The use of emerging technology in post-disaster reconnaissance missions

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Abstract

Recent advances in unmanned aerial vehicles (UAV) or drones and omnidirectional camera technology may have a useful role to play in improving the outcomes of post-earthquake reconnaissance missions. High-resolution aerial images acquired using UAVs can provide additional vantage points to observe damage, and omnidirectional imagery can be used to virtually 'walk through' damaged streets with a 360 degree view. In this study we explore the potential for virtual damage surveys by comparing damage surveys completed on the ground (ground-truthing) with omnidirectional images collected during the mission and interpreted by a virtual surveyor after the mission . Our results show significant abilities in the identification of construction typology, number of storeys and for aggregated 'low' and 'high' damage grades. Our work also highlights issues with correct identification of unaggregated lower damage grades (EMS 98 damage grades 0 - 3). Challenges identified in the virtual survey included poor image quality, insufficient photo sphere captures, and obstructions such as trees, walls or vehicles. Aerial images can have numerous benefits to reconnaissance missions: construction of a 3D model of a damaged building created from a series of drone images enable much clearer identification of damage and failure mechanisms when compared to 2D photos, however challenges, such as flight restrictions, transportation of the drone, and pilot training may prove problematic. We conclude by offering guidance for the use of UAVs and omnidirectional cameras on future EEFIT missions.

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Introduction

Post-earthquake reconnaissance missions play an important role in learning about the performance of infrastructure, the social impacts, the disaster management process, and the science of seismic events. The Earthquake Engineering Field Investigation Team (EEFIT) is a UK based organisation that organises reconnaissance missions in order to: 1) carry out detailed technical evaluations, 2) collect geological and seismological data, 3) assess the effectiveness of earthquake protection methods, and 4) to study disaster management procedures and socio-economic impacts. To better meet these objectives, technology is being increasingly employed on missions, and future technological advances may enhance mission capabilities even further. Over the years, EEFIT missions have used film and then digital cameras and GPS stamping to record the post-earthquake situation; hence advances in technology for image capture are of particular interest to reconnaissance missions.

Omnidirectional cameras capture a photo sphere providing the views of the surroundings in a damaged street or in a damaged internal space. Chains of omnidirectional images are used by Google Street View to give the viewer an immersive 'walk through' of a street, and these chains can be collected post-earthquake and used to derive statistical damage data. UAVs (unmanned aerial vehicles) or drones allow images to be taken from an elevated vantage point, providing additional views of damaged buildings and the surrounding affected area. They have been used in numerous contexts including geographical mapping, site inspection, agriculture, and search and rescue (Chen et al., 2016).

Both drones and omnidirectional cameras have the potential to improve the findings of post-earthquake reconnaissance missions, however their purpose needs to be clearly defined and their capabilities and limitations understood to enable confidence in the reliability of the data that they can captured. This study investigates the latter objective by testing both of these technologies in a post-earthquake reconnaissance mission environment; namely the EEFIT mission to the 16 April 2016 Musine earthquake in Ecuador. Details of the event can be found in the EEFIT report and in Franco et al. (2017). This study focuses particularly on structures and the impacts on buildings, but these technologies also have capabilities in investigating geological, seismological, and socio-economic impacts in post-disaster contexts.

This report considers the increasing role technology has played in recent years in earthquake engineering reconnaissance missions, and investigates how the technology has and can help EEFIT teams to meet their objectives. Results from in-field testing are presented and the benefits and challenges of using drones and omnidirectional cameras are discussed. Finally, guidance on the use of this technology in future EEFIT missions is offered.

Advances in imaging technology

The omnidirectional camera

An omnidirectional camera takes 360 degree videos and photos, also called photo spheres. A range of omnidirectional cameras are available; the main differences are in the camera quality (i.e. image resolution), and available settings for the photographer (i.e. timers, exposure settings, etc.). Most come with GPS tagging capabilities. Recently, a number of new models have come onto the market at the lower price range from the main camera manufacturers.

The camera tested on the Ecuador mission was the Ricoh Theta S (see Figure 1). The camera is attached to a pole and held above the photographers head or attached to a vehicle (see Figure 2). Photographs or videos are taken through an app on a smart device. The images can be plotted using the tagged GPS onto a map and viewed by uploading to online platforms such as Google Street View or Mapilliary (see Figure 3).

Extensive damage data is difficult to collect on reconnaissance missions due to the lack of resources (time and people), however it is important for the derivation and calibration of fragility and vulnerability functions and to guide future risk management initiatives. The use of an omnidirectional makes extensive surveying more viable through ‘virtual surveying’, where users can remotely ‘walk through’ the streets on a computer or even using virtual reality headsets, and complete damage surveys. Clearly there are significant uncertainties with the validity of information inferred from this remote method, and these, along with the benefits of this process, are investigated in this study.

Figure 1 - Ricoh Theta S omni-directional camera

(a) (b)

Figure 2 - Omnidirectional camera (a) surveying by foot © EEFIT or (b) using a vehicle © Harriette Stone

Figure 3 - The online Mapillary street viewer with images from Pedernales, Ecuador. The route is plotted in the bottom left corner with the current location and direction of view marked in orange. Link: https://www.mapillary.com/app /?lat=0.06918967561799573&lng=-80.05812317253317& z=17&pKey=ZDHfvfvwCwRX6WKBZmxJHg&focus=photo

The UAV

Ownership of UAVs has increased vastly in recent years, as the technology has become more affordable. As well as for leisure purposes, UAVs are used for an array of commercial purposes (Chen et al., 2016). UAVs come in all shapes and sizes and have a range of capabilities and price tags. More advanced models have a camera attached which can take photographs and record videos; some have a stabilising gimbal to hold the camera steady and others allow the live image to be viewed and controlled remotely on a smart device. The most advanced models currently available can fly inside buildings and confined spaces using radar collision-avoidance technology. Each advance in technology usually includes improvements to the UAV's batteries, which are the main limiting factor in the length of flight times. Smart batteries are used on advanced models, where feedback on the battery status is given and if it falls below a certain level the UAV uses an on-board GPS to automatically 'returns to home', before the battery runs out, reducing the risk of an accident due to power failure. The UAV used in Ecuador was a DJI Phantom Vision 2+ drone (see Figure 4), which has its own camera on a stabilising gimbal and allows real-time viewing and controlling of the camera through a smart device (e.g. smart phone or tablet).

