli, et al., 2008; Zhan, et al., 2021). The ground evidence of the houses cracks, land cracks and the steep of the landslide gave the conclusion that an earthquake was occurred but do the locals were aware of this? An early morning first fissures but vibration as earthquake was not reported although compaction and perforations tasks may be occurred on the bridge site. Therefore, the evidence of the angle, slope, visual representation, and videos of the surroundings provided an understanding of causation regarding the landslide. The bridge construction was a new element that was interacting within the proximity of the community. Different construction works were carried out at the edge of the river that it was inferred that the landslide was provoked by mass movement and drilling tasks in the proximities of the community. Then, the nature by itself restored it equilibrium by moving mass from the opposite site of the construction. Therefore, possible explosions, material extractions and construction work directly affected the landslide site provoking vibrations that moved mass for natural environmental restoration as close mentioned in the different typologies in (Zhan, et al., 2021; Hungr, et al., 2014) with small-collapse landslides or rotational landslide. Further research was carried out in the near school as it presented a risk of occurrence during the bridge construction. Furthermore, the workflow of the UAV implementation for landslide was partially successful as different limitations were involved. For future assessment, the workflow of UAV implementation may seem as the Fig. 3 where it is explained the conditions to consider before operation.

6. Conclusion

In this study was evaluate the methodology of UAV application for landslide. In the literature was found few studies related to this topic and also in the context of the Dominican Republic. The typologies of landslides are related to the flow and materials of the soil. The methodology of UAV was partially useful for data acquisition as the site was inaccessible and measurements were not considered. Each approach helped to support the understanding process of the landslide origin. Furthermore, the acquisition of data for update the database was an advantage perceived against the traditional workflow in the organisation. The 3 elements of images, 3D reconstruction and videos were suitable for the purpose of data sharing. Visual representation of the outcomes provided insights of the type of landslide in place as rotational landslide. The contribution to knowledge of this paper was to provide to professionals in operating with UAVs an appropriate methodology for change management within their organisation. Small rural communities can be positive benefitted as real-time capturing data provide updates of the hazards in the area. Different aspect in change management, digital twin and decentralised systems should be contemplated for further research.

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Conflict of Interest/Competing Interests

The author declares that there are no known conflicts of interest.

Code or Data Availability

The data that support the findings of this study are available from the corresponding author, [HRV], upon reasonable request. Software used: Pix4D and MeshLab.

Author's Contributions

Hamlet Vanderhorst: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Visualization, Investigation, Writing- Reviewing and Editing.

Consent to participate

Written informed consent was obtained from the project.

Consent for publication

The participant has consented to the submission of the case report to the journal.

