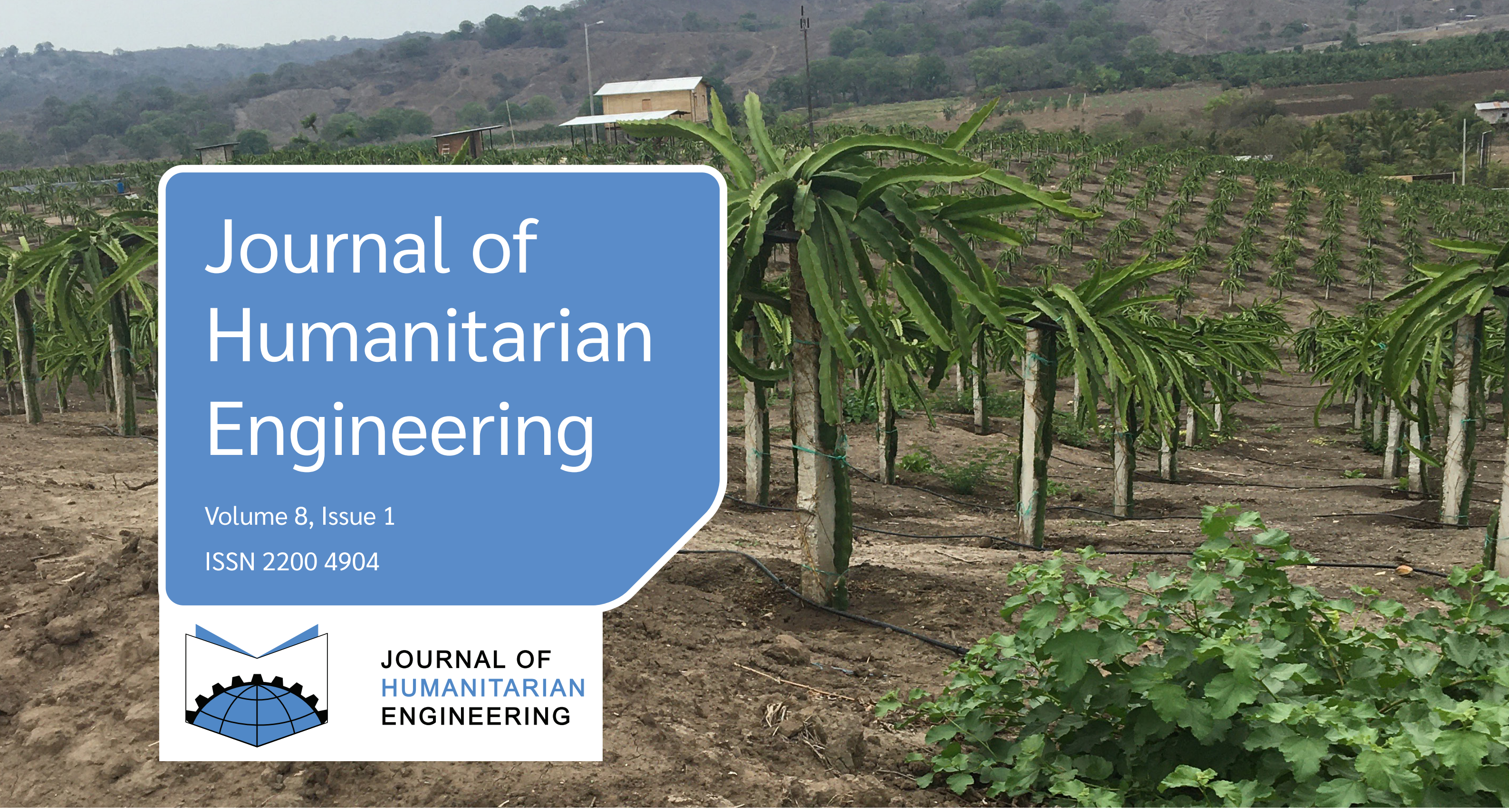

Journal of Humanitarian Engineering

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Journal of Humanitarian Engineering (JHE)

The Journal of Humanitarian Engineering (JHE) is an open access publication that publishes outcomes of research and field experiences at the intersection of technology and community development. The field of "humanitarian engineering" describes the application of engineering and technology for the benefit of disadvantaged communities. The field spans thematic areas from water to energy to infrastructure; and applications from disability access to poverty alleviation. The JHE aims to highlight the importance of humanitarian engineering projects and to inspire engineering solutions to solve the world's most pertinent challenges.

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INDIGENOUS AUSTRALIAN ACKNOWLEDGEMENT

EWB respectfully acknowledges the Traditional Owners of the Country on which we work.
To learn more about our commitment to reconciliation, read EWB's Reconciliation Action Plan.

Cover photos:
Top - El Guarango dragon fruit plantation by Ann-Perry Witmer
Middle left: EWB project team by Ann-Perry Witmer
Middle right - Dr. Andreas Braun working with satellite images by Universität Tübingen / Christoph Jäckle
Bottom: Rocafuerte Treatment Plant by Ann-Perry Witmer

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JOURNAL OF HUMANITARIAN ENGINEERING

GUEST EDITORIAL

We are excited to provide the guest editorial for this issue of the Journal of Humanitarian Engineering as the new co-Editors in Chief of the journal. Our sincere thanks and appreciation go to Dr Dani Barrington-Francis for her leadership and work on the journal for the last 8 years. It needed two people to fill her big shoes!

We join the journal at a time of global heartache and upheaval as COVID-19 is fundamentally changing the ways we live and work. From a Humanitarian Engineering perspective, it poses a double-edged sword. While making the value and importance of our work more apparent than ever, it also brings disruption and threats.

Like most crises, COVID-10 amplifies societal inequities and highlights the important role humanitarian engineers play in eliminating these. Pandemics do not affect all equally. Vulnerable groups once again bear the brunt of the burden, not least because COVID-19 disproportionally affects older people and people with low immunity. But vulnerable groups are also more likely to live in tight quarters, making social distancing challenging, and are more likely to lack access to health services and information. They are more likely to lose their jobs, may be unable to buy in bulk, and may find home-schooling more challenging. For us, as humanitarian engineers, COVID-19 especially brings to light the disparities in access to technology we, as a global society, are still facing. It is impossible to wash your hands for 20 seconds to halt the spread of disease if you do not have access to clean water or soap. Approximately 2.3 billion people globally are in this situation. Furthermore, more than 20% of health services in least developed countries have no water and/or no sanitation and/or waste management services. How can medical workers save lives under these conditions?

The COVID-19 pandemic also highlights the important role engineers play in urgently managing humanitarian emergencies. Engineers have, for example, responded to COVID-19 by rapidly designing low-cost face masks, face shields, and ventilators, and promptly converting manufacturing facilities to fulfil the growing demands for PPE. Engineers have also provided crucial data to support policy making by modelling and tracking the spread of the disease. One example is the dashboard developed by the Centre for System Science and Engineering at John Hopkins University in the U.S., which has had over 1 billion usage requests per day. These, and many other remarkable efforts by engineers, will continue to play a crucial role in the long battle against COVID-19.

While the current crisis highlights the importance of humanitarian engineering, it also disrupts our work, and makes it more challenging. So much of what we do every day, whether internationally or locally, requires us to build strong relationships and work directly with vulnerable and marginalised groups to co-design solutions that improve life and well-being. COVID-19 threatens to weaken or even break those relationships by replacing face-to-face collaboration with online interactions, which the world is now discovering is a poor substitute. We must find new and innovative ways of empowering our collaborators from afar and continue to support them through the crisis.

COVID-19 also threatens the important work the Humanitarian Engineering community has done to transform engineering education over the past decade. Engineers Australia, and other engineering peak bodies, have long recognised the need for engineers to apply their practice ethically and collaboratively. However, until recently, this has not been reflected in the way engineering students have been educated. Engineers have often paid lip service to community consultation as another tick that gets big infrastructure projects approved. Humanitarian Engineering educators have, in collaboration with Engineers without Borders Australia, played an important role in changing this. Over the last 10 years, we have seen a number of courses and programs developed at universities across Australia and New Zealand that aim to train the next generation of engineers with the skills to lead our profession in human-centred design. What will happen to these efforts as engineering education moves online and universities across the region are looking to cut budgets?

In these uncertain times, we should, as a community, band together to take advantage of this unique opportunity to demonstrate the value of our work, while finding ways of collectively navigating the current and potential future challenges and threats. We believe the Journal of Humanitarian Engineering provides an important avenue for doing this and warmly invite you to join the conversation.

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CONTENTS

PRACTICAL PAPER

Space borne radar imagery – An under-utilised source of information for humanitarian relief

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ABSTRACT: *This practical paper gives an overview about the widely unused potential of radar satellite imagery to assist humanitarian action. It briefly introduces the basic differences between optical and radar images, and demonstrates the practical use of radar images in different settings, based on their information content, and their potential for multi-temporal analyses. The paper gives recommendations on further reading, and closes with suggestions on the practical integration of radar data into humanitarian work.*

KEYWORDS: *Data collection, remote sensing, refugee camps, humanitarian operations, earth observation, monitoring, emergency response*

1 INTRODUCTION

Techniques of earth observation are increasingly valuable for humanitarian work for assisting the retrieval of information required for decision making, both in cases of emergencies and for the long-term support of people in need (Lang et al., 2015). They allow to the collecting of consistent data for large areas; this is especially important when observed phenomena changes rapidly over time, and when systematic monitoring and data collection in the field are time-consuming, expensive or dangerous. Whilst visual interpretation and digital analysis of images from optical satellites (e.g. Google Earth aerial imagery) is already part of many working routines of humanitarian non-government organisations (NGOs), the role of radar imagery is still neglected (Braun and Hochschild, 2017b). Radar imagery offers capabilities that make them attractive for the humanitarian domain. This paper introduces radar imagery as a potential source of information the humanitarian field and provides examples on potential applications to increase uptake in operational routines, and to initiate further inter-disciplinary discussions. Each section closes with a short list of references for further reading.

2 BENEFITS OF RADAR IMAGES FOR HUMANITARIAN WORK

One of the main barriers preventing transfer of radar data into humanitarian practice is that most studies published are technically oriented and aim at scientific novelty. What is needed to highlight the benefits of the use of radar images, are case studies and practical examples. The following section will highlight the benefits of the practical application of radar data for humanitarian work, and in doing so, create a basis for conversations and discussions between scientists and experts from the humanitarian field.

2.1 Basic Principles and Specifications

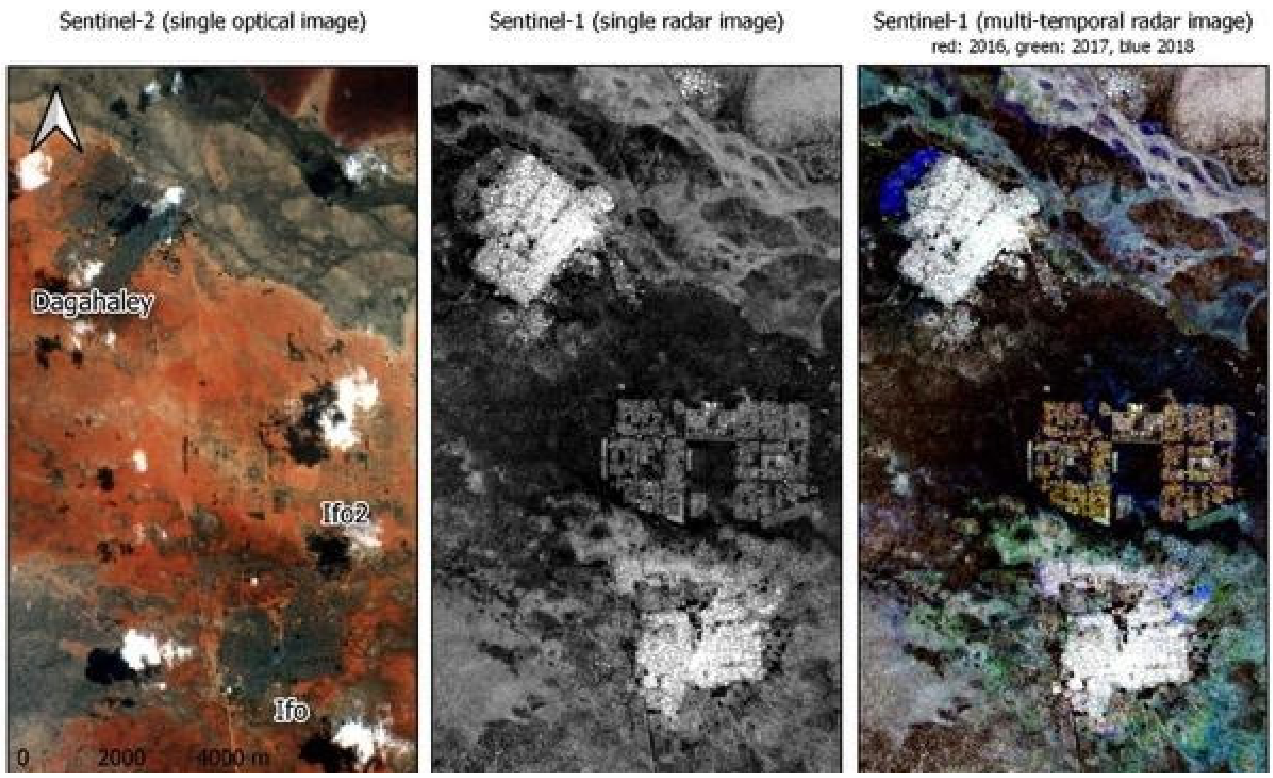
Radar satellites send signals to the earth's surface to form an image. These signals consist of microwaves that penetrate cloud cover independently from daylight. This allows reliable image acquisition for emergency response, and a constant monitoring of an area at regular intervals. Radar images do not show natural colours; instead the intensity of the returned signal is determined by the physical characteristics of a surface (i.e. roughness, moisture, material, size, structure, and orientation). This means radar images can be used to identify structures that are not visible, or only mildly visible, to the human eye at low contrast.

Figure 1 illustrates the sensitivity of radar imagery to different surface characteristics. Figure 1 displays the area of Dadaab and Kenya (including the refugee camps of Dagahaley, Ifo and Ifo2), depicted through optical (leftmost) and radar (middle and rightmost) satellites. All images are of the same spatial resolution (pixel size of 10 m) and are freely accessible through the Copernicus Programme of the European Space Agency (Aschbacher, 2017).

As can be seen in the optical imagery in Figure 1, the built-up areas have similar bluish grey colour tones as the braided river system in the northeast and the shrublands in the southwest. The built-up areas become more clearly visible in the radar image (middle) as the horizontal structures of the buildings, and their solid construction materials (stone and partly metal), cause high radar backscatter intensity. Furthermore, the radar images (single and multitemporal) reveal more variation in the centre of the images and the river systems due to different levels of soil compaction and moisture. The Figure 1 radar imagery also shows that the building structure of Ifo2 is different, because it consists of light tents with a more regular structure.