Figure 4 - DJI Phantom Vision 2+ model UAV

Technology in past EEFIT missions

Omnidirectional camera

Omnidirectional image collection was completed for the first time on the Ecuador mission (see Figure 5), with over 2000 images taken in a number of cities and towns. The Amatrice, Italy mission team subsequently used the camera in urban areas.

UAV

UAVs have been taken by EEFIT on reconnaissance missions since the 2015 Gorkha earthquake in Nepal, although they were not flown in Nepal due to flight restrictions. The three EEFIT missions in 2016 to Kumumoto, Japan; Musine, Ecuador (see Figure 6); and Amatrice, Italy all took UAVs with differing levels of success. In Japan, the team used the UAV to map sections of the fault rupture and photograph landslides. In Ecuador, the team used the drone to photograph landslides, map large-scale ground failures, and observe building failures from a safe distance. In Italy, the geotechnical team was unable to use the UAVs due to poor weather conditions, and in urban areas it was only used for a short flight as restrictions on flight were not clear.

Figure 5 - Omni-directional camera in use in Canoa, Ecuador © EEFIT

Figure 6 - The pilots of the EEFIT drone in action in Pedernales, Ecuador © EEFIT

Methodology of equipment testing

Both UAVs and omnidirectional cameras were tested on the EEFIT Ecuador 2016 reconnaissance mission. The different capabilities were tested, and the challenges of use in the field noted. Upon return from the mission, the data collected has been analysed further to investigate any additional benefits or challenges. Here, the methodologies for testing are presented.

A number of ground surveys were completed in the field to collect information on the construction type, number of storeys and the EMS-98 damage grade (Grunthal, 1998) of each building on various routes selected. This enabled the team to report some damage statistics as one of the key findings. The omnidirectional camera was used to collect photo spheres along the routes used for ground surveys in Pedernales, Portoviejo, and Manta. This collected omnidirectional imagery was uploaded to Mapillary (see Figure 7). An independent experienced engineer was recruited to act as a virtual surveyor. They were given a briefing on the main construction typologies found on the mission and the EMS-98 damage grade system. Two calibration exercises were completed, where the author and the virtual surveyor discussed the results each would record, discussing the reasons for the decisions until agreement was made. The virtual surveyor worked for 30 hours virtually walking the survey routes and assessing each building on both sides of the road. In total, over 450 buildings were surveyed. The virtual surveyor was interviewed at the end of the exercise to understand the main challenges that they faced. The results from the virtual survey were then compared to the results from the survey carried out on the ground in order to investigate the challenges and benefits of working with this technology.

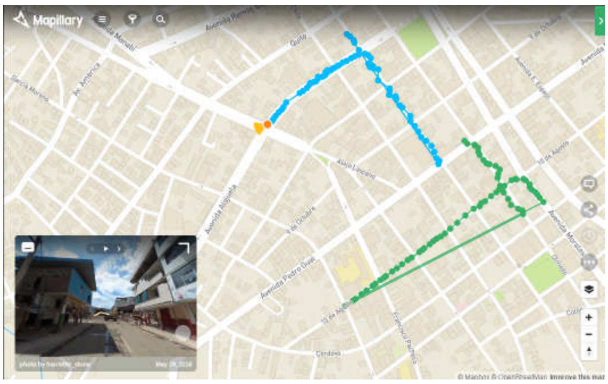


Figure 7 – Mapillary view of upload of photo spheres. Link: https://www.mapillary.com/app/user/harriette_stone?lat=-1.0560257101561206&lng=-80.45393932642779&z=15.923973722035676&pKey=Sj2r-qVLVeMDHTDNPKTtvg&focus=map

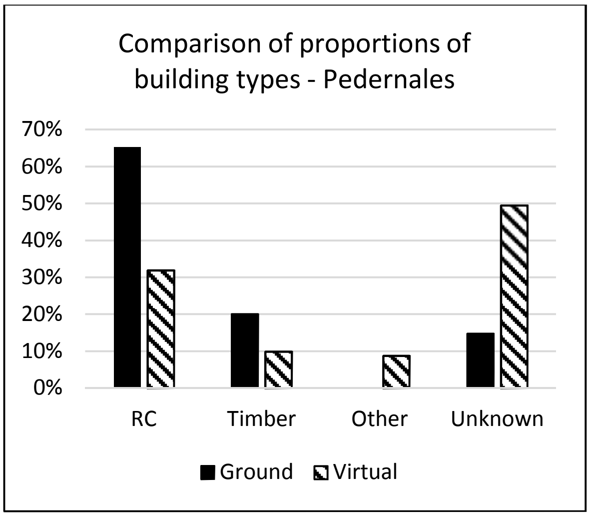
The UAV was used to take aerial images of damage streets to assess the viability of observing additional information about damaged structures. Additionally, the UAV was used to test the formation of a 3D model of an individual building using a series of videos of a damaged building in Portoviejo. Upon return, a 3D model of the building was constructed using frames from the video footage and photographs from the ground. The software Agisoft PhotoScanPro was used to stitch together the images into a 3D surface model using the same method as described by Yamazaki et al. (2015). The resulting model is used to discuss the potential benefits of this technology, as well as the challenges faced, helping to guide future usage on reconnaissance missions.

Results and discussion

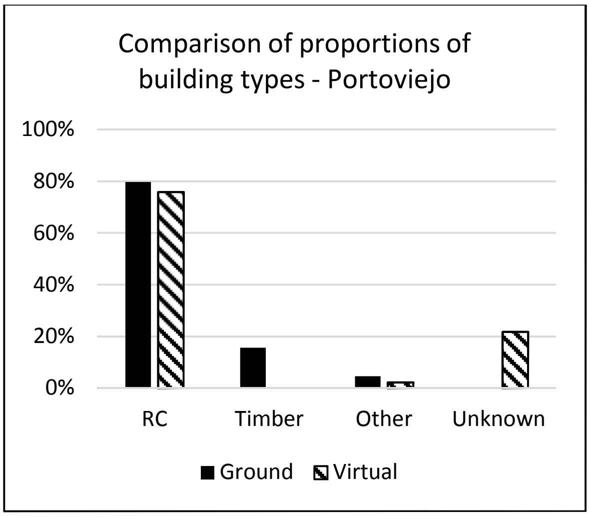
Omnidirectional imagery

The comparison of results between ground and virtual surveys offer an insight into the ability of virtual surveys to accurately capture the post-earthquake situation. Differences in results between the virtual results and the ground results could, of course, arise due to surveyor biases and errors (both on the ground and virtually), or difficulties in observing buildings (or demolished plots), however other discrepancies will be down to the challenges of using this technology. In this work, we do not assess differences that may occur between surveyors collecting data by the same means (i.e. difference between results from different ground truthers).