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Figures

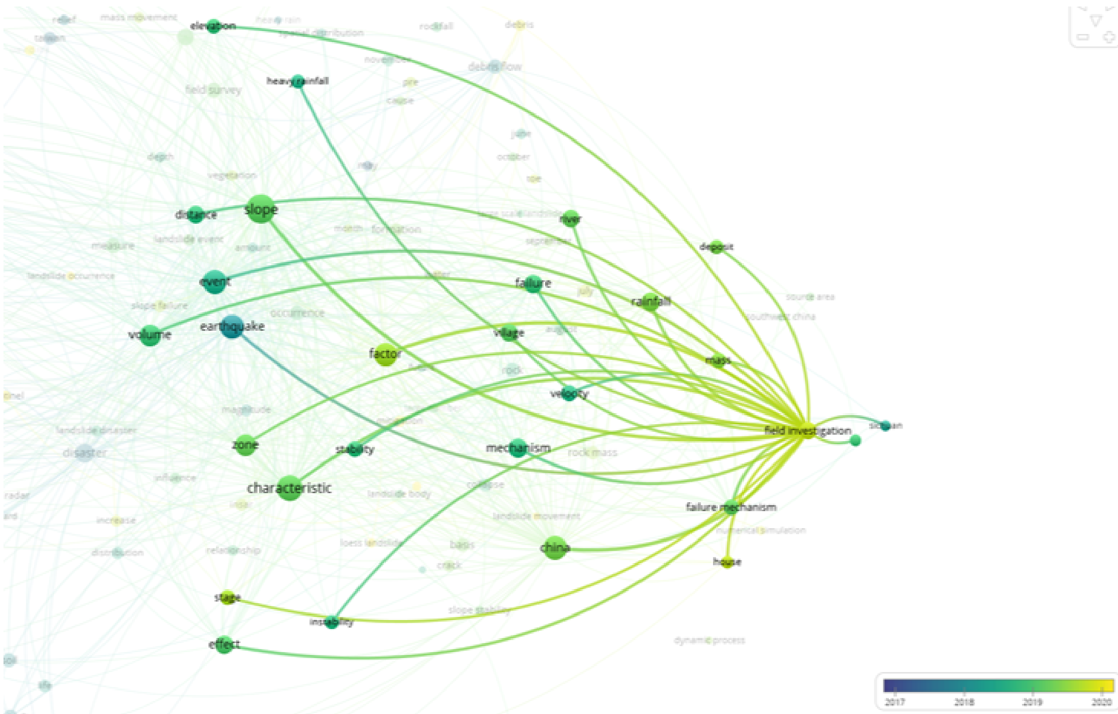

Figure 1

Keywords of VOS viewer of Landslide and UAV literature research (2004-2022)