The multi-temporal radar image on the right consists of the overlay of three images acquired at different times; the images were coloured to represent the year the image was taken (i.e. red: 2016, green: 2017, blue: 2018). This form of additive colour mixing allows the identification of temporal dynamics of the area over time, represented in a singular image (Beatty, 1983). For example, an extension of camp Dagahaley can be seen to have occurred in 2018 (indicated in blue), whilst Ifo2 experienced increasing soil compaction and vegetation retrogression as visualised by the red tones in the surroundings of Ifo2 which indicate that former volume scattering from plants was successively replaced by simple surface scattering from bare and flat soils. How the information content of radar imagery can contribute to humanitarian work, as well its potential for temporal analyses, is demonstrated in more detail in the following sections.

Figure 1: *Comparison between optical (left) and radar (middle and right) satellite images.*



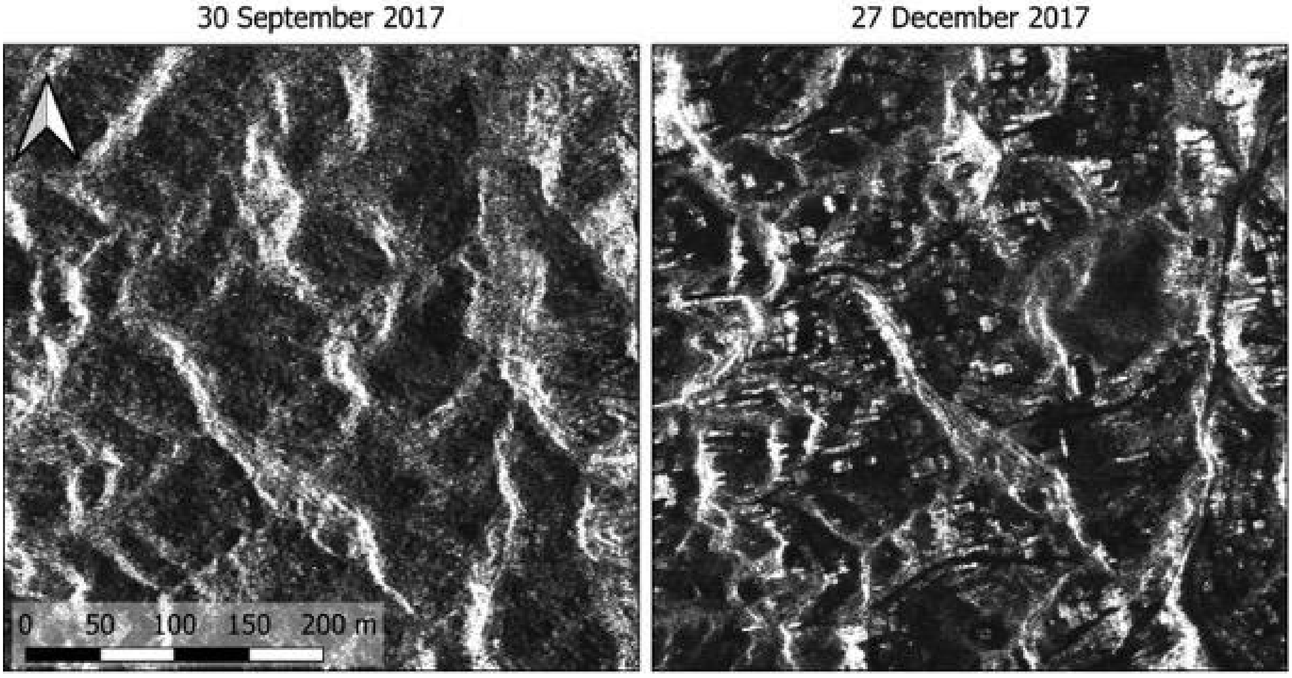


Figure 2: Radar image of Kutupalong before (left) and after (right) the arrival of 650,000 refugees.

As a first reading recommendation, a compact and nicely illustrated introduction to radar remote sensing is given by Moreira et al. (2013). It uses comparably simple language to outline the technique of radar remote sensing, and its possible applications.

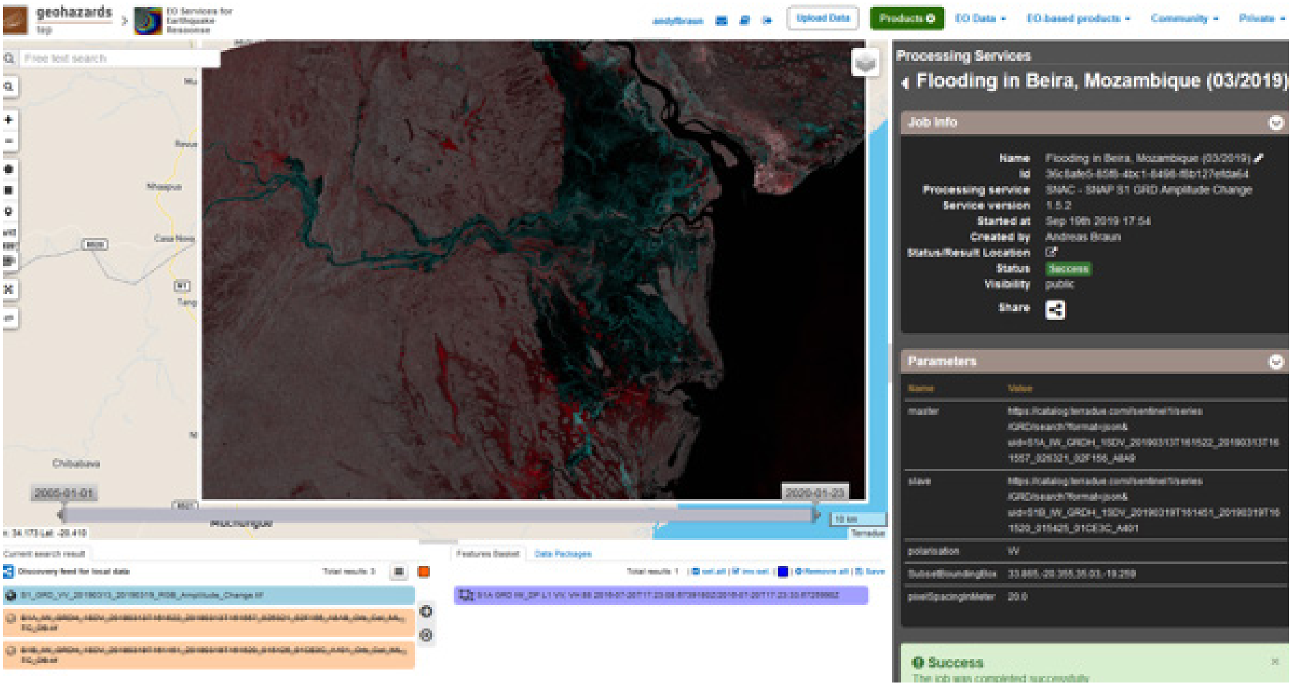
2.2 Information Content

As shown in the previous example, radar images are suitable to highlight buildings and urban structures, for example to estimate the number of people in need. As suggested by the Handbook for Emergencies published by the United Nations High Commissioner for Refugees (UNHCR, 2007) satellite images allow as assessment of the numbers of people in need by assessing the areas of their camps or by counting their dwellings. To give another visual example, Figure 2 shows a small part of the area of Kutupalong in Bangladesh in a very high-resolution radar image. It was acquired by the sensor TerraSAR-X at a spatial resolution of around 50 centimetres and impressively illustrates the change in land cover between 30 September and 27 December 2017. During that period, over 650,000 refugees crossed the border to Bangladesh to seek shelter from violent persecution in Myanmar, leading to enormous growth of the camp (UNHCR, 2017).

The maps document the construction of new shelters (rectangular bright shapes) in a previously forest-covered area (darker areas), as well as the development of a network of paths (black lines). However, it also demonstrates the downsides of radar imagery. The level of detail is often lower than that of optical imagery of the same resolution. This is due to noise-like patterns caused by signal interference or the ‘speckle effect’. (Lee et al., 1994). Additionally, white linear features (mostly ranging from north to south) caused by steep slopes can make the visual interpretation difficult for people with little knowledge of the area. Lastly, small dwellings constructed from light or natural materials are sometimes hard to identify because they cause lesser radar backscatter. Still, observations like this contribute to a better understanding of camps and the dynamics of displacement, and help to assess the need for action.

While built-up objects are bright in radar imagery, water bodies are mostly black because only a small share of the signal is reflected back to the sensor. This is of great advantage for the mapping of surface waters as a resource, but also for the assessment of natural hazards. Figure 3 shows how emergency response can be assisted by radar imagery within a web-based platform. Cyan colours indicate flooded areas derived from Sentinel-1 data. As these images are openly available within a few hours after acquisition, such maps can be utilised for evacuation planning and logistics management. This is especially valuable as flooding is generally accompanied by thick cloud cover where optical data cannot be gathered.

Another example on the increased information content of radar images is given in Figure 4. It shows the nomad city of Kidal in eastern Mali and its surroundings. Many of the landforms and subsurface structures cause variations in



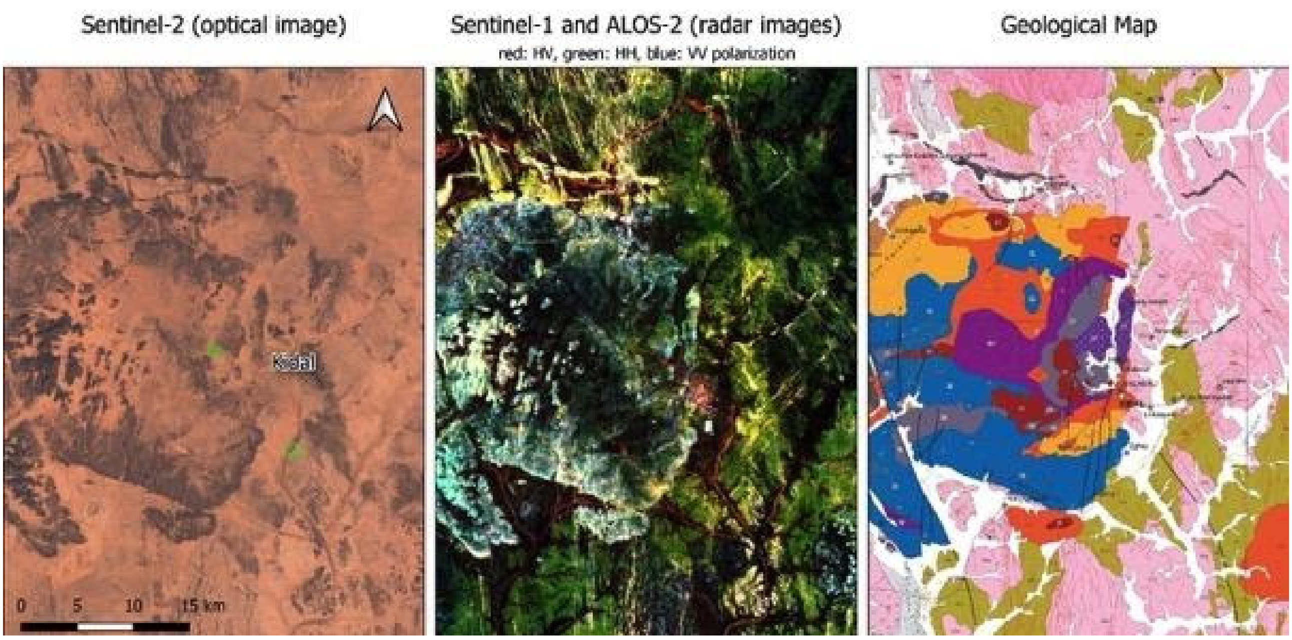


Figure 3 *(top): Identification of flood extents (black and cyan) in Mozambique in March* 2019 *in an open and web-based image processing platform (Braun,* 2019*a).*

Figure 4 *(bottom): Comparison of optical (left), radar (middle) and geological map (right) images for structural mapping and groundwater exploration.*

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backscatter intensity that can be used to identify structures, such as geological faults (as indicators for groundwater storage in crystalline basements), or buried channels that potentially carry water that can be extracted from shallow depths. Especially the areas and shapes of the wadis are clearly visible in red. The comparison with the geological map of this area (Figure 4 right) shows that the variations in radar backscatter intensity also correspond to the different geological formations that are useful for hydrological reconnaissance. These indications were partly provable by in-site geophysical measurements (Vanden Borre, 2011). For instance, different backscatter mechanisms retrieved from the radar imagery correlated with the depth of the wadis and the porosity of their sediments. In the case study, two areas were suggested (Figure 4 left, green rectangles) as new drilling sites for water extraction based on the analysis of measurements and interpretation of satellite data (Braun, 2019b, chapter 3.3.2). However, it has to be noted that such recommendations have to be validated in the field. At the time of writing, no information was available to indicate that drilling was conducted at these locations, and if the wells produced the expected amount of water. Only if such information is reported to the analysts, can existing approaches can be optimised and transferred into operational routines.

Reading recommendations:

- Practical aspects on the visual interpretation of radar images of refugee camps were demonstrated in an online document published by Astrium (2011) using the example of Dadaab in Kenya, a region hosting more than 350,000 displaced persons.
- It was shown by Braun (2019b) that freely available Sentinel-1 data can be used to map rural settlements, which were required for vaccination campaigns in Guinea. Using radar imagery resulted in nearly the same number of identified settlements than using optical imagery, which is often inconsistent regarding time of acquisition and image quality.
- The capabilities of microwaves to penetrate dry soils were already utilised in a humanitarian setting by Bouchardy (2005) who used radar imagery to identify moisture variations in sediments in the Darfur crisis to locate water resources. This directly assisted the UNHCR with planning and relocation of refugee camps.
- As one of the first researchers, Wegmüller et al. (2002) explain the benefits of radar data for rapid mapping, hazard mapping and thematic mapping in a humanitarian context.

2.3 Data Continuity and Time-Series Analyses

Due to the independency from daylight or cloud cover, operational radar satellite missions deliver usable images at constant intervals. This makes radar satellite missions a reliable source of information over longer periods, and allows an understanding of historical events. Looking at imagery that tracks changes over time, facilitates the ability to identify points in time when specific events have occurred, for example when a building was demolished (Figure 5) or a certain area was flooded (Figure 6). This information is important for the management of camps and the planning of supply and humanitarian logistics. However, the interpretation of radar imagery requires on-site validation to ensure the information retrieved for entire camps is not biased by false interpretation of specific patterns. Unfortunately, humanitarian workers engaged in refugee camps are often busy with more important tasks, such as the provision of food and basic medical services (Braun, 2019b). Methods have to be established for continuous and time-effective feedback, such as the use of mobile devices, as proposed by Vinek et al. (2016).