Firstly, the resulting proportions of different construction types are presented in Figure 8 for the three towns separately and together. We can see that the virtual results consistently report more unknowns, due to the difficulty in positively identifying construction types. This is particularly present for the lesser damaged buildings where cladding and finishes are more likely to remain intact. For Portoviejo and Manta, the proportions of each construction type are comparable whereas in Pedernales the number of unknowns is much larger. This is likely to be due to the vast number of demolished buildings, for which ground surveys had a better chance of ascertaining the number of and the construction type of the removed building through remaining foundations or the local knowledge of assistants or people on the street; however, this also presents difficulties as field observations collected in this manner may be biased. In Manta, timber buildings were not identified accurately in the virtual survey, probably due to timber elements being obscured by facades or finishes, e.g. see Figure 9, to give the appearance of RC structure: on the ground this practice was more obvious as surveyors could view the columns more closely, or see timber structure on the underside of overhangs potentially not visible on the nearest photo spheres.



(a)



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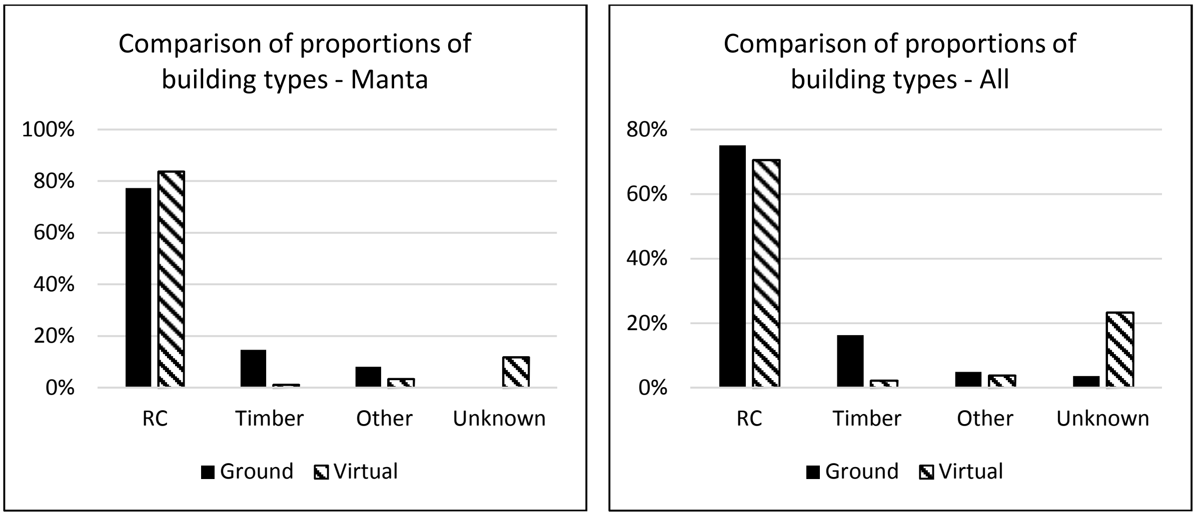

(c) (d)

Figure 8 - Comparisons of proportions of building types identified for (a) Pedernales, (b) Portoviejo, (c) Manta, and (d) Overall

Figure 9 - Hidden timber structure, Manta, Ecuador © EEFIT

The number of storeys is another surveyed parameter that has been compared between ground and virtual surveys; the results are given in Figure 10. Generally, the results compare well, however, there are clear issues with unknown heights of demolished buildings in the virtual survey, which were understood by the ground surveyors, especially in Manta where most demolished buildings could be viewed prior to the earthquake in Google Street View, (and this was used in the ground survey results only).

In addition, the virtual surveyor reported that they had ignored any additional light metal roof structure constructed on top of an RC frame, e.g. see Figure 11, unless masonry walls had been raised up to the new roof level, whereas in the ground survey all storeys, regardless of material, were recorded. This discrepancy could be overcome with appropriate training. This building practice (as seen in Figure 11) was common on the Manta and Portoviejo survey routes. Also, the number of storeys recorded was the maximum for each individual structure, and sometimes buildings had extra floors but set back away from the road. In some circumstances the highest floor height may not be visible or clear in the nearest photos spheres, e.g. see Figure 12.