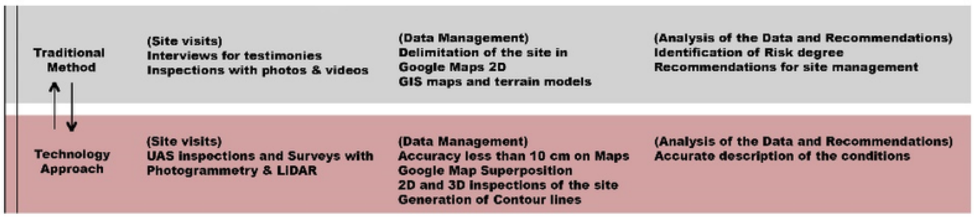

Figure 2

Traditional Workflow improvement

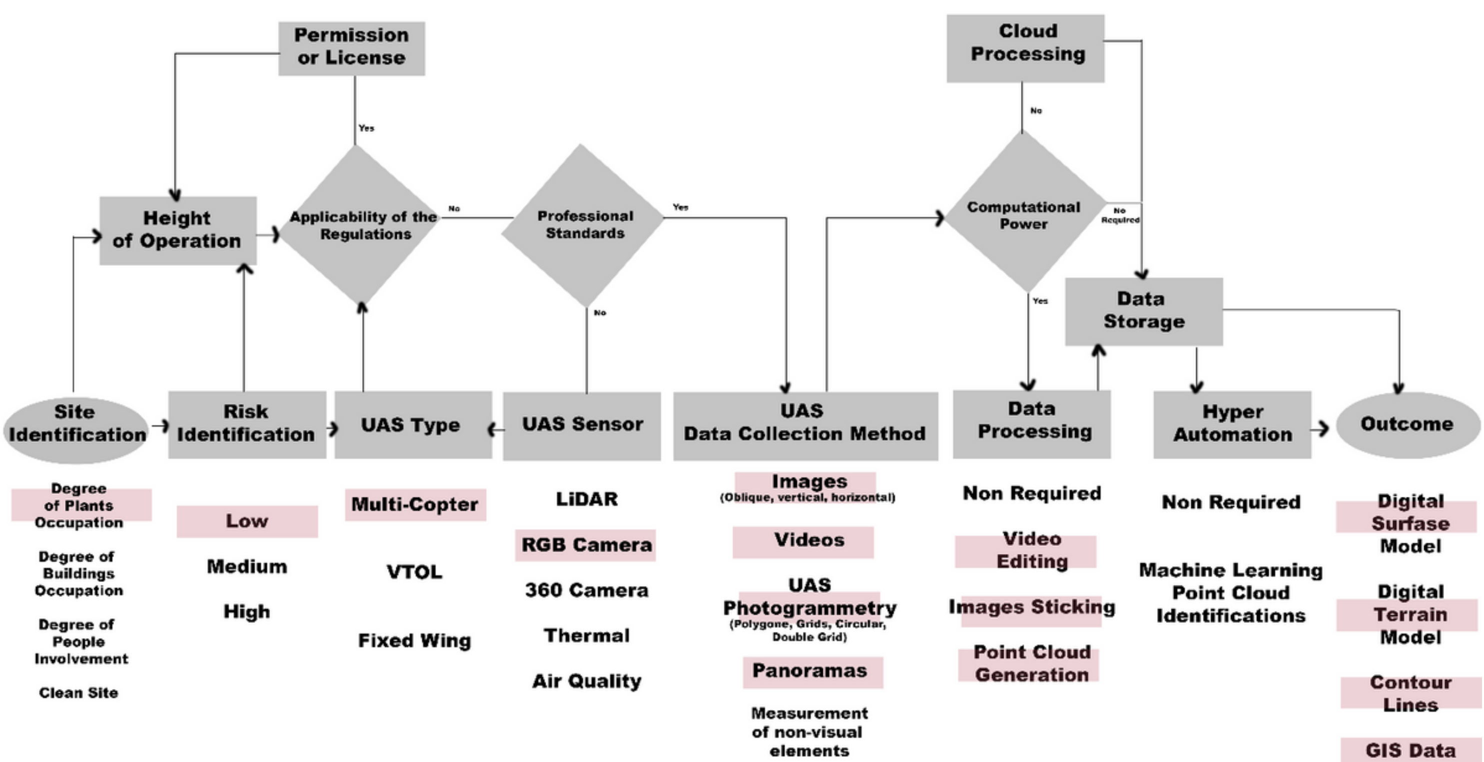

Figure 3

Workflow for UAV Deployments and Data acquisition

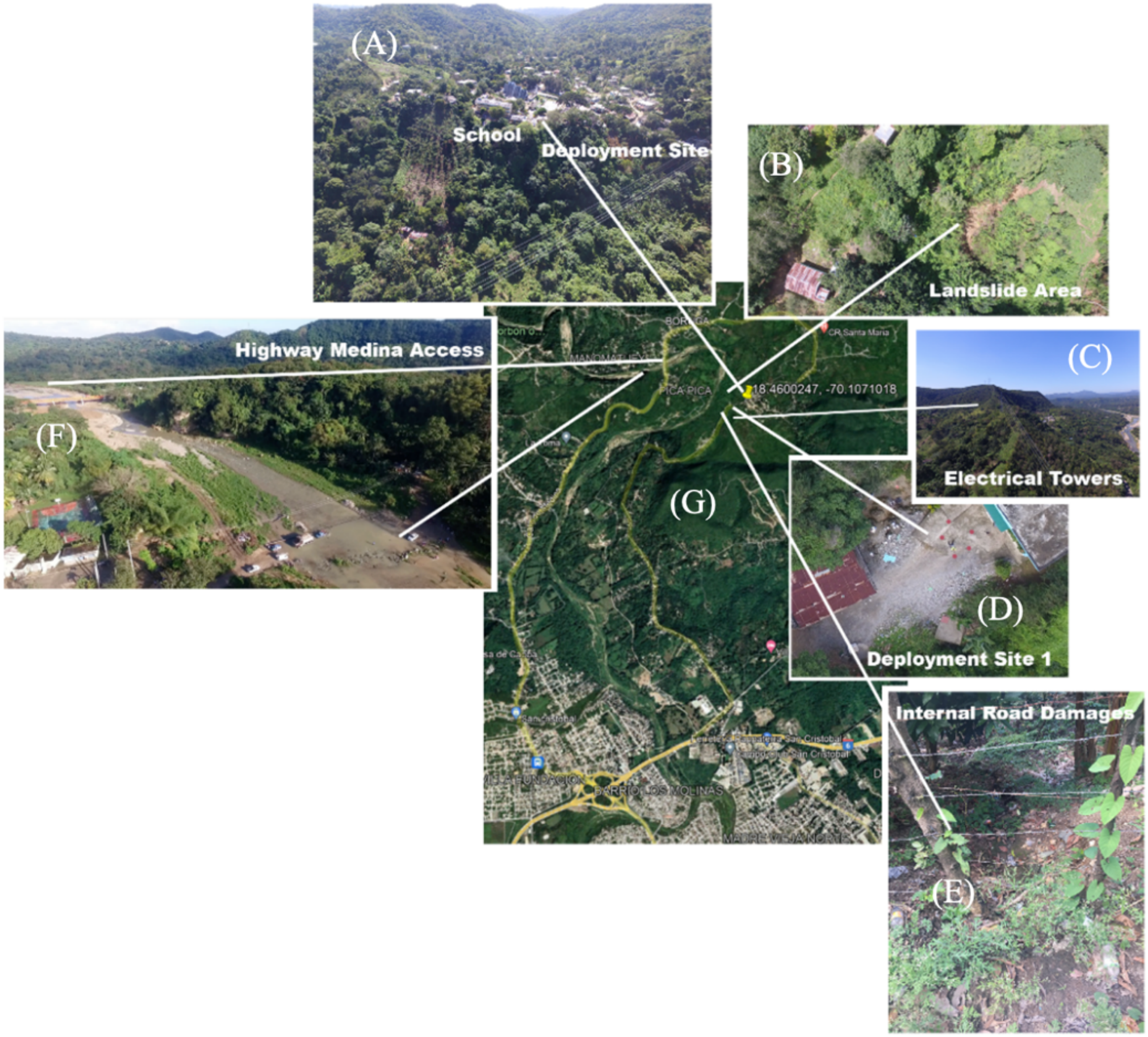

Figure 4

Site Study Descriptions

Figure 5

Risk Evaluations of the site

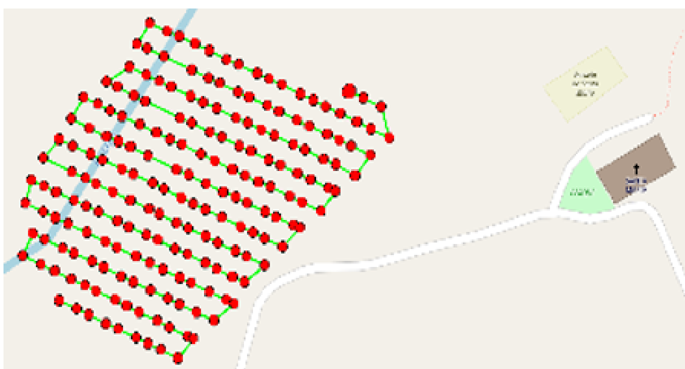

Figure 6