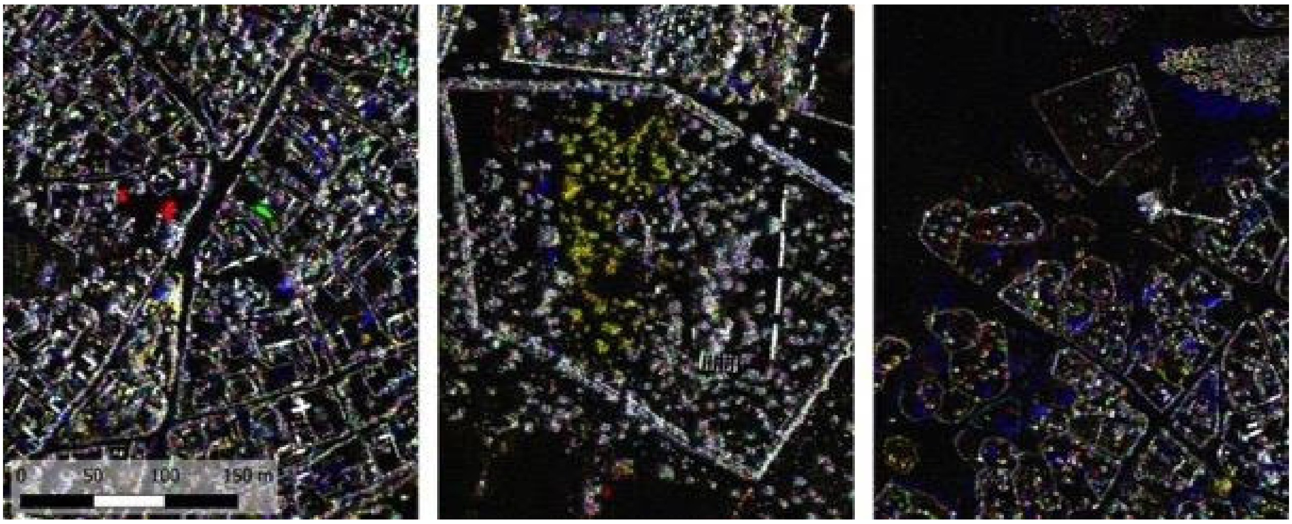

Figure 5: Changes in camp Dagahaley visualised by a colour composite overlay (red: 08 June 2014, green: 30 June 2014, blue: 10 March 2015). Left image: Demolished (red and green) and newly constructed (blue) buildings. Middle: Logging of trees (indicated in yellow). Right: Expansion of the north-western camp outskirts by planting of vegetation around the households (indicated in blue) (Braun, 2019b).

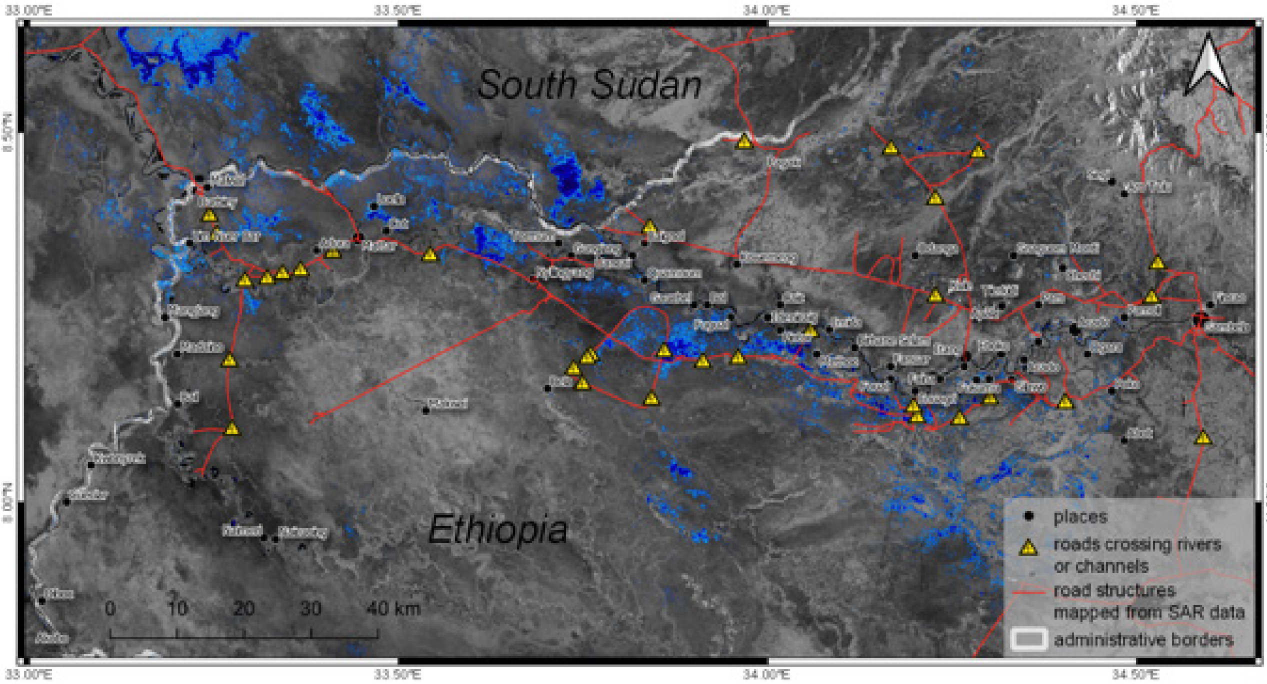

Figure 6: *Road infrastructure in Gambella region, Ethiopia, as mapped from images of Sentinel-*1. *Blue areas indicate derived flood extents in May* 2016 *and September* 2017 (*Braun,* 2019*b*).

Another advantage of archived images is the possibility to assess the situation of an area before a disaster has occurred, and compare it to a post-disaster imagery, as it was done in the flood-mapping example in Figure 3. This is applicable for natural hazards (earthquakes, floods, landslides), but also to systematically track ecosystem changes related to displaced persons. This is important to estimate the velocity of land degradation, the capacity of ecosystems, and the sustainable development of host communities (Jacobsen, 2002). In the example given in Figure 7, land cover changes were assessed based on radar data at regular intervals for the area of Kutupalong (the case introduced in section 2.1) to measure the expansion of the camp and the retreat of forests.

Due to pronounced rainy seasons, such regular time-series analysis was not possible utilising optical data. It is therefore important to develop routine analysis of radar imagery before emergency situations, such that the required information can be extracted quickly and enable a fast response.

Routine radar imagery analysis should be undertaken by both scientists or technicians and the users of any information products produced from imagery analysis on the humanitarian side. This ensures that the information

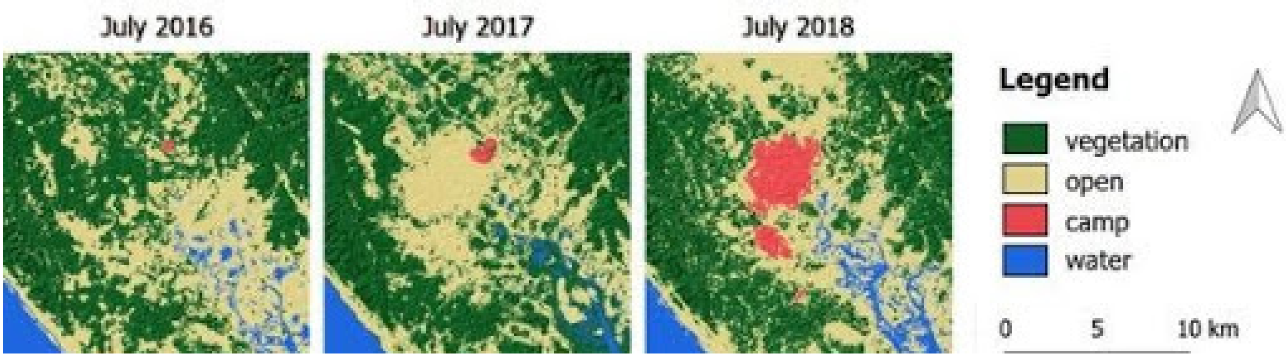

Figure 7: *Land-use changes in Kutupalong, Bangladesh, before and after the influx of over* 650,000 *arrivals, as measured by radar data* (*selection of three out of eleven analysed dates, Braun et al.,* 2019) products generated fulfil their exact needs, and that they understand the information they contain. Only if a product is useful, reliable, readable and transferable, can be implemented in operational frameworks (d'Oleire-Oltmanns et al., 2015). This also requires the data that these analysis routines are based on to be freely available and directly accessible. An example of this is the Sentinel-1 mission that delivers new radar imagery for most parts of the Earth every 6 days. This imagery is made available within 24 hours of general image capture, with priority area imagery being available within three hours post image capture (Potin et al., 2019). Frameworks for automated routines could be based on predefined data processors using scripting languages, such as python (Truckenbrodt et al., 2019) or graphic processing tools such as the Sentinel Application Platform (SNAP) which allows the users to apply minor adjustments according to the area and purpose of the captured imagery (ESA, 2019). In addition to technical automation, humanitarian organisations also require a knowledge management framework that allows all persons involved to exchange the latest findings and data products as well as prioritise crises and submitted information requests, as proposed by Zhang et al. (2002).

Reading recommendations:

- Flores-Anderson et al. (2019) published an open-access work on resource monitoring based on radar data with many hands-on examples and practical guidelines.
- The impacts of refugee camps on their environments were analysed in Kenya (Braun et al., 2016), Chad (Braun and Hochschild, 2017a) and Bangladesh (Braun et al., 2019) based on time-series of radar images to assess landscape changes over longer periods.
- Hardy et al. (2019) utilised time-series imagery produced by Sentinel-1 to locate water bodies suitable for mosquito breeding habitats in order to combat the spread of malaria in Zambia.
- Braun (2018) mapped damages on buildings in the city of Raqqa during the Syrian Civil War, to assist evacuation and clean-up efforts, and to record the time and severity of damage to assist tasks related to human rights protection and advocacy.

3 WHERE TO START?

Radar remote sensing can be difficult to approach, as it is not as well documented as working with optical data. However, large advancements have been made in the last five years regarding data access, processing systems, and user documentation. But a potential user must be clear about his or her main intentions. If the visual interpretation of images is sufficient (e.g. for the quick assessment of camp areas, land use, current developments, or the verification of new encampments), online platforms such as the EO Browser (Figure 8) allow for the search, display and combination of data of the most important operational missions (including Sentinel-1) free of charge for non-commercial use. Online platforms also allow for the generation of time-lapse videos of specific areas (Sentinel-Hub, 2019).

To reduce the risk of misinterpretation of the colours and patterns within radar images, it is recommended that the reader of the imagery understands the fundamental principles of radar backscatter mechanisms and its visual evaluation for humanitarian purposes. This fundamental knowledge can be acquired through short online courses on-site with expert instructors accompanied by self-tuition based on the various current tutorials and guidelines available (Betzin et al., 2019; Simms, 2019; Smith, 2012).

More advanced portals allow the application of fully prepared workflows to user-defined areas. For example, the map in Figure 3 was computed with the Geohazards Thematic Exploitation Platform (Terradue, 2019) within a couple of minutes. These portals are usually well documented and user friendly, and can be used within short time periods by users with little to no experience with data processing. These portals allow for the quick generation of results for sharing with colleagues via web browsers, within hours of an emergency occurring. These results should then contain value added information and be understandable by any humanitarian worker to avoid misinterpretation of the original radar imagery.

Users who are technically more experienced can also access and analyse Sentinel-1 data via the Google Earth Engine (Google, 2019) with custom scripts in JavaScript language. All these portals allow access to data without having to download the data. This is especially useful for workers in the field, as long as a stable Internet connection can be guaranteed.

The more traditional way to work with satellite imagery is to download the data and process it through local computers. This takes more time but provides more control over the data processing, and greater opportunity of varying input data, analysis tools, and the visualisation of the results. One of the most user-friendly and free of charge software solutions is the Sentinel Application Platform (SNAP) (ESA, 2019), accompanied by an up-to-date and plain tutorial of data sources and processing techniques given by Meyer (2019). It includes commercial satellite missions and their capabilities for revisiting time,

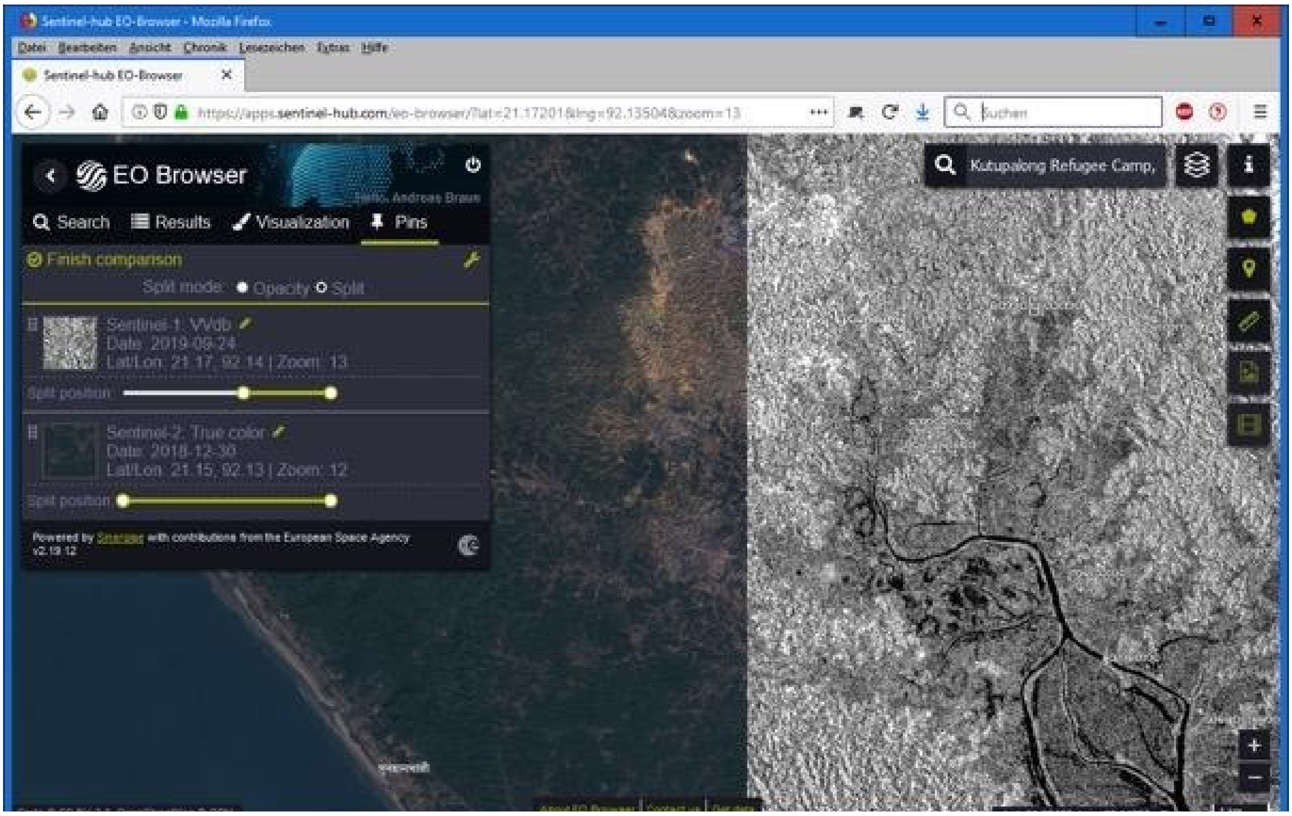

Figure 8: Online visualisation of Kutupalong in Bangladesh in the EO Browser. Optical imagery (left) and radar imagery of the same (right).

coverage, and spatial resolution so users can compare and decide on a data source that meets their requirements. To fully understand and utilise the different steps of radar data processing and the output parameters requires more time, routine and experience. Depending on the technical experience of the user, this can range between a couple of weeks to several months.

Lastly, users from in the humanitarian field who are interested in working with radar data are encouraged to get in touch with the authors of the studies provided in this paper. Most researchers are open to new ideas and welcome invitations to discuss or to collaborate. Moreover, science needs information from the user side, especially in application-oriented fields like humanitarian aid. This not only includes feedback on the usability of proposed methods, but also the provision of field data for training and validation purposes (UNHCR, 2007). The sustainable transfer of developed approaches only works if they can be tested and successfully conduced in real use cases. Accordingly, technical innovation alone is not enough; there is a large need for stronger collaboration, inter-disciplinary discussion, and mutual teaching and learning (Braun, 2019b). Especially the risk of misinterpretation has to be mitigated through collaboration and capacity building to avoid improper use or the drawing of false conclusions. Otherwise, the current lack of confidence towards this underutilised methodology cannot be easily reverted. This paper hopes to initiate further discussion and contribution to a culture of exchange and data sharing, with solutions jointly-developed by scientists, companies, and humanitarian organisations.

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Performance evaluation of the quality of CINA cement and BASF admixture commonly used in concrete production in the Republic of Haiti

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ABSTRACT: *A Haitian general contractor and civil engineer was having difficulties achieving the target compressive strength in concrete mixes that are complaint with both regulations and client criteria. An experiment was conducted to assess the quality and performance of CINA cement and BASF PolyHeed 997 water-retarding admixtures commonly used in construction practice in Haiti. The results of this experiment demonstrated that the CINA cement product did not meet adequate compressive strength requirements and can be considered an inferior product when compared to cement manufactured in the United States (U.S.). On average, the compressive strength of final hardened cement was approximately 56% less where using Haitian derived cement in comparison to US-derived cement. Several tests were conducted to understand the impact of curing, cement content and the addition of admixtures to the compressive strength of the final product. Curing was shown to have a significant positive impact on the compressive strength. When the mixtures were subject to air curing only the Haitian-derived concrete did not reach the required target compression strength of 27.6 MPa despite the cement content from the original design was increased by 50% and/or exposed to a setting time of 56 days. The addition of admixture posed no negative effect on the concrete mixtures and did not act as a retarding agent. Significant increases in compressive strength observed for both the Haitian and US-derived mixes. No significant increases in compressive strength when the setting time was increased from 28 days to 56 days. The overarching results of the research demonstrated that the most adequate solution for improving the existing quality of concrete mixtures containing Haitian-derived cement products is to increase the cement content to at least 30% by weight from the original design to achieve the designed compressive strength. It is recommended that the Haitian*

Government, concrete producers, cement manufacturers, and researchers combine their expertise, effort, and resources to produce appropriate solutions to improve the current condition of concrete construction practices in Haiti to increase the robustness of infrastructure design to natural disasters such as hurricanes and earthquakes.

KEYWORDS: *admixtures, cement, compressive strength, concrete, cured, and uncured.*

1 INTRODUCTION

Haiti, like many other islands in the Caribbean, is prone to major natural disasters such as hurricanes and earthquakes. On October 4, 2016, Hurricane Matthew struck southwestern Haiti as a category 4 hurricane with wind speeds of approximately 240 km/h (150 mph)). The impact of this hurricane left widespread damage across the nation resulting in catastrophic flooding of up to 1.0 metre (40 inches) and storm surges of up to 3.0 meters (10 feet) in height (Rice, 2016). Approximately 842 people were killed and more than 28,000 houses were damaged by the effects of the hurricane (IOM, 2016).

On January 12, 2010, a powerful earthquake with a magnitude of 7.0 on the Richter scale hit the south and central parts of the Caribbean island of Haiti. Approximately 250,000 people perished as a result of this earthquake (CNN, 2018) and over 1.5 million Haitians were estimated to be left homeless (USAID, 2011). According to the United Nations Office of the Special Envoy for Haiti, $13.34 billion USD of aid was allocated by international agencies over the time period spanning 2010 to 2020. The United States' (US) Congress authorised a total of $1.14 billion USD for rebuilding Haiti following the 2010 earthquake (Archibold, 2013).

On October 6, 2018, a 5.9 magnitude earthquake struck the northwest of Port-de-Paix on Haiti's north coast, resulting in the death of at least twelve (12) people (Diebel and Bacon, 2018). Prior to the 2010 earthquake, it was recognised that infrastructure located on the island of Haiti was constructed with inappropriate quality of materials and inadequate workmanship (Lang, 2011).

Assessments conducted by engineers and construction experts have concluded that prior to the 2010 earthquake, all concrete structural elements including hollow concrete blocks and columns in infrastructure located on the island was constructed using Type I Portland cement (Lang, 2011). It is therefore, important to evaluate the quality of the cement used in Haiti.

The President of GDG Concrete & Construction, a Haitian general contractor (referred to as "contractor" throughout the paper) and civil engineer with over of 20 years' of experience in concrete manufacturing in Haiti contacted the main author of this paper, a U.S. resident of Haitian descent. The contractor described difficulties he experienced in achieving the target concrete design strength despite the concrete mix being compliant with relevant design regulations and client specific criteria.

In order to evaluate the appropriateness of the concrete material used for construction on the island of Haiti, samples of the Portland Type 1 cement and concrete admixtures were transported from Haiti and subject to testing in the United States. It was hypothesised that the Haitian cement and admixtures were of similar quality to those manufactured in the United States and subsequently would perform similarly when subject to testing.

As the effects of climate change are expected to increase the occurrence and intensity of natural disasters such as hurricanes in the Caribbean region and the United States of America (USA), designing and constructing infrastructure from appropriate materials is imperative in to reduce the risk of fatalities and damage associated with infrastructure failure during natural disasters. It is anticipated that the results generated from this research may serve as guidance for government officials, engineers, and contractors to take adequate measures to develop appropriate cement materials that can withstand the environmental conditions present in the Republic of Haiti and thereby, minimise fatalities and damage associated with infrastructure failure during major natural disasters.

2 OBJECTIVES

The objectives of this research were to:

- Evaluate the current state of the construction practice in Haiti
- Compare the compressive strength of mixes made with Haitian and U.S. cement
- Evaluate the effect of curing on the compressive strength of the mixes
- Analyse the effect of admixtures commonly used in Haiti on the compression strength of concrete samples.

- Conduct a sensitivity analysis to optimise the quantity of Haitian cement for a desirable compressive strength of concrete.

3 LITERATURE REVIEW

On January 12, 2010, an earthquake with a magnitude of 7.0 hit the south and centre regions of the Republic of Haiti. Through all of the extensive death tolls and destruction, one factor was exposed– the building environment was a true weakness in the region. With an in depth look after the earthquake hit, engineers assessed the materials and methods that were used in concrete application prior to the destruction.

Concrete is a mixture of cement, water, coarse and fine aggregates and admixtures (if required). Well-made concrete is a strong, impermeable and durable construction material capable of resisting changes in temperature and wear and tear from weathering and traffic.

Compressive strength is one of the most important engineering properties of concrete and is utilised to compare the performance of concrete in its final hardened state. Typical concrete compressive strengthens in the United States vary by application, with compressive strengths of 20.7 MPa (3,000 psi) used in residential concrete structures and 27.6 MPa (4,000 psi) and higher used for commercial structures. Previous in-situ compression tests conducted on Haitian cement samples have showed average maximum compressive strengths of approximately 11.0 MPa (1,600 psi) with a standard deviation of 2.5 MPa (360 psi) (Lang and Marshall, 2011). For the 28-day compressive strength tests of fresh mix with proper curing, Haitian concrete samples ranged from peaks of 8.7 MPa (1,260 psi) to lows of just 2.8 MPa (410 psi) (Gordon, et al., 2016; Holliday et. al., 2011). These results are comparatively low to the typical design standards required for minimum specified concrete strength in the United States (US) is at 20.7 MPa (3,000 psi) and may be causes of concern, particularly in areas that are subject to extreme environmental conditions.

The properties that affect the strength and durability of concrete include the following:

- type of and proportion of cement
- water to cement ratio
- aggregate type and size
- addition of admixtures
- concrete application and handling (e.g. compaction and curing)

These properties are discussed in more detail below within the context of cement production in Haiti.

3.1 Type and Proportion of Cement in Mixture

Portland cement is limestone derived product and is the most widely used concrete type construction materials throughout the world due to its high durability and its high early strength at a relatively low cost (Khazanovich, et al., 1998). Portland Cement consists of silicates, gypsum, and aluminates from limestone and shale, that forms a paste with the addition of water. Cement is by far the most expensive material as compared to the other components in a traditional concrete mixture.

CINA – Cimenterie Nationale Haiti (Haiti National Cement) is a major producer of cement in Haiti. CINA cement is certified in accordance with the ASTM C1157 Standard Performance Specification for Hydraulic Cement. Type I cement certified under this standard expected to meet the performance requirements for general use. Assessments conducted by engineers and construction experts prior to the 2010 earthquake concluded that Type I Portland cement was used exclusively for all concrete structural elements on the Republic of Haiti, including hollow concrete blocks and columns (Lang, 2011).

It is understood that in some Haitian cement mixtures, the proportion of cement is elevated which can potentially affect the hydration process and thereby the rate at which the concrete hardens. The effect of cement proportion on the compressive strength of the hardened cement product was tested following the minimum 28 days of setting time required for concrete hardening.

3.2 Water-to-Cement Ratio

As the water-to-cement ratio in the concrete mixture increases, the strength of the hardened concrete decreases. Low water-to-cement ratios are preferred in order to maximise the concrete strength whilst still maintaining workable cement mixtures for use in construction (Cement Concretes and Aggregates Australia, 2010).

3.3 Aggregate Type and Size

Aggregate materials make up approximately 75 percent of the whole concrete mix and providing the requisite strength of the final concrete product (Mamlouk and Zaniewski, 2017). The composition, shape and sizes of aggregate material included in the cement mixtures influences the resulting strength of the hardened concrete (Siregar, et. al., (2017). Ideal aggregate composition includes both coarse and fine aggregate comprising of strong and hard materials (Cement Concretes and Aggregates Australia, 2010). The aggregate should be clean to maximise the bond between aggregate and cement-water paste and graded into a range of sizes to enable a dense and strong structure. Rounded aggregates typically give a more workable mix whilst angular aggregates make a less workable but can increase the strength of the final product (Cement Concretes and Aggregates Australia, 2010).

Haitian derived concrete can include unwashed and poorly graded rounded gravel and sand collected from beaches which may in turn may lower the compressive strength of concrete. (Chang et al., 2013; Lang and Marshall, 2011). In the most populated city region, Port-au-Prince, one and two-story residential structures are constructed using reinforced concrete frames with infilled hollow concrete blocks (Paultre et al., 2013). The inclusion of aggregates harvested from the sea environment can cause corrosion of the surrounding steel reinforcement.

3.4 Addition of Admixtures

Chemical admixtures can be added to a cement mix to perform specific functions such as reducing mixture segregation and accelerating the rate of strength (Musbah, et al., 2019, Mamlouk and Zaniewski, 2017). Admixtures such as water reducers and superplasticisers can be used to increase workability whilst reducing the water-to-cement ratio (W/C) (Medina, et al., 2015 and Corinaldesi, et al., 2001). Admixtures can also be used to improve the durability and strength characteristics of a given concrete mixture (Medina et al., 2015, Corinaldesi et al., 2001).

The Haitian contractor engaged in this research work hypothesised that the addition of admixtures in the Haitian cement production negatively impacts the concrete compressive strength by increasing the required curing time from a typical 28 days to approximately 56 days. The work conducted as part of this research project therefore included testing of this hypothesis.

3.5 Concrete Application and Handling

Compacting the concrete during the setting process removes the entrapped air from the concrete allowing it to form a dense structure. Curing the concrete by keeping it continuously damp/moist for long periods allows the concrete to reach maximum strength and increases its durability.

It is common for concrete to remain uncured in Haiti, even on major projects. This is often due to lack of resources, means and/or lack of knowledge in appropriate concrete application. The effect of curing was tested as part of this research project by designating samples of concrete to be left uncured, exposed only to the natural elements (sun, air, and rain) from the time of mixing until final setting and testing.

Removal of concrete formwork is normally carried out only after the time when concrete has gained sufficient strength, at least twice the stress to which the concrete may be subjected to when the formworks are removed. Generally, the American Concrete Institute (ACI) recommends the removal of formwork 7 days for Type I cement. Although the 28 days is the most accepted age (days) by the construction industry that concrete takes to cure and reach its ultimate strength (Hasan and Kabir, 2013). In order to test the effect of admixtures on curing times the research work included testing of mixtures at varying time spans (3, 7, 14, 28 and 56 days) with and without curing.

4 EXPERIMENTAL DESIGN AND MATERIALS

4.1 Concrete Test Sample Preparation

Two (2) concrete mixture compositions were provided by the Haitian general contractor for testing for this research project, these two compositions have different 28-day compressive strength test results of 24.1 MPa (3,500 psi) and 27.6 MPa (4,000 psi) respectively. For ease of understanding, these two mixture compositions will be referred to as the "24.1 MPa" and "27.6 MPa", respectively.

The 27.6 MPa mixture is a typical mixture commonly used in construction (especially in business construction) in the Republic of Haiti. Two batch types of mixture were prepared for testing – a batch consisting of the Haitian derived cement and a batch consisting of the US-derived cement.

In addition to the 27.6 MPa, batches of the 24.1 MPa mixture were developed for testing consisting of both Haitian-derived and U.S.-derived cement. The characteristics of which can be seen in Table 2 of Section 4.3. The composition of each of the two mixtures is described in more detail in Section 4.3.

Admixture was added to a subset of both the 27.6 MPa and 24.1 MPa mixtures to allow for testing of the effect of the addition of admixtures. Testing cylinder samples of all the mixtures were made in accordance with the ASTM C-192 standard to facilitate compressive strength testing of all test samples produced.

4.2 Materials

Two cement types were tested in this study: Haitian cement Type I - general use, and U.S. Portland cement Type I/II - general and moderate sulfate resistant use (Figure 1).

Five (5) bags of Type 1 cement manufactured by CINA were transported from Haiti to be tested as part of this research project. The U.S-derived cement was produced by Titan America. The cement produced by Titan America is designated as a Type I/II (general and moderate sulfate-resistant use) and meets the requirements of the ASTM C150 Standard Specification for Portland Cement. As per the Haitian derived cement, the Titan America cement can

Figure 1: *Photographs of cement used on this project; Left Haiti Cement and Right US Cement*

used for general use in most concrete construction jobs. Upon visual inspection of both cements, there was no apparent difference noted. Both cements were fine and appeared to contain a similar grain size distribution. The US-derived cement appeared darker (greyer) in colour.

Potable drinking water was added to all the concrete mixtures prepared. Potable or fresh water (i.e. containing less than 1,000 mg/L of dissolved solids) should always be employed in the production of concrete to enable it attain maximum compressive strength over time (Obi, 2016).

The admixture added to all concrete mix samples was added at a rate of approximately 780 mL/100 kg of mixture (12 fl oz/100 lb) for both concrete mixes. This dosage is appropriate for high performance and for producing self-consolidating concrete mixtures. The admixture purchased for inclusion in the Haitian concrete samples was PolyHeed 997 as manufactured by BASF Construction Chemicals. Based on the information presented in the datasheet, PolyHeed 997 admixture is a patented multi-component, non-chloride, mid-range water reducing admixture. Due to issues with corruption at the governmental level in the Republic of Haiti, the research team questioned the quality of the admixtures manufactured in the Republic of Haiti.

The Haitian general contractor provided two concrete mixture compositions for testing. Each mixture contained

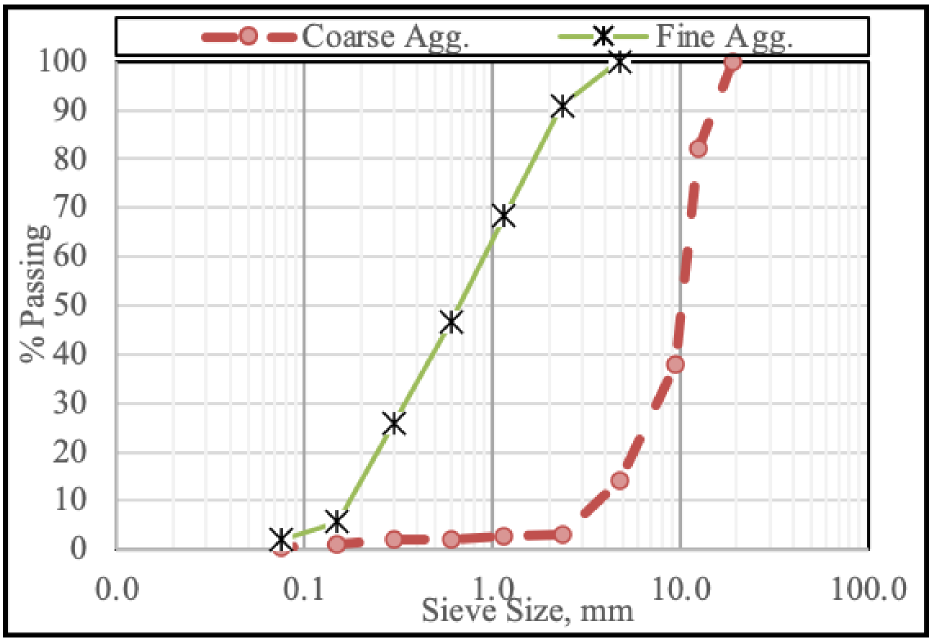

Figure 2: *Gradations of coarse and fine aggregates*

Table 1: Physical and mechanical properties of the aggregate used in this research project

Parameter	**Type of Aggregate**	
	No. 57 Stone (Coarse Aggregate)	**131 – Screening (Fine Aggregate)**
Maximum size, mm	19	N/A
Fineness modulus	N/A	2.60
Passing No. 200 sieve, %	0.50	2.02
Bulk specific gravity	2.400	2.422
Absorption	5.5%	4.3%
Maximum Dry Density (kg/m^3)	1,557.0	N/A
Los Angeles Abrasion	36.0	N/A

a coarse aggregate composed of medium sized gravel ranging from 6 mm to 25 mm and fine aggregate composed of washed sand. Haiti has deposits of volcanic, silica, and limestone aggregate (Hadden, R and Minson, 2010). The coarse aggregate and fine aggregate commonly used in Haiti was not available for this research project.

Haitian limestone was substituted with Southwest Florida (USA) derived limestone aggregate for this study. Likewise, the coarse aggregate was substituted with No. 57 stone and fine aggregate was substituted with No. 131 – screening fine aggregate. These aggregates have been approved by the Florida Department of Transportation (FDOT). These two types of aggregates are widely, most commonly used aggregates in concrete mixtures in the State of Florida.

Grain size distribution, also known as sieve analysis (gradation), is used to determine aggregate particle size distribution. Figure 2 represents the average grain size distribution on a semi-log scale for the US-derived aggregate substitutes utilised in this research. All sieve analysis tests were performed according to the AASHTO T 27 and ASTM C 136 standard testing procedures. Physical and mechanical tests performed on these aggregate substitutes are presented in Table 1.

Both coarse and fine aggregates were found to be dense and absorptive. The average specific gravity was 2.400 and 2.422 for the coarse and fine aggregate respectively. The absorption was 5.5% and 4.3% for the coarse and fine aggregate, respectively. These values were within typical range values for limestone aggregate. The coarse aggregate was denoted as tough and has a high resistance to crushing and degradation with an LA Abrasion value of 36.0. The maximum particle size for the coarse aggregate 19 mm. Both the coarse and fine aggregates are believed to be superior in quality as compared to the typical aggregates found in concrete production in Haiti. The high quality of the US-derived aggregate mixtures may be due to the presence of quality control procedures during aggregate production.

4.3 Concrete Mixture Composition

Two (2) concrete mixture compositions were provided by the Haitian general contractor for testing for this research project. The 28-day target compressive strength of these mixes was 24.1 MPa (3,500 psi) and 27.6 MPa (4,000 psi), respectively. Despite the use of substitute aggregates for the Haitian mixture samples, effort was made to balance the weight of the materials of similar values of those from the mixes in Haiti. The mixes were originally designed to contain the following constituents: No. 57 limestone as coarse aggregate, No. 131 screenings as fine aggregate, and admixture. The mixture compositions were designed following the weight and absolute volume methods (Mamlouk and Zaniewski, 2017).

The total weight of the concrete mixtures inclusive of all its constituents (i.e. aggregates, water, cement, and admixture) are presented in Table 2. The design slump for these mixes was selected as 125 ± 25 mm, non-air-entrained concrete, and nominal maximum coarse aggregate size of 12.5 mm. The variation in the slump was due to variability of the equipment and operator during mixing. As can be seen in Table 2, the slump in the Haitian mixtures was reported to be lower or equal to the corresponding US-derived mixtures.

In this study, a comparative approach between the Haitian mixtures versus the US-derived mixtures was used to

Table 2. Composition of concrete mixtures

Mix Name[a]	Cement kg/m³	Water kg/m³	Slump[b] mm	No. 57 kg/m³	131-Scr. kg/m³	Adm mL/m³	W/C
H-27.6-Adm-UC	434	296	200	701	980	2,591	0.68
US-27.6-Adm-UC	434	263	200	701	980	2,591	0.61
H-27.6-Adm-C	434	286	129	701	980	2,591	0.66
US-27.6-Adm-C	434	286	220	701	980	2,591	0.66
H-27.6 -C	434	286	81	701	980		0.66
US-27.6 -C	434	286	113	701	980		0.66
H-24.1-Adm-C	380	239	81	933	693	2,266	0.63
US-24.1-Adm-C	380	275	125	933	693	2,266	0.72
H-24.1-C	380	258	150	933	693		0.68
US-24.1-C	380	261	156	933	693		0.69
H-27.6-Adm-UC-15%	499	269	200	701	980	2,980	0.54
US-27.6-Adm-UC-15%	499	259	119	701	980	2,980	0.52
H-27.6-Adm-UC-30%	564	288	88	701	980	3,368	0.51
US-27.6-Adm-UC-30%	564	254	50	701	980	3,368	0.45
H-27.6-Adm-UC-50%	651	319	106	701	980	3,887	0.49
US-27.6-Adm-UC-50%	651	306	106	701	980	3,887	0.47
H-24.1-Adm-C-15%	437	223	100	933	693	2,606	0.51
US-24.1-Adm-C-15%	437	267	150	933	693	2,606	0.61
H-24.1-Adm-C-30%	494	222	94	933	693	2,946	0.45
US-24.1-Adm-C-30%	494	247	100	933	693	2,946	0.50
H-24.1-Adm-C-50%	570	279	113	933	693	3,399	0.49
US-24.1-Adm-C-50%	570	296	115	933	693	3,399	0.52
H-27.6-Adm-C-15%	499	240	88	701	980	2,980	0.48
US-27.6-Adm-C-15%	499	274	106	701	980	2,980	0.55
H-27.6-Adm-C-30%	564	254	106	701	980	3,368	0.45
US-27.6-Adm-C-30%	564	282	106	701	980	3,368	0.50
H-27.6-Adm-C-50%	651	286	113	701	980	3,887	0.44
US-27.6-Adm-C-50%	651	293	119	701	980	3,887	0.45

Notes:

[a] H-27.6-Adm-UC = H → Haiti Mix; 27.6 → 27.6 MPa; Adm → Admixture; UC → Un-Cured
US-24.1-Adm-C = US → US Mix; 24.1 → 24.1 MPa; C → Cured;
15% → 15% of additional cement; 30% → 30%of additional cement; 50% → 50% of additional cement

[b] N/A → Not available

assess performance. The only difference between the mixtures produced for the research study versus that produced by the Haitian general contractor was the amount of water added to each mixture. The amount of water added to the text mixtures produced for this research study was higher producing an average water-to-cement ratio of 0.65 as opposed to the water-to-cement ratio of 0.40 adopted by the Haitian general contractor at a slump of 75 mm. A water-to-cement ratio 0.65 is considered high, however research shows that mixtures with higher water-to-cement ratios can still achieve 27.6 MPa (4,000 psi) by 7 days of setting (LeBow, 2018; Wassermann, et al., 2009).

4.4 Testing Methodology

The hypothesis tested as part of this research work was the assumption that the Haitian and US-derived cement, being similar in quality, would produce comparable performance results when subject to a battery of testing. The 24.1 MPa and 27.6 MPa samples were subject to compressive strength testing to understand the following:

- The effect of cement proportion on the compressive strength of the final hardened concrete product - test samples of the 24.1 MPa and 27.6 MPa Haitian-derived and U.S.-derived mixtures were subject to increasing concentration of cement content ranging from 15 to 50%.
- The effect of curing on the compressive strength of final concrete product test samples - the 24.1 MPa and 27.6 MPa Haitian-derived and U.S.-derived mixtures were cured according to ASTM C-192. All the specimens were immersed in a water bath maintained at temperature 25^{o}C) until the nominated testing period.
- The effect of air curing on the compressive strength of the mixtures - the 27.6 MPa test samples were left outside subject to natural weather conditions over the month of May to September. The temperature in Fort Myers, Florida ranged from 20^{o}C (68^{o}F) to 34^{o}C (93.2^{o}F) which are similar temperatures to

Table 3: *Testing matrix*

Test sample labels	Description	Purpose
27.6 -C	• 27.6 MPa • Cured	Understand the effect of curing on for a 27.6 MPa sample
27.6-Adm-UC	• 27.6 MPa • Air cured • Containing Admixture	Understand the effect of addition of admixture to uncured sample
27.6-Adm -UC- 15% 27.6-Adm -UC - 30% 27.6-Adm - UC - 50%	• 27.6 MPa • Air cured • Containing Admixture • Varying cement quantities	Understand the effect of addition of admixture to an uncured 27.6 MPa sample at varying cement proportions
27.6-Adm-C-15% 27.6-Adm-C-30% 27.6-Adm-C-50%	• 27.6 MPa • Cured • Containing Admixture • Varying cement quantities	Understand the effect of the addition of admixture in the curing process for cement at varying cement proportions
24.1-C	• 24.1 MPa • Cured	Understand the effect of curing on for a 24.1 MPa sample
24.1-Adm-C-15% 24.1-Adm-C-30% 24.1-Adm-C-50%	• 24.1 MPa • Cured • Containing Admixture	Understand the effect of addition of admixture to an uncured 24.1 MPa sample at varying cement proportions

that experienced in Port-au-Prince, Haiti during the same time of year (Crawford-Adiletta, 2019, NOAA, 2020) with the exception of humidity. The average humidity in Fort Myers was 90% in comparison to 50% in the Republic of Haiti.

- The effect of the addition of admixtures on the compressive strength of the final hardened concrete product, and the effect of the addition of admixture have on the curing time required to achieve the required compressive strength, batches of 24.1 MPa and 27.6 MPa Haitian-derived and U.S.-derived mixtures both containing admixture and not containing admixture were subject to testing.

A summary of the testing samples produced as part of this research study are summarised in Table 3.

5 RESULTS AND DISCUSSIONS

5.1 Un-cured (Air-cured) Treatment

The 14, 28, and 56 days' compressive strength tests for the uncured Haitian-derived cement mixtures and the uncured US-derived cement mixtures are presented in Figure 3.

As can be seen in Figure 3, the Haitian-derived cement mixture increased in strength by 39% between the 28 day to 56 day setting period. The compressive strength of the Haitian mixture however never reached the target strength even at a setting period of 56 days. The highest compressive strength recorded for this mixture was 19.6 MPa at 56 days setting time. At 28 days, the compressive strength for the Haiti mix was 42% lower than the target strength of 27.6 MPa. The US-derived mixture reached the target strength of 27.6 MPa at approximately 14 days. No significant increase in strength was noted on the U.S.-derived mixture over the setting time period.

From the results shown in Figure 3, it can be inferred that the hydration reaction for the US-derived cement mixture appears to have slowed down significantly after day 14 of setting. The U.S.-derived cement mixture compressive strength at 28 days was recorded at 30.5 MPa (11% higher than the target strength of 27.6 MPa). The critical point to note is that, on average, the compressive strength of the U.S.-derived mixtures was 44% stronger than the Haitian-derived mixtures.

5.2 Effect of Cement Content on Air-Cured Samples

A sensitivity analysis was conducted by varying the amount of cement content in both the Haitian-derived concrete mixtures and U.S.-derived concrete mixtures. The purposed of this sensitivity analysis was to evaluate the effect of increasing the cement content on the compressive strength of the final concrete product. Compressive strength is understood to increase as the proportion of cement in the mixture increases.

All Haitian-derived and US-derived samples tested were uncured and contained admixture. The cement content in each sample was increased by 15%, 30%, and 50% by mass, relative to the total mass of the cement content in the original mixture composition. All other parameters,

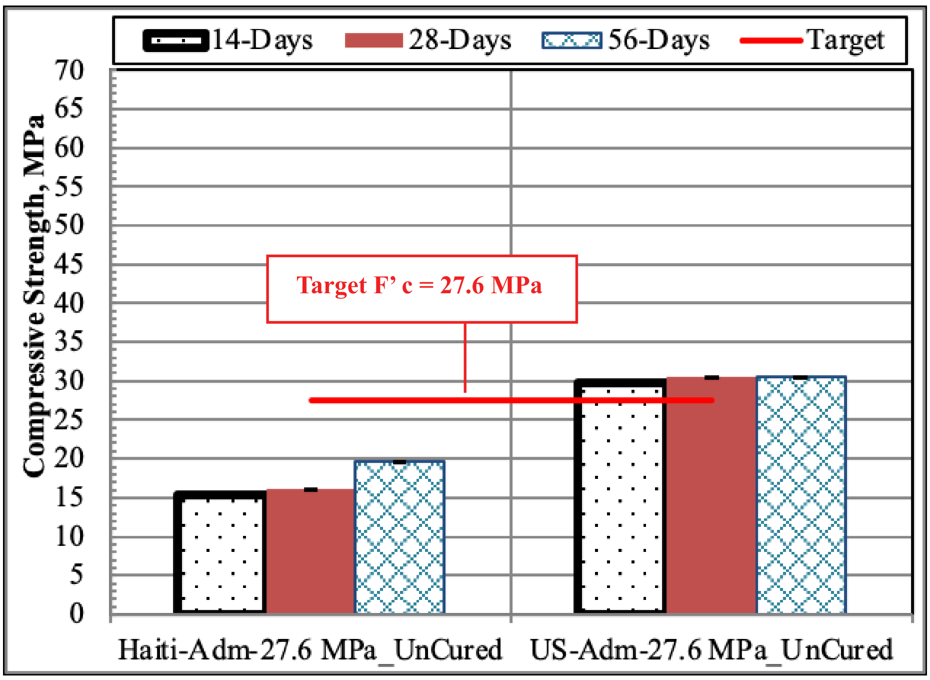

Figure 3: Compressive strength results for the 27.6 MPa using both Haiti cement with admixture and US cement with admixture (Un-cured mixes).

including coarse and fine aggregates, were kept constant (Table 2). The amount of water was adjusted to maintain the original slump of 125 ± 25 mm. The compressive strength is presented in Figure 4 for the Haitian-derived and US-derived mixtures, respectively

As seen in Figure 4, an increase in the cement content of both the U.S.-derived and Haitian-derived mixtures resulted in an increase in the compressive strength. A greater increase in compressive strength was observed for the Haitian-derived mixtures in comparison to the U.S.-derived mixtures. On average, the compressive strength of the Haitian-derived mixtures increased by 34%, 44%, and 36% as the cement content increased by 15%, 30%, and 50%, respectively. For the U.S.-derived mixtures, the increase in compressive strength was 17%, 30%, and 33% for the same increase in cement content. When the cement content was increased from 30% to 50% in the Haitian-derived mixture, no apparent increase in compressive strength was observed.

Although both the Haitian-derived and U.S.-derived mixtures increased in compressive strength over the setting period as the cement content increased, the change in the compressive strength between days 28 to 56 was marginal for both the Haitian-derived and U.S.-derived mixtures (Figure 4). As can be seen in Figure 4, the compressive strength for the Haitian-derived mixtures increased by 10% from day 14 to day 28 and another 6% from day 28 to day 56. The compressive strength of the U.S.-derived mixture did not increase as much as compared to the Haitian-derived mixture over the setting period. The increase in compressive strength was approximately 4% and 2% for the U.S.-derived mixture.

Although a noticeable increase in compressive strength was observed in the Haitian-derived mixture, it did not reach the target compressive strength value of 27.6 MPa, even at the highest cement content and/or at 56 days setting time. A maximum compressive strength of 26.5 MPa was noted at 28 days setting time when the cement content was increased to 30%. This value is still 4% lower than the target strength of 27.6 MPa (Figure 4). As the test sample dimensions were the standard size of 100 mm by 200 mm specimens, a five (5) percent reduction in strength should be expected should the standard 150 mm by 300 mm (6″×12″) specimens be used instead (Jihad Hamad, 2017).

In addition, the aggregates used in the mixtures were superior to the typical aggregates used in concrete production in Haiti. Better quality aggregate is expected to produce higher compressive strength in the final hardened concrete. Furthermore, the quality control used to produce the mixtures was well maintained; this is not known to be the standard practice in construction projects on the Republic of Haiti. The highest compressive strength of the U.S.-derived mixture was 44.4 MPa (68% higher than the Haitian-derived mixture). The maximum compressive strength was observed in the samples containing 50% cement content on the 56th day of setting.

5.3 Effect of Curing

An analysis was conducted to determine the effect of curing on the concrete mixtures. Curing plays an important role

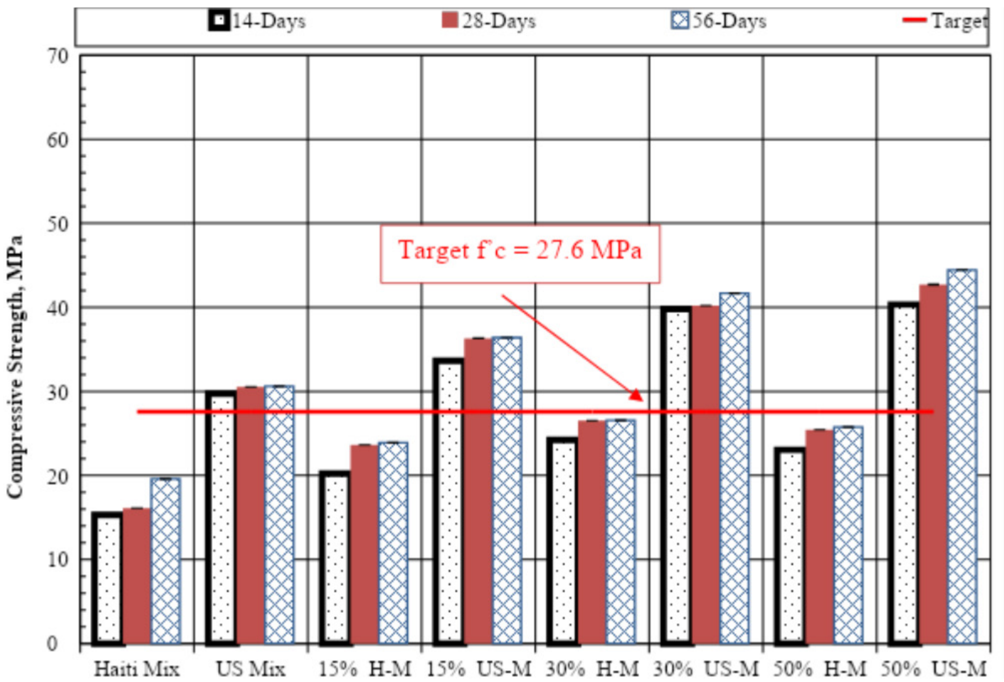

Figure 4. Sensitivity of 27.6 MPa Haiti mix with admixture and 27.6 MPa U.S.-derived mixture with admixture – (Un-cured mixes).

on strength development and durability of concrete. The strength of appropriately cured (i.e. continually moistened) concrete is normally three times greater than the strength of air-cured concrete (Mamlouk, M and Zaniewski, 2017). Test samples of the 27.6 MPa Haitian-derived and U.S.-derived mixtures were cured according to ASTM C-192. All the specimens were immersed in a water bath maintained at temperature 25°C) until the testing period. The compressive strength of the samples at days 14, 28, and 56 days are presented in Figure 5. A significant increase in compressive strength can be seen for both the cured Haitian-derived and U.S.-derived mixtures in comparison to the uncured samples.

The compressive strength of the Haitian-derived mixture was doubled when subject to curing. Similarly, the compressive strength of the U.S.-derived mixtures was increased by 77%. This increase in compressive strength is

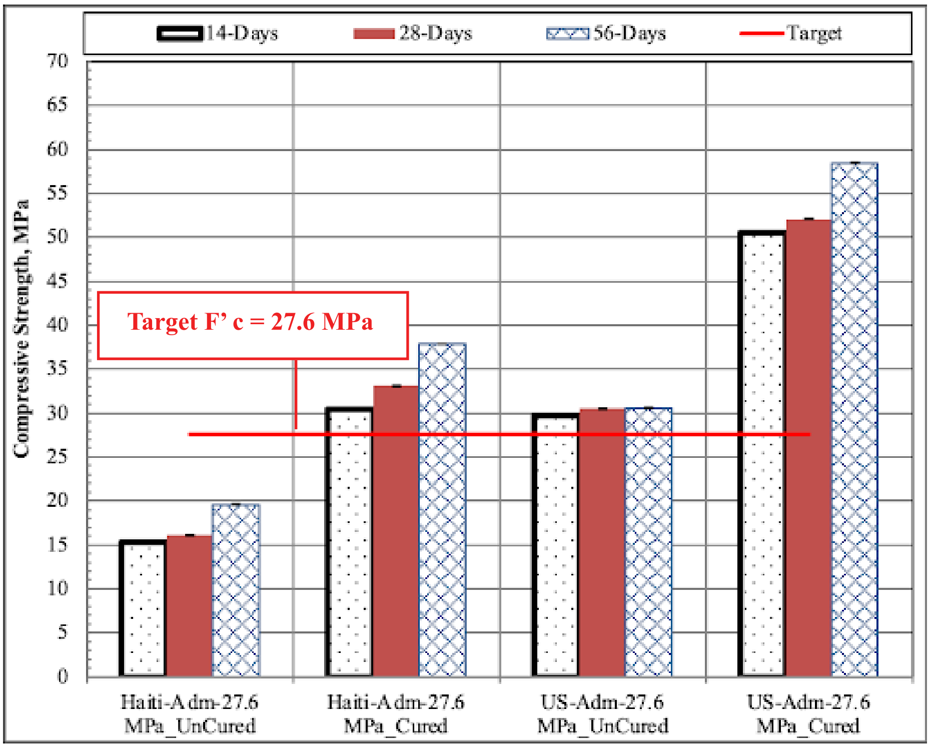

Figure 5. Effect of curing on both the 27.6 MPa Haitian-derived mixtures and 27.6 MPa U.S.-derived mixtures.

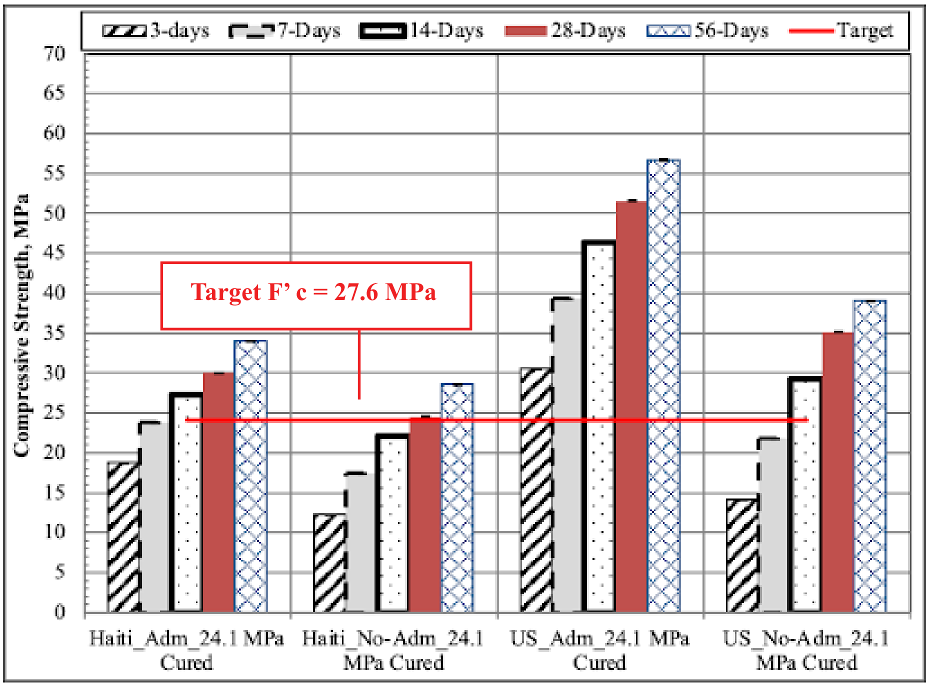

Figure 6. Effect of admixture on the compressive strength of the 24.1 MPa mixtures

due to the continual moistening of the concrete mixture, allow the sample to undergo the hydration reaction continuously to develop and increase the bond between the aggregate and the cement-water paste. The 28 day compressive strength test result for the Haitian-derived mixtures was 33.1 MPa which is 20% higher than the target strength of 27.6 MPa.

Although the increase in strength observed in the Haitian-derived mixture was encouraging, the U.S.-derived mixture was still seen to outperformed the Haitian-derived mixture. The compressive strength of the un-cured U.S.-derived mixture was comparable to that of the cured Haitian-derived. Furthermore, when the U.S.-derived mixture was cured, the maximum compressive strength was reported to be 58.6 MPa, 55% higher than the Haitian-derived mixture.

5.4 Effect of Addition of Admixtures on Compressive Strength

The Haitian contractor hypothesised that the admixture typically used in construction practice in Republic of Haiti increased the total minimum curing time required for concrete work, presumable by decreasing the rate of hydration experienced during the settling time. To test this hypothesis, an analysis was conducted to test the effect of the addition of admixture to the concrete mixtures on the compressive strength of the concrete.

Based on the data presented above, it is evident that the addition of admixture to U.S.-derived mixtures does not pose negative effects on the compressive strength of the concrete product. Both the 24.1 MPa and 27.6 MPa mixes were produced for the Haitian-derived and U.S.-derived cement mixtures, with the exclusion of the admixture. The compressive strength for the 24.1 MPa and 27.6 MPa mixtures were tested on days 3, 7, 14, 28, and 56 of the setting period. The results of these tests are presented in Figure 6 and Figure 7, respectively.

The admixture had significant effect on the compressive strength of all the samples tested. All the sample mixtures tested gained strength over the setting period where the admixture was present. For the 24.1 MPa cured mixtures, the 28-day compressive strength was 30.1 MPa (Haitian-derived, with admixture), 24.6 MPa (Haitian-derived, no admixture), 51.6 MPa (U.S.-derived, with admixture), and 35.1 MPa (U.S.-derived, no admixture), respectively (Figure 6). Where the admixture was omitted, the 28-day compress strength of the cured Haitian-derived mixture decreased by 18% with the U.S.-derived mixture decreasing by 32%.

For the 27.6 MPa cured mixes the compressive strength of the Haitian-derived mixture decreased by 11%. Similarly, for the 21.4 MPa mixes, an increase in strength was observed for the 27.6 MPa mixtures where admixture was included. On average, a 22% increase in compressive strength was observed in the Haitian-derived mixture where admixture was included as compared to the Haitian-derived mixture where the admixture was omitted. The increase in compressed strength observed in the U.S.-derived mixture was approximately 5%.

Another benefit of the addition of admixtures is the time taken for the concrete to reach an adequate strength. The

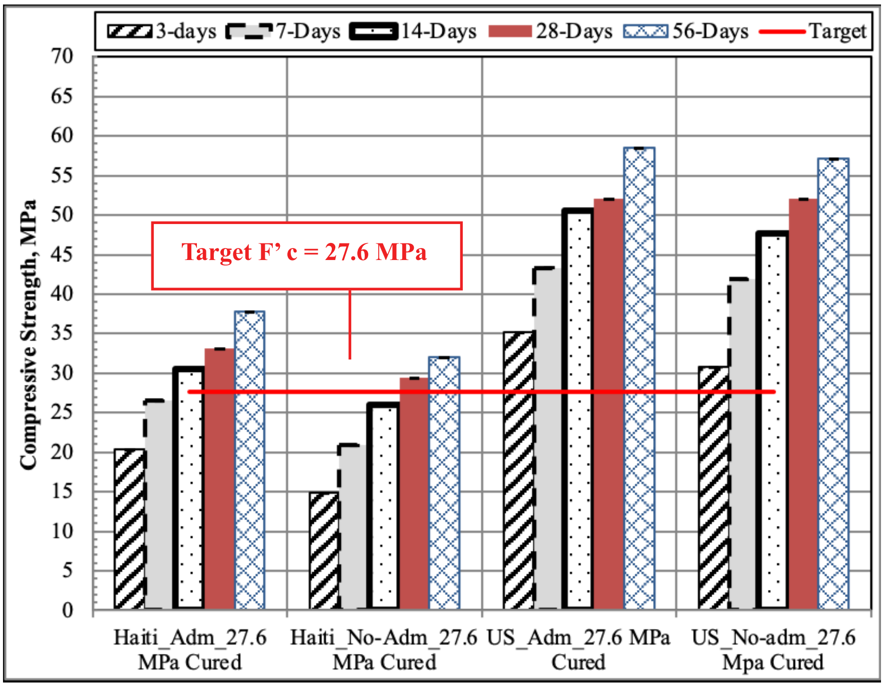

Figure 7. Effect of admixture on the compressive strength of the 27.6 MPa mixtures

removal of the concrete formwork is normally carried out only after the time when concrete has gained sufficient strength. As a rule of thumb, 75% of the ultimate strength of a good quality concrete is reached in 7 days. Using this rule, when admixture was used, formworks could be removed on the third (3rd) day after pouring for the Haitian-derived mixtures; this increased to approximately 14 days of setting time for mixtures where admixture was not included. The addition of admixture and time taken for concrete setting are important financial considerations to take into account for the total cost of a project.

5.5 Effect of Cement Content on Cured Samples

A sensitivity analysis was conducted by varying the amount of cement content in both the Haitian-derived concrete mixtures and U.S.-derived concrete mixtures. The purpose of this sensitivity analysis was to evaluate the effect of increasing the cement content on the compressive strength of the final concrete product assuming the concrete is appropriately cured. Compressive strength is understood to increase as the proportion of cement in the mixture increases.

The cement content in each sample was increased by 15%, 30%, and 50% by mass, relative to the total mass of the cement content in the original mixture composition for both the 24.1 MPa and 27.6 MPa mixtures. All samples were cured until testing. Admixture was included in both the Haitian-derived and U.S.-derived mixtures.

The compressive strength test results for all samples are presented in Table 4. For the 24.1 MPa and 27.6 MPa mixtures, respectively. Table 4 contains the results for compressive strength for all the mixtures tested as part of this study. This provides a broader comparison of the compressive strength for all mixtures tested across the 14, 28, and 56 day setting periods.

Similar to the results of the uncured samples presented in Section 5.3, increasing the cement content of the mixtures has a significant effect on the compressive strength of the mixtures where the cylinders were continually cured prior to testing. On average, the compressive strength for the Haitian-derived 21.4 MPa mixture increased to 14% from day 14 to day 28. An additional increase of 14% was observed from day 28 to day 56. For the U.S.-derived mixture, the increase observed was approximately 12% and 11%, respectively. The maximum compressive strength of the 24.1 MPa Haitian-derived mix was 45.9 MPa on day 56 of the setting periods where the cement content was 50%. A similar increase in compressive strength was observed for the 27.6 MPa mixtures.

A more notable increase (18%) in compressive strength was observed when the cement content in the 24.1 MPa Haitian-derived mixture increased by 30%. For the 27.6 MPa Haitian-derived mixture, the compressive strength increased to 25% when the cement content was increased by 15%. An additional 14% increase in compressive strength was noted when the cement content of the mixture was increased by 50%. The maximum compressive strength of the 27.6 MPa Haitian-derived mixture was 54.4 MPa on day 56 of the setting period where the cement content was 50%.

The U.S.-derived mixtures out-performed the Haitian-derived mixtures. On average, the U.S.-derived mixtures produced a 40% greater compressive strength as compared to the Haitian-derived mixtures. The maximum compressive strength of the 27.6 MPa U.S.-derived mixtures was 66.2 MPa where cement content was increased to 30%.

6 CONCLUSION AND RECOMMENDATIONS

The main objective of this project was to evaluate the quality of the cement and admixture commonly used in concrete production in Haiti. CINA cement and BASF admixtures were obtained from a construction contractor in Republic of Haiti for the purposes of this study. Extensive data was produced. Based on the analysis conducted, the following conclusions can be drawn:

- A literature review was conducted to understand the current state of the construction practice in Haiti. The country is prone to very powerful earthquakes and hurricanes which can result in damage of poorly constructed infrastructure leading to high loss of life. The 28-day compressive strength tests of concrete in Haiti showed that the typical ranges of compressive strength ranged from 2.8 MPa (410 psi) to 8.7 MPa (1,260 psi). This is much lower than the minimum specified concrete strength for residential building in the United States (US) is 20.7 MPa (3,000 psi) and may be a cause of concern for the robustness of infrastructure in the Republic of Haiti that is subject to extreme weather conditions.
- The results obtained from this work reject the hypothesis that the Haitian manufactured cement tested produced comparable results to U.S. manufactured cement. The cement used in construction in the Republic of Haiti can be considered inferior quality material in comparison to U.S. manufactured cement. The average 28-day compressive strength of the concrete mixes produced with cement commonly used in construction practice in the Republic of Haiti was 56% weaker compared to the concrete mixes produced with cement manufactured in the U.S.

Table 4: Compressive strength of all the mixtures tested in the research study

Mixture	**Compressive Strength (MPa)**		
Name[a]	**14-Days**	**28-Days**	**56-Days**
H-27.6-Adm-UC	15.3	16.1	19.6
US-27.6-Adm-UC	29.8	30.5	30.6
H-27.6-Adm-C	30.5	33.1	37.8
US-27.6-Adm-C	50.5	52.1	58.5
H-27.6 -C	26.1	29.4	32.1
US-27.6 -C	47.7	52.1	57.1
H-24.1-Adm-C	27.2	30.1	34.0
US-24.1-Adm-C	46.4	51.6	56.7
H-24.1-C	22.1	24.6	28.6
US-24.1-C	29.3	35.1	39.0
H-27.6-Adm-UC-15%	20.2	23.6	23.9
US-27.6-Adm-UC-15%	33.6	36.3	36.4
H-27.6-Adm-UC-30%	24.2	26.5	26.5
US-27.6-Adm-UC-30%	39.8	40.2	41.7
H-27.6-Adm-UC-50%	23.1	25.4	25.7
US-27.6-Adm-UC-50%	40.3	42.7	44.4
H-24.1-Adm-C-15%	28.2	35.9	39.1
US-24.1-Adm-C-15%	46.5	53.3	59.3
H-24.1-Adm-C-30%	32.8	35.1	40.6
US-24.1-Adm-C-30%	55.1	60.1	66.8
H-24.1-Adm-C-50%	33.9	38.8	45.9
US-24.1-Adm-C-50%	52.2	58.5	65.3
H-27.6-Adm-C-15%	38.0	42.2	47.1
US-27.6-Adm-C-15%	51.3	55.7	56.6
H-27.6-Adm-C-30%	39.6	44.0	49.8
US-27.6-Adm-C-30%	56.6	64.7	66.2
H-27.6-Adm-C-50%	45.9	50.6	54.4
US-27.6-Adm-C-50%	55.5	62.1	62.7

Table Notes:
[a] H-27.6-Adm-UC = H → Haiti Mix; 27.6 → 27.6 MPa; Adm → Admixture; UC → Un-Cured
US-24.1-Adm-C = US → US Mix; 24.1 → 24.1 MPa; C → Cured;
15% → 15% of additional cement; 30% → 30% of additional cement; 50% → 50% of additional cement

- Curing had a significant effect on the compressive stress of all samples tested, both Haitian and U.S. derived cement mixtures. When the specimens were not cured, the Haitian mixes did not reach the target compressive strength of 27.6 MPa. This observation was noticed even when the cement content in the original design was increased by 50% and/or the mixtures were tested at 56 days.
- The admixture used in the construction practice in Haiti was not shown to have any negative effects on the Haitian-derived concrete mixes. However, the admixture should not be treated as a retarder as originally assumed by the contractor in Haiti. When the admixture was added, the mixtures, especially those made with U.S.-derived cement, reached the target strength as early as 7 days. No significant increase in compressive strength was noted from 28 days to 56 days.
- According to the Haitian contractor, it was not feasible to import cement to the Republic of Haiti. Therefore, in order to produce hardened concrete products of suitable compressive strength, concrete producers in Haiti should consider increasing the cement content of existing concrete mixtures to at least 30%. Doing so, will increase the cost of construction, however maintaining appropriate concrete products in construction will enable the construction of robust buildings that are prone to the effects of natural disasters like hurricanes and earthquakes. Other alternative methods such as the use of different admixture and curing techniques need to be evaluated.
- The mixtures used in this research study were sensitive to the amount of water added. Although high quality control was set in place during mixing, high variation in slump was observed. This was due to variation in equipment and operator skill. The general rule is the higher the slump the lower the compressive strength. However, the variation in slump did not undermined the findings of this research. At all the times, the slump in the Haitian-derived mixtures were lower or equal to the corresponding U.S.-derived mixtures.
- The research work conducted was limited to the testing of one cement type and one admixture type manufactured in the Republic of Haiti. Continued research in this area is encouraged. Work is in progress to evaluate the effect of various cements and admixtures in differing proportions. In addition, effort will be made to include typical aggregates used in concrete product in the Republic of Haiti. It is also recommended to verify if Haitian cement can be classified as Portland Cement.

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Cultivating the Assimilative Perspective in Contextual Engineering – Knowing What You Don't Know

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ABSTRACT: *Contextual Engineering methodology affords engineering practitioners a more robust process for identifying socioeconomic and cultural conditions within a client community that could affect adoption and sustainability of a technical infrastructure. This methodology seeks to build an assimilative view of the client through direct interactions, which enable practitioners to assess critical local conditions without filtering their understanding through the lens of their own experiences. Some practitioners assert that direct interaction with a client community is unnecessary to achieve an assimilative view, particularly in an era when information is widely available via the internet, and communication with remote partners is possible using a variety of technologies. But assessments of the perceptions of engineering practitioners engaged in two separate projects in Latin America before and after travel to the client communities demonstrate that their understanding of community conditions were altered dramatically once they interacted with residents and experienced site conditions first hand.*

KEYWORDS: *Humanitarian engineering, Contextual Engineering, international development, perceptions*

1 INTRODUCTION

The practice of Contextual Engineering relies strongly upon an assimilative understanding of client conditions if the engineering practitioner intends to implement an effective technological intervention for an unfamiliar society and builds upon a body of research that exhaustively explores current practices in humanitarian engineering (Witmer, 2018a). This new framework for international engineering draws from existing processes for project design preparation, which can be grouped roughly into two classifications:

- Conditions assessment, as proposed by such researchers as Otte (2013), who used checklists of social variables; Diallo and Thuillier (2005), who used surveys of stakeholder perceptions; and Adomavicius et al. (2007) who modelled conditions using an ecosystem parallel; and
- Decision-making tools, such as a Capacity Factor analysis model proposed by Bouabid and Louis (2015); a project-outcome predictor as proposed by Wicklein (1998); and a dynamic-link logical framework advocated by Khang and Moe (2008).

Unlike these frameworks, though, Contextual Engineering focuses on building within practitioners an assimilative perspective, which requires a self-awareness on the part of practitioners so that they may recognise and compensate for the imposition of their personal beliefs and values upon the design process. But how can an assimilative perspective be developed, and what constitutes sufficient assimilation?

Assimilative perspective is defined in the literature (Witmer, 2018a) as the ability to experience societal context non-judgmentally and with full understanding of alternative conditions, values, and perspectives. This level of perception is advocated in Contextual Engineering, a rapidly emerging approach to addressing recipient societal needs through technical interventions that relies upon integration of place-based conditions and identities with technology design (Witmer, 2018b). Before the advent of Contextual Engineering, humanitarian engineers have historically solved technical problems using the Engineering Problem Solving (EPS) procedure, a six-step method that explicitly excludes "listening" as a part of the process (Lucena et al., 2010). Some engineering educators actively disparage direct interaction with client societies (Paterson et al., 2016) on the grounds that it doesn't produce a transformative experience for the practitioner, without acknowledging the activities undertaken while interacting are more responsible for influencing outcome than the act of travelling itself. EPS, then, trivialises the value of identifying and understanding unfamiliar contexts that range from divergent belief systems to exotic physical conditions, any of which could have a dramatic impact on functionality, adaptation, and sustainability of an engineered design for the client community.

In reality, EPS unintentionally substantiates the principle of satisficing, a concept first proposed by Herbert A. Simon in 1947 and later refined by others to define the act of looking for a course of action that is satisfactory, rather than a course of action that provides the greatest benefit possible (Simon, 1997). Applying this principle to humanitarian engineering, one would conclude that extended exposure to client conditions results in unnecessary effort and expense, particularly when a project can implement technology familiar to the designer by using insights collected from information media and global communications tools. Especially since internet access has become widespread, there's been a strong movement toward relying on remote data such as video logs and virtual reality imagery, which – combined with print and photographic resources – are heralded as a cost-effective way to develop clear understanding about client conditions (e.g., Pahre, 2017). Thus, for projects undertaken in remote locations, where travel may be expensive and unwieldy, the opportunity to learn about the community using such resources is not only contemplated but encouraged as an efficient way to identify conditions (Stainfield, et al., 2000).

But do such remote methods of inquiry provide a pathway to assimilate the actual physical and societal conditions under which the client society operates? This question perhaps may be best answered using the analogy of myopic individuals who set about cataloguing tree varieties in their neighbourhoods. Not realising their vision is blurred, they identify tree species based on their available perceptive capabilities, using tree size and shape, diciduosity, or colour to distinguish one tree from another. When these same individuals obtain corrective lenses, however, they discover significant additional details they had previously lacked the capability to recognise – bark texture, leaf shape, or symbiotic organism growth, for example. Without the visual capacity to identify these details – resulting in lack of awareness that these details even exist – observers could logically have concluded they had observed all there was to know about a tree. But introduction of a sharper visual acuity creates a new understanding of tree characteristics that couldn't have been understood previously.

Is an engineering designer functioning myopically when trying to understand a client community from a remote location, using information technology and controlled visuals? This paper explores a preliminary research effort to answer this question, using as case studies two projects in which practitioners from a variety of backgrounds and experiences evaluated client societal conditions – some before traveling and again afterward using a predictive tool developed to assist in Contextual Engineering design. Comparison of evaluations among practitioner-travellers, as well as analysis of evaluations by native translators and local NGO liaisons who provided initial information about the client community for the projects, offers insight into how societal context may be recognised or ignored based upon personal experiences, objectives, and predispositions. Comparison of pre-travel and post-travel evaluations among one of the groups further suggests that individuals are likely to draw upon their own predispositions initially when predicting place-based conditions, but after assimilative investigation they may be much more convergent in their understanding.

2 METHODOLOGY

The processes and subjects employed in this study are detailed in this section.

2.1 Research Subjects

Initial evaluation of practitioner perceptions was performed using members of a Midwestern Engineers Without Borders (EWB) professional chapter working with a rural village in the Panamanian indigenous region of Ngabe-Bugle Comarca. This evaluation consisted of using a predictive tool developed for Contextual Engineering to assess non-technical conditions that influence adoption and maintenance of an engineered intervention (Witmer, 2018b). Approximately 15-20 active members of the EWB chapter are practicing professional engineers, and six of those chapter members travelled to Panama in February 2019 to perform first hand assessment of community needs and conditions.

Panama research subjects also included a family of Panamanians who, while not from the project community, are familiar with the area and have assisted the community to seek engineering assistance from the United States. Three family members travelled to the community with the EWB professionals and acted as translators and facilitators. A fourth family member, who completed the EWB application with the community, is a student in the United Kingdom and did not travel with the team but provided them with advance information about local conditions in their preparation for travel. One additional Panamanian engineering student travelled with the team as well, though he had not been involved in providing project information to the group in advance of the trip.

To provide additional analysis of practitioner understanding, the same tool was used by another Midwestern EWB chapter – this time composed primarily of undergraduate engineering students at a large public institution – working with a farming village in the coastal region of Ecuador. Six undergraduate students from the project team, whose members range from freshmen to seniors, travelled to Ecuador in January 2020 for project assessment. Joining this team were two experienced Ecuadoran field managers who work with a partnering Non-Government Organisation (NGO) that assisted the coastal community to apply for EWB support.

2.2 Predictive tool use

To assess consistency of non-technical perception, the Contextual Engineering International Predictive Tool was used with both groups. This tool initially was developed and tested as part of a doctoral dissertation exploring the significance of context in engineering design (Witmer, 2018c). It has since been adopted by EWB-USA as a diagnostic tool that is available for use to all chapters undertaking new projects, and variations of the tool have been created for use domestically and in entrepreneurial applications. The tool consists of 41 questions for the practitioner to answer by observing during travel a variety of local conditions that range from the way people interact and the processes they employ in decision-making to the accessibility of education and public services to the demographics that are prevalent in the client community. By scoring each of the questions on a Likert scale of 1-5 after completing an on-site assessment trip, practitioners must think deeply about differences between their own experiences and the community's, pushing them to assimilate rather than simply bear witness to conditions they could easily observe without thought.

After returning from travel and completing the tool questionnaire, users upload the results to a web portal and scoring is completed by the tool manager to determine the relative importance of each of five critical non-technical influences to implementation of a technical process. Total values for each influence are summed and normalised to 100% so that relative percentage of each influence is determined. In a utopian society in which all five influences balance equally, we would expect to see 20% scores for each influence. Thus, the larger an influence's absolute deviation from the mean, the greater the critical significance that influence will have upon engineering decision-making (Witmer, 2018b).

The five influences of Contextual Engineering and their significance are presented here:

- Cultural – A shared identity that predominates in a client society, not necessarily shaped by a greater, shared societal identity
- Political –The power dynamics that reside within a client community, regardless of formal governance structures
- Economic –The ability of residents within a client community to meet what they regard as their basic needs, unrelated to monetary wealth
- Educational – A desire of client community residents to acquire new knowledge, distinct from the level of formal schooling or school accessibility
- Mechanical –An aptitude for creating, repairing, adapting, and/or refining devices to make them more functional, unrelated to formal technical training level

The directions given to tool users when they obtain the questionnaire state that travellers should review the questionnaire in advance but resist answering questions until they have spent significant time in the client community. For those questions with which the practitioner struggles, guidance recommends making a best-guess after the trip has ended so that all items have been completed by the time the tool is submitted for scoring.

When the tool was downloaded by the professional chapter before its Panama site visit, one team member (User 1) completed the questionnaire and submitted it immediately, unaware of the guidance to wait until after travel. User 1 relied upon both the information that her own teammates had gathered from previous trips and the first-hand reports from college-educated, local partners who lived near the project and were accustomed to communication in both English and Spanish. These sources were supplemented using web-based research that included both written and visual documentation of the region and its conditions. User 1 was informed that her tabulated results would not be provided to her until after she travelled and completed a new set of questionnaire answers. At that time, both pre-travel and post-travel results would be calculated and she could compare her assumed knowledge of the community with her first hand observations. Teammates, translators, and field representatives also were invited to complete post-travel questionnaires so that conformance of results could be assessed among Panamanians versus non-Panamanians. Additionally, the travel team was invited to complete the tool post-travel as a collaborative exercise, which would allow the team to reach consensus on each answer by filling in each other's gaps in observation and experience.

To further evaluate the difference between assumed client knowledge and observed conditions, a travel team from the student EWB project was invited in January 2020 to complete the Predictive Tool questionnaire before travel, both individually and as a group, and again after returning from the project site. The project team was advised that they would not be given calculated results from the pre-trip data until after completing their post-travel questionnaires. In this case, the student group relied upon detailed information provided by a multi-national, highly trained NGO staff who work frequently with engineering providers in the United States and undergo rigorous training in information-gathering, relationship-building, and intercultural communications.

Table 1 lists the questionnaire-completion process in terms of recommendations for use, use by Panama User 1, use by Panama travel team, and study-controlled use by the Ecuador student team.

2.3 Follow-Up Interviews

Practitioners from both teams were interviewed individually as well as jointly after tool use and processing to assess how they scored the tool, from where they had

Table 1: *Contextual Tool procedures as recommended by the developers, compared with the steps that were followed by participants in Panama and Ecuador travel teams. Note that the process followed by Panama User* 1 *was accidental, while the process followed by the Ecuador team was prescribed for research purposes.*

Contextual tool use for study subjects				
Tool Procedure	***Established Procedure***	***Panama User*** 1	***Panama Travel Team***	***Ecuador Student Team***
Before Travel				
Download Tool from Web	X	X	X	X
Become Familiar with Questions	X	X		X
Individually Complete Questionnaire (no results provided)		X		X
Consult Teammates on Question Meanings	X	X		X
Collaboratively Complete Questionnaire (no results provided)				X
During Travel				
Refine/Discuss Understanding of Questions	X	X	X	X
Perform Field Observations that Address Questions	X	X	X	X
After Travel				
Individually Complete Questionnaire (results provided)	X	X	X	X
Consult Teammates/Collaboratively Complete Questionnaire (results provided)		X	X	X

gathered their information before travelling, how their understanding of contextual influences shifted during travel, and whether they considered the results they received to be accurate. Interviews were performed via phone for Panama team members and in person for Ecuador team members, were semi-structured to incorporate unexpected experiences and observations shared by team members as they implemented the tool process, and ranged in length from 30 minutes to 90 minutes.

3 RESULTS

Data collection and analysis using the methodology discussed above is presented in this section.

3.1 Pre-Travel versus Post-Travel Perceptions for User 1

The accidental completion of the predictive tool before travel by professional EWB practitioner User 1 provided a glimpse into how a design-team member may perceive a client community, relying on her own information filters and the veracity of her information sources, before conducting a first-hand on-site investigation. Table 2 shows the calculated relative influence results of User 1's tool responses before and after travel. Before visiting the community, she perceived that members of the client community struggled to meet their perceived basic needs (Economic Influence) and this governed their ability to adapt and operate an engineered infrastructure. But after visiting and completing a new predictive-tool questionnaire, User 1's understanding of the community shifted strongly toward recognising the influence of a strong local identity, values, and beliefs (Cultural Influence), which became the predominate infrastructure-acceptance determinant identified by her tool scoring.

3.2 Pre-Travel versus Post-Travel Perceptions for Panama Travel Team

User 1's post-travel perception aligned closely with the observations of a fellow practitioner who travelled at the same time and completed only a post-travel questionnaire, as is shown in Table 3, as well as with the scores produced from tool use by the majority of translators and field-support local resources and community liaison who worked with the travel team.

Interviews with the practitioners after travel indicated that they realised when reviewing the tool results that they did not actually possess a strong understanding of the society with which they were working before they travelled, though they had previously believed they were cognisant of all local conditions. Several interviewees indicated that while they knew more about their client than they would have without employing the tool, they also developed a strong awareness of the limitations of their knowledge, which they described as beneficial in that it challenged them to question their assumptions and predispositions more rigorously. The image they had constructed pre-travel was built mostly from information they had received through correspondence and conversations with the community liaison, whom they deemed to be honest and forthright in communications but unable to fully convey a clear picture of conditions about a community that was so unlike the home experience for the EWB professional team. As a supplement to the information provided by the liaison, the team relied upon data gleaned from web searches and available publications, again deemed to be accurate and honest in their depiction of the Panamanian society but incomplete in their descriptions.

Table 2: Individual perception of team member 1 before and after travel for Ngabe-Bugle Comarca, Panama, client community (red cell is greatest influence for a given subject, green cell is least)

Results for Panama 1 User		
Influence	***Weighted Score pre-travel***	***Weighted Score post-travel***
Cultural	19.9%	26.1%
Political	19.5%	19.3%
Educational	20.3%	19.7%
Mechanical	17.7%	17.7%
Economic	22.5%	17.3%

Table 3: Comparison of scores for translators, community liaison, local resource and EWB traveling team members (red cell is greatest influence for a given subject, green cell is least).

Results for Panama Travel Team					
Subject	***Cultural***	***Political***	***Educational***	***Mechanical***	***Economic***
User 1 (pre)	19.9%	19.5%	20.3%	17.7%	22.5%
User 1 (post)	26.1%	19.3%	19.7%	17.7%	17.3%
Fellow Traveller	26.6%	20.3%	18.6%	12.8%	21.6%
Translator 1	26.1%	20.0%	19.5%	12.8%	21.6%
Translator 2	21.9%	23.3%	17.1%	18.0%	19.7%
Translator 3	25.7%	19.9%	20.2%	17.4%	16.9%
Community Liaison	26.5%	20.9%	18.8%	13.1%	20.8%
Local Resource	20.4%	22.5%	20.0%	18.1%	18.9%
Collaborative[1]	26.2%	21.0%	18.0%	14.0%	20.7%

Key:
TM=team member; Trans=Translator; CL=community liaison; LR=local resource
Collaborative group = TM 1, TM 2, Trans 1, Trans 2, CL 1

3.3 Pre-Travel versus Post-Travel Perceptions for an EWB Ecuador Team

Because the unexpected opportunity to compare pre-travel and post-travel perceptions yielded startling differences in community understanding for User 1, an additional trial was performed in which an entire team's understanding of their own client community was tested before travel and compared to post-travel perceptions, using the Predictive Tool. In this case, six members of a university EWB team travelled to coastal Ecuador in January 2020 after spending nearly a year researching their client's conditions and identity. Team members filled out the Predictive Tool individually then completed it collaboratively, negotiating scores for each of the 41 questions to reach a consensus. The team then spent eight days on site, following the Contextual Engineering tool recommendation of investigating physical, societal, political, and economic conditions, before completing the questionnaire once more both individually and collectively. The results of pre- and post-travel relative influences identified by the team are shown in Table 4.

One can see from the colour scale of relative influences for each individual practitioner that perspectives before travel varied widely among the group in identifying the most critical influence, with two members viewing cultural influence as most significant, two members viewing political influence as dominant, and one member each viewing educational and mechanical influences as most critical. Not one of the practitioners, however, perceived the economic influence as strong within the client community, even when the team completed the tool collectively after negotiating their pre-travel scoring. After travel, however, all six practitioners viewed the client community's contextual influences similarly, at least in terms of most and least significant relative influences. The tool scores that resulted from those individual perceptions also aligned strongly with the influence scores for the group-negotiated tool outcome, which identified as the most dominant influence the community's inability to meet what it considers its basic needs; the group outcome also found that the least significant influence was a commonly shared and valued sense of identity that aligns with a set of values and/or beliefs – the very influence that they jointly identified as most critical before travel.

3.4 Perceptions based on project role

After the professional team's travel to Panama was complete and individual questionnaires were returned and processed, the Predictive Tool was distributed to the travel team's translators and local resources, including the

Table 4: Individual and team perceptions before and after travel for El Guarango, Ecuador Project Team indicate that site observation produced strong conformity of understanding (red cell is greatest influence for a given subject, green cell is least)

Pre-travel					
Individual	***Cultural***	***Political***	***Educational***	***Mechanical***	***Economic***
Individual	21.90%	19.10%	20.00%	18.20%	20.80%
	22.40%	24.20%	13.70%	18.60%	21.10%
	18.00%	20.70%	22.90%	18.60%	19.80%
	22.40%	18.70%	19.00%	23.00%	16.90%
	23.20%	27.10%	12.60%	12.20%	24.80%
	23.10%	22.20%	17.60%	15.40%	21.80%
Group	**21.70%**	**20.20%**	**18.70%**	**18.10%**	**21.20%**
	Cultural	***Political***	***Educational***	***Mechanical***	***Economic***
Individual	18.50%	18.90%	20.50%	19.50%	22.60%
	17.20%	19.80%	21.40%	19.20%	22.50%
	19.30%	20.20%	20.00%	19.10%	21.40%
	18.80%	21.60%	17.40%	19.00%	23.10%
	14.30%	20.70%	21.40%	19.50%	24.10%
	14.10%	21.50%	20.50%	18.70%	25.10%
Group	**16.50%**	**19.00%**	**20.70%**	**19.10%**	**24.70%**

community liaison, to determine whether perceptions differ depending upon the role the assessor plays. Additionally, combinations of team-role participants were invited to complete the tool collaboratively. The purpose of this exercise was to determine whether those experts already familiar with Panamanian society had a different understanding of its context than the U.S. practitioners