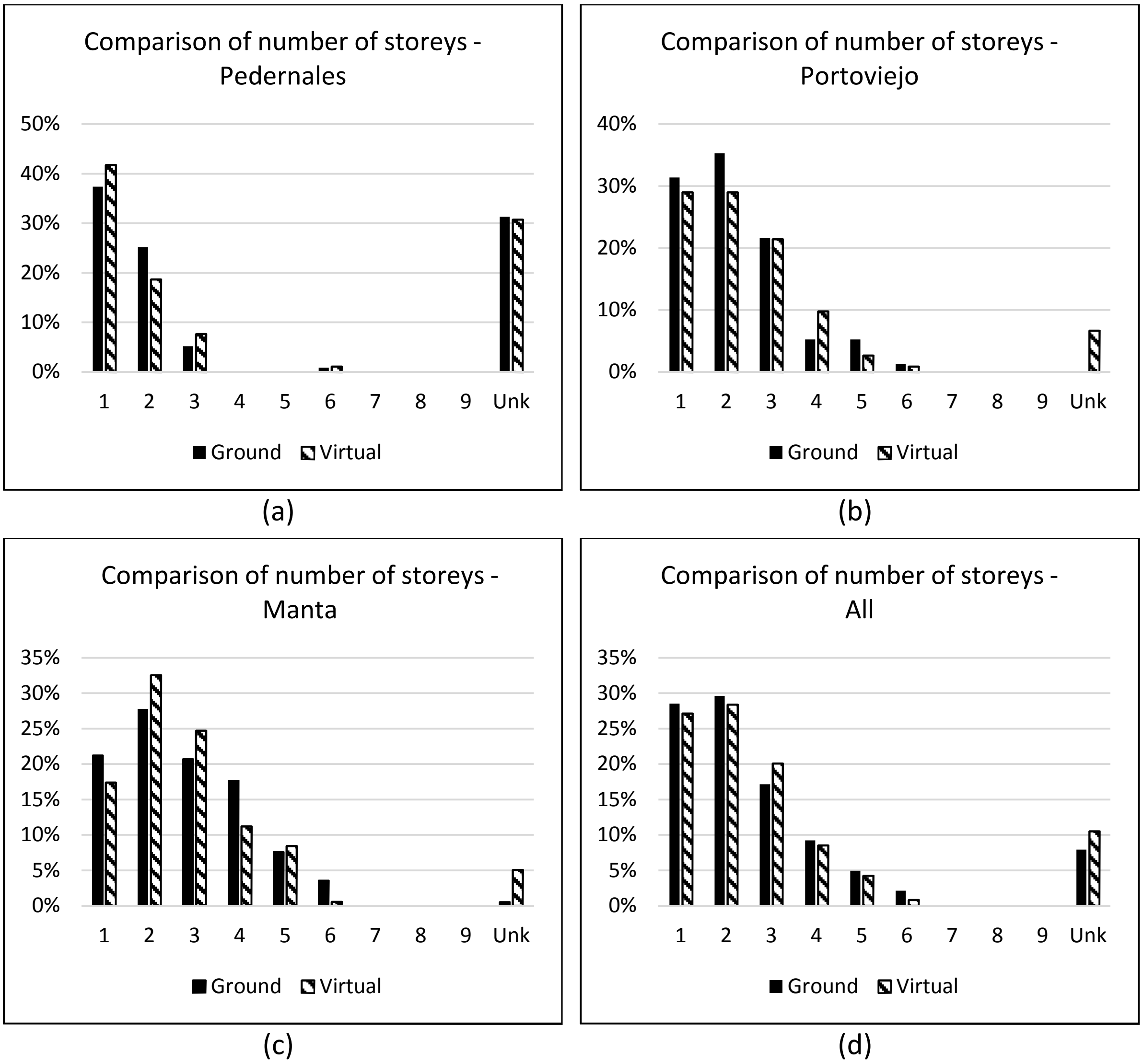

Figure 10 - Comparisons of proportions of number of storeys identified for (a) Pedernales, (b) Portoviejo, (c) Manta, and (d) Overall

Figure 11 - Light metal roof addition, Manta, Tarqui ©EEFIT

Figure 12 - Set back additional floors in Manta, Ecuador © EEFIT

The final comparison between survey results is between recorded damage grades. This is the most difficult data to collect and is likely to attract a significant proportion of surveyor bias and error. It is particularly challenging at the lower damage grades as it can be more difficult to define a clear grade that satisfies both the structural and non-structural damage criteria. Additionally, clues of light damage cannot always be observed in a rapid walking speed survey or in relatively low resolution photo spheres. A number of benchmarking exercises were completed by the ground team, aiming to reduce biases in the results.

The results show that it was difficult to identify the lower damage grades accurately in the virtual survey which agrees with the comments from the virtual surveyor who cited poor image quality and stretches of street with photo spheres spaced too far apart. This finding highlights a potential need for a new damage scale that may be used for virtual surveying, aggregating little or no damage together, but still distinguishing between significant damage, and partial or total collapse.

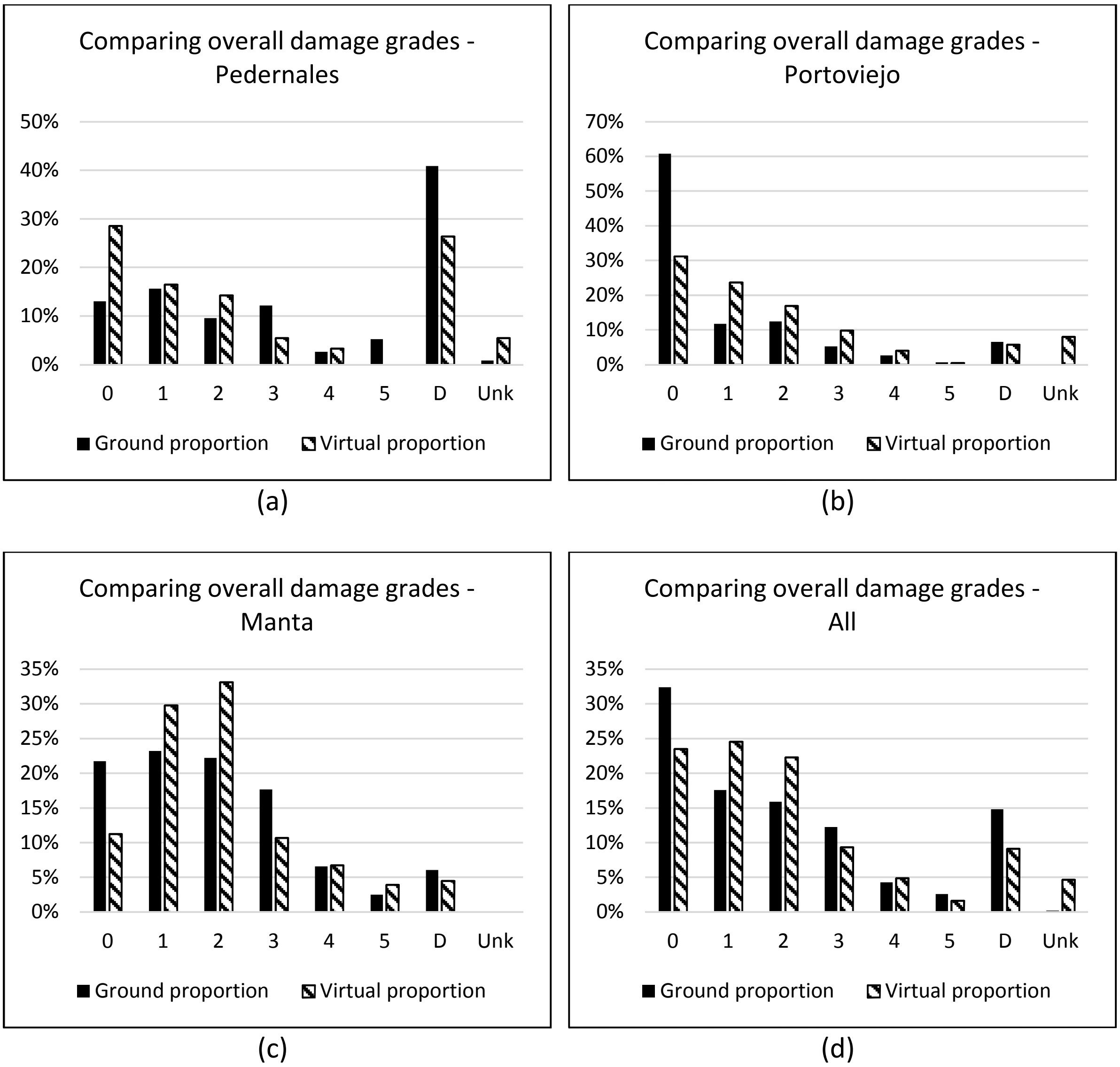

Figure 13 - Comparisons of proportions of overall damage grades identified for (a) Pedernales, (b) Portoviejo, (c) Manta, and (d) Overall

When the damage grades are aggregated into ‘Low’ and ‘High’ damage, corresponding to EMS-98 damage grades 0 to 3, and 4 to demolished, the results compare well (see Figure 14), except in Pedernales where differences appear due to the high number of demolished structures, and the lack of available information for the virtual surveyor to judge how many demolished buildings were found in an empty block (where all buildings had been removed) - ground surveyors had the advantage of being able to observe the bases of old columns or details in the ground that suggest delineation of properties and employ the knowledge of locals in the field – although this may also add bias to the ground-truthed data.

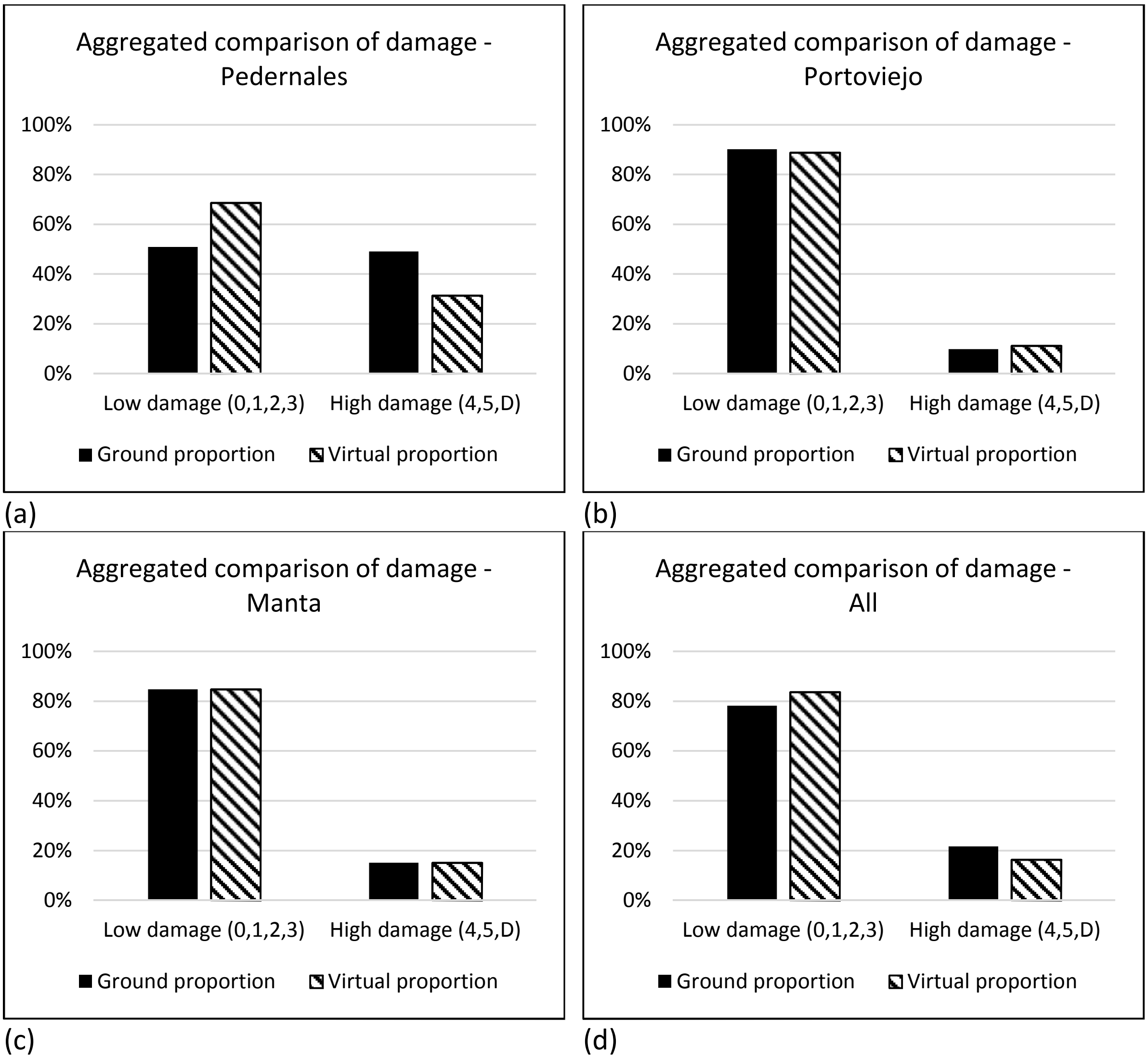

Figure 14 - Comparisons of proportions of aggregated damage identified for (a) Pedernales, (b) Portoviejo, (c) Manta, and (d) Overall

Many of the issues with the virtual survey were reportedly due to poor image quality or the lack of regular photo spheres close enough to each other. Additionally, buildings were often obscured by objects such as trees, walls or vehicles, making judgements difficult for a virtual surveyor whereas ground surveys can often exclude these obstructions by finding an alternative view point.

UAV

A 3D model of a damaged building in Portoviejo is presented in Figure 15 and Figure 16. The building is captured, along with the immediate surroundings. The drone flights were only conducted on one side of the building due to safety restrictions, so the back of the structure is not well captured, but with a better flight plan, a comprehensive 3D model would have been possible (e.g. see Yamazaki et al. (2015)).

This type of output from the drone may enable:

- improved communication of the impact on buildings
- improved diagnosis of the primary failure mechanisms

- improved processing of post-survey analyses
- damage tagging of structures

Figure 15 - View of the 3D surface model of building in Portoviejo

Figure 16 - View of the 3D surface model of building in Portoviejo

In addition to the 3D models, the aerial views of structures can offer a different perspective on the damage. Figure 17 shows an aerial view of a demolished plot alongside a partially damage structure on the right hand side; the extent of the damage may not have been visible from street level. Further along the street Figure 18 shows some roof level failures that because they are set back from the street may have been missed from a street survey. The high resolution of the image along with acute angle of view offers a more useful vantage point as soft storeys and localised damage is visible.

UAV technology can be used to map an area of around 300m x 300m at high resolution in around 20 minutes, and powerful (albeit expensive) software can stitch together the images to offer a high resolution aerial image and event form a 3D surface model. A trial has been completed in other work by the main author in Guatemala City and the example is given in Figure 19 to demonstrate the capabilities. If a 3D model is built of an entire damaged area it might be possible to identify construction types, number of storeys and damage states on a larger scale.

Figure 17 - Aerial view of Ground Zero, Portoviejo, Ecuador

Figure 18 - Aerial view of ground zero, Portoviejo, Ecuador

Figure 19 - Example 3D model of an urban area

Assessment of technology

Omni-directional imagery

The use of omnidirectional imagery has a number of shortcoming which have been exposed in the field and post-analysis. These include poor image quality, the lack of photos close enough to each other, and objects obscuring the view. The quality of the image could be improved with the use of more advanced (and expensive) cameras (the model used for this experiment was the cheapest available on the market). The lack of photos or the need for additional viewpoints could be improved by decreasing the distance between images. This will increase the data storage burden of devices in the field but will increase the abilities of the virtual surveyors to observe buildings and make the required judgements. The optimal distance between images is reportedly between 10-12m, however on more obstructed streets (e.g. tree-lined), this could be reduced to allow more chance of useful images to be taken. This guideline was for gathering Google Street View images (i.e. a general perspective of the streetscape), and wasn't intended for analysis purpose, so for this more intense use it may be more appropriate to reduce this distance to between 6-8m.

Despite the challenges, the comparative results here show a strong link between ground surveys and virtual surveys. When quantity of data is important, virtual surveys could offer an effective option. With advances in online tools, such as Mapillary and Humanitarian Open Street Map, 'citizen-scientists' (or citizen engineers) and volunteer engineers could analyse large amounts of data to gather a rapid idea of damage levels to different types of building post-earthquake. There are other agencies or organisations that would be able to use the collected images in their post-disaster response too, so there are co-benefits in collecting this type of data; in fact in the future Mapillary are aiming to map disaster areas with an omnidirectional camera to aid humanitarian response (Uddback, 2016), and engineers could utilise this data.

In terms of EEFIT reconnaissance missions, this technology could improve the scope of efficiently reporting of statistical damage data, as data can be collected and analysed upon return or upon upload. Guidance on the use of omnidirectional cameras follows in Appendix A incorporating the results of this study and the author's experience on EEFIT reconnaissance missions.

UAV

A number of challenges exist in the use of UAVs in reconnaissance missions. Primarily, there have been difficulties in obtaining the required permissions to fly in countries with strict regulations in urban areas. These permissions may be difficult in normal circumstances, but in a post-disaster situation this may be even more difficult. Regulations are generally not well understood, and local contacts may be unsure about what permissions are required in and from whom to obtain them and regulations are quickly evolving in response to advances in and inappropriate use ofUAV technology.

Where permissions can easily be obtained, or regulations do not exist, UAVs should be piloted with due care. There have been some incidents on EEFIT missions caused by unskilled or unpractised pilots. This is not only potentially expensive, but is also possibly very dangerous. It is advised that users of drones take the time to be trained by a competent UAV pilot prior to any mission where they will be used. This should include a practical session in a space where UAV flight in permitted for the UK this can be checked on the Civil Aviation Authorities (CAA website) (https://www.caa.co.uk/Consumers/Model-aircraft-and-drones/Flying-drones/). Piloting courses are also available and recommended where possible, for example the 'Learn to Fly a Drone' course from UAVAir (http://uav-air.com/drone-courses/learn-to-fly-a-drone/). It is also recommended that pilots join the UAViators (for free), an organisation that promotes safe usage of UAVs in humanitarian and development settings (http://uaviators.org/).

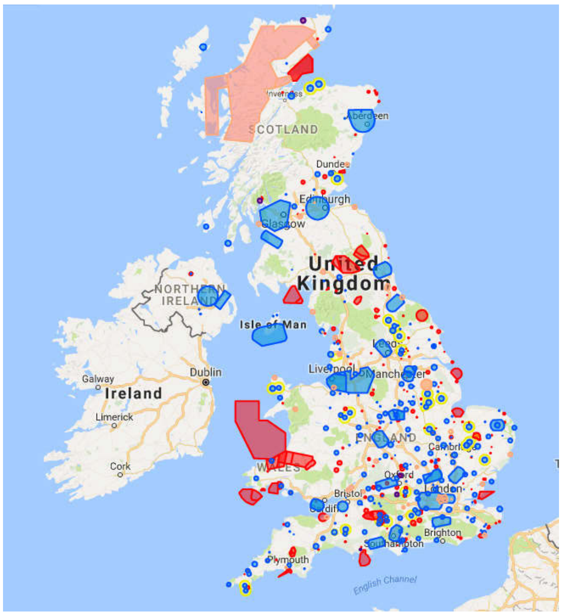

Figure 20 – Current UK map of no fly zones for drones, accessed from http://www.noflydrones.co.uk/ on 20th December 2016

Guidance on the process of setting up, taking off, flying, landing, and putting away the current EEFIT UAVs (DJI Phantom Vision 2+) was prepared for and trialled successfully on the Ecuador and Amatrice missions and is included in Appendix B. It is advised that these guidelines are consulted prior to each flight, in addition to the usual manufacturer's instructions.

Despite the many challenges with the use of UAVs, they can offer the potential to capture a wealth of imagery which can be processed into information that can better help meet the aims of reconnaissance missions, including 3D building models, high resolution images of damaged urban areas, landslides, ground failures, fault ruptures, etc. Images can advance our understanding of the impacts of earthquakes by offering a different perspective of the impacts, but also help the lessons learnt to be communicated more clearly and in a more engaging manner.

It is recommended that the future of UAV use on EEFIT missions should attempt to keep up with the advances in technology (where feasible).

Conclusions and further work

There are continuous advancements of technology for capturing imagery, useful for post-earthquake reconnaissance missions. Examples include drones or UAVs, and omnidirectional cameras.

The challenges with the use of drones on reconnaissance missions have been discussed, and include obtaining permissions to fly or sometimes even knowing if permissions are needed, transportation of the drone to remote areas, and adequate training of drone pilots. The benefits of this technology are clear: high-resolution aerial images can be quickly captured over large areas and the 3D models that can be constructed from them can help surveyors see damage more holistically, identify damage not visible from street level, and help to identify failure mechanisms. Guidance is offered on the use of UAVs on future EEFIT reconnaissance missions in Appendix B.

Omnidirectional cameras can be used, in collaboration with online viewing platforms, to 'virtually survey' damage in an urban area. Initial results are promising for identifying construction types and number of storeys. Assigning EMS-98 damage grades is more difficult, however when aggregated to two categories of low or high damage, the results were much more promising. If major challenges such as image quality, sparsity of images, and obstructions are improved upon, the results are likely to improve. The report offers guidance on the use of omnidirectional cameras in future EEFIT reconnaissance missions.

Further work is required to identify the scale and nature of biases that exist between surveyors in damage surveying exercises both on the ground and virtually. Additionally, further analysis of comparisons between ground and virtual surveyors is needed in different post-disaster contexts. Further work could also test the ability of aerial imagery to survey buildings. Additionally, work could be completed to understand if both omnidirectional images and aerial images could be used in tandem to gain accurate damage survey results. In the future, it would be worthwhile to investigate the ability of using remote 'citizen-engineers' and volunteer engineers to help in the rapid assessment of damage, post-earthquake, using omnidirectional imagery, aerial imagery, and a combination of the two.

As technology advances, it is important that the earthquake engineering community continues to embrace the relevant and useful technological options, employing them in future missions to more effectively learn about the impacts of earthquakes.

References

CHEN, S., LAEFER, D. & MANGINA, E. 2016. State of technology review of civilian UAVS. *Recent Patents on Engineering,* 10**,** 160-174.

FRANCO, G., STONE, H., AHMED, B., CHIAN, S., HUGHES, F., JIROUSKOVA, N., KAMINSKI, S., LOPEZ, J., VAN DRUNEN, N. & QUEREMBAS, M. 2017. The April 16 2016 Mw 7.8 Musine Earthquake in Ecuador - Preliminary Observations from the EEFIT Reconnaissance Mission of May 24 – June 7. *16th World Conference of Earthquake Engineering.* Santiago, Chile.

GRUNTHAL, G. 1998. European Macroseismic Scale Luxembourg: European Seismiological Commission.

UDDBACK, S. 2016. *RE: Mapillary Emergency Response.* Type to STONE, H.

YAMAZAKI, F., MATSUDA, T., DENDA, W. & LIU, W. 2015. Construction of 3D models of buildings damaged by earthquakes using UAV aerial images. *Tenth Pacific Conference on Earthquake Engineering.* Sydney, Australia.

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Appendix A: Proposed guidelines for use of omnidirectional cameras on EEFIT reconnaissance missions

Safety considerations

- Carefully consider the route, busy roads, traffic, other pedestrians when surveying with the OD camera.
- You will likely be surveying with the OD camera near to damaged buildings. Please adhere to the appropriate safety plans for being near such structures.

Route planning

- It is important that the best view of the whole street is captured. This will usually be from the middle of the road, which on foot is, in most circumstances, unsafe.
- If surveying by car ensure that is it safe to drive at the slow speeds required and that one-way streets have been considered in the route plan.

Other information

- Ensure all apps are downloaded (including most recent updates) and signed into whilst an internet connection is available. Some apps require this prior to offline use in the field.
- Trial the OD camera prior to travel to check whether the pole attachments fit the camera, and also to check whether the camera processes the images to all face in one direction or if the photos spheres remain in the orientation taken. If the latter is true, it is preferable to keep the camera steady and the front facing in the direction of travel.
- The ideal distance between images is around 8-10m. More frequent images may be beneficial in highly obstructed streets (with trees, walls, vehicles, etc.). More images will increase the data storage required.
- The OD cameras often takes a few seconds to process an image. Bear this in mind, especially when surveying by car as the maximum rate of image capturing will determine the speed required by the vehicle.
- Make a strategy for the analysis of the images, i.e. which platform will you use, who the virtual surveyors are, will they analyse as soon as uploaded or only upon return, etc.
- Ensure that the camera and the smart device (if required) have sufficient battery and storage for the planned surveys.
- If surveying in a hot country, prolonged use of devices such as OD cameras can result in overheating. Be prepared to remove the camera from direct sunlight for periods during surveying if this beomces an issue.
- Rain will often deem an OD camera survey untenable, whilst low light might impact on the quality of the images taken.
- OD camera rain covers are available, however in the author's experience, they severely impact on the image quality.

Appendix B: Proposed guidelines for use of EEFIT DJI Phantom Vision 2+ drones

Note: this set of guidelines is appropriate for competent drone pilots only. It is proposed that it is used as a checklist for flight during EEFIT missions. Some guidance may differ if different drones are used.

Permissions

- Each country differs in its regulation of UAV flight. Ensure that you have the required permissions before flight.

Transport

- The EEFIT drones come with a hard travel case which will need to be checked in on an aeroplane.
- Within the case it is advisable to place each individual drone battery in separate zip-lock bags as airport authorities require this.
- The case is heavy and bulky so consider how you will transport the drone in the field.

Pre-flight checks

- Check for wires, trees, poles, and other obstructions on the flight path.
- Do not fly near airports or military bases.
- Do not fly the drone in wet conditions.
- Do not fly the drone in wind speeds over 20 mph.
- Ensure the DJI Vision app is downloaded and you have registered and signed in whilst you have an internet connection. The app is currently available in iOS and Android.
- Before flight, check battery levels in the drone battery packs, the wifi transponder, the controller, and the phone you are using.
- Determine the proposed flight path and ensure that you (and the wifi transponder) will be able to maintain a line of sight at all times and that the drone will not pass directly above you.
- Ensure that there are at least two people (the pilot and one other) to help with the flight.
- As the pilot, your eyes will be on the drone at all times. This means that your awareness of nearby obstructions, trip hazards, etc. will be reduced. Consider this in your flight planning.

Remember:

- Always take off and land from the hands of a colleague and be very careful whilst doing so. Most drones crash because they fail to land and take off from the ground properly.
- Use two fingers on each joystick on the controller to allow better control.
- Aim to fly the drone facing forwards (lights at the back), unless purposefully performing a manoeuvre.
- Always have the wifi transponder facing towards the drone.

- Never fly the drone out of direct line of sight. It is likely to lose signal.
- Always fly with a sensible amount of battery. It is suggested that all battery levels never go below 20% on either of the three batteries used in flight (controller, wifi trasponder, drone). The controller displays the battery level on the front of it. The wifi transponder's and drone's battery level are checked within the app.

Step-by-step flight instructions

1. Remove drone, controller, and props from case.
2. Insert a full battery pack into the drone.
3. Remove lens cap from the drone camera.
4. Gently remove drone camera gimbal clamp.
5. Attach the props. Silver props on silver screws, black props on black screws. Tighten by thumb. Check the props are properly attached by trying to lift them off (if they are not they may injure someone when the motors are started).
6. Turn off Bluetooth on the phone.
7. Turn the controller power on.
8. Ensure that S1 and S2 are set to the top.
9. Turn on wifi transponder.
10. Turn on the drone.
11. Connect to the drone's wifi on the phone and place it in the clip on the controller.
12. Open the DJI vision app on the phone.
13. In the top right corner click on the button and go through the checklist.
14. Click on 'calibrate compass'.
15. When ready click 'start calibration'. The drone lights will go to solid yellow.
16. Follow the instructions on the screen to calibrate the compass.
    a. Hold the drone upright and turn 360 degrees until the drone lights turn to solid green.
    b. Hold the drone on its side with props away from you and camera facing down. Turn 360 degrees again till the drone lights flash. If drone lights are flashing red the compass has not calibrated and the drone cannot fly. Try calibrating the compass again.
    c. To manually calibrate the compass (if doing it through the app fails), click S1 up and down six times until the drone lights flash yellow. Repeat step 16a and 16b.
17. On the phone, click on the camera button from the main menu and check the settings. Check the following:
    a. Ensure that the memory card has been formatted correctly.
    b. Ensure units are set as the preferred option.
    c. Turn 'auto return to home' (RTH) on.
    d. Turn 'dynamic home point' on.
    e. Change the current RTH altitude to a height that will clear all nearby obstacles.
18. By now the drone should have found sufficient GPS signal. If it has, the drone lights will be flashing green and it is ready to fly.
19. Re-check the status of the battery in the drone, the wifi transponder, and the controller and the phone. Only fly if you are certain that you have sufficient battery and contingency for the planned flight.

20. The pilot's colleague who will help launch the drone should now hold the drone with both hands on the side of the legs above their head.
21. To start the motors the pilot should move both joysticks down and towards the middle and release as soon as the motors start back to the middle.
22. Ease the left joystick upwards gently to take off from the hands holding it. Remember to use two fingers pinching the joystick for improved control.
23. Perform the flight as required.
24. To land, fly the drone back into the raised hands of a colleague. Once caught they should hold it tight above their head until the motors have been turned off and the rotors have stopped spinning.
25. Drop the left joystick down to turn off the motors.
26. Turn off the drone.
27. Turn off the wifi transponder.
28. Turn off the drone controller.
29. Remove props gently.
30. Turn drone upside down and gently replace the gimbal clamp very gently.
31. Replace lens cap.
32. Remove the SD card to retrieve imagery.
33. Return drone safely to the case.

During flight

If the wifi signal is lost a message will appear on the phone. The drone will start its automatic 'return to home' procedure. Place the joysticks in the middle. Make sure the wifi transponder is pointing towards the drone with no obstructions between the two (including people). The signal is likely to reconnect. To manual encourage reconnection, flick S2 up and down once. Upon reconnection, the drone will stop its return to home procedure and will hover in the air until you start to pilot it again. If the wifi cannot reconnect and the drone comes in the land itself near the pilot's locations, make every effort to have someone catch it and hold it tight and still above their head until the motors automatically power down. Make every effort to not let the drone land itself on the ground.

Notes on 3D building models

To enable the development of a 3D model it is important to capture images of the structure from as many angles as possible. It is easiest to take a video (and export frames at a later stage) or use a 2-3s interval shooting setting, depending on how fast you will fly the drone. The best route for obtaining the correct images is to start at ground level and rise up to a good distance above the structure so the roof is fully visible, ensuring that the camera is facing the building at all times. This will require changes in the cameras angle which can be done using the smart device. Then move either clockwise or anti-clockwise around the structure, and fly downwards, gradually angling the camera up to ensure the structure remains in view. Then move around the building again and repeat. The number of segments will depend on the building size and the surrounding area, but generally, the more images, the better the model. Additionally, walk around the structure (where possible) and take images from street level. For an averaged size and height structure, this process can be completed in around 10-15 minutes.