Photogrammetry Mission

Figure 7

Landslide Cross Section

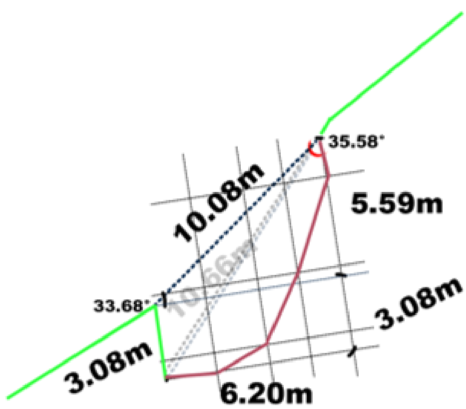

Figure 8

Cross section of the landslide for Angle and Slope Identification

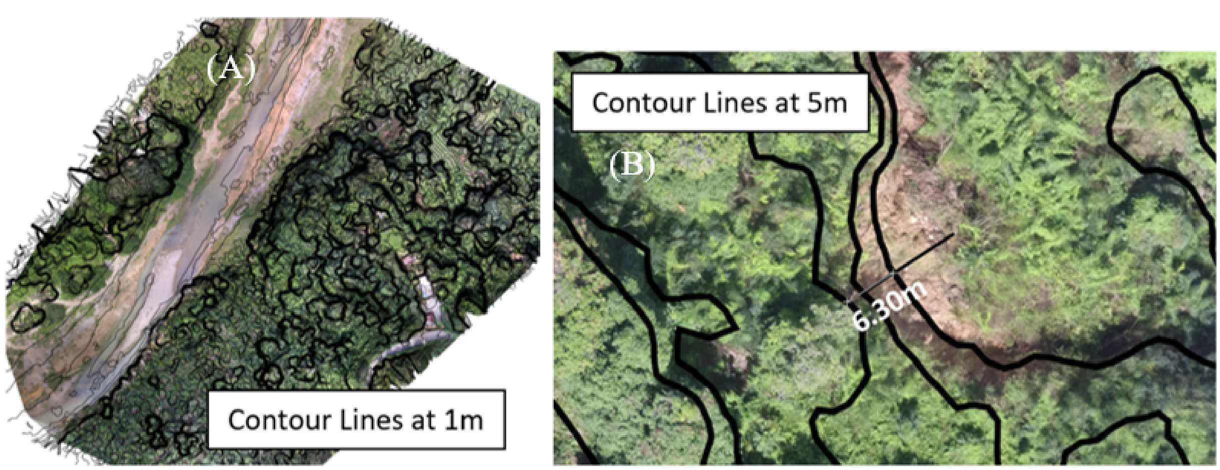

Figure 9

Contour Lines for Slope identification

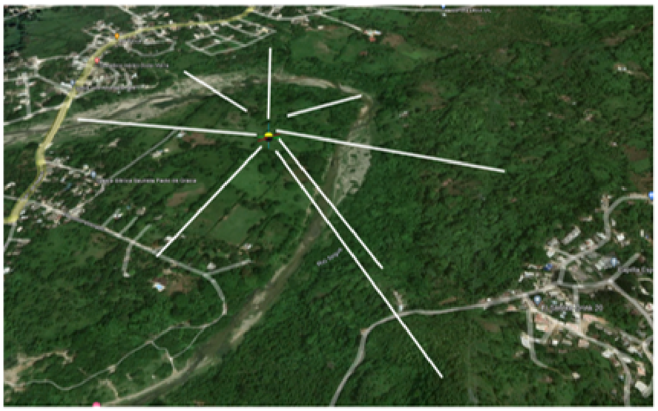

Figure 10

Video Visualisation and 360° views of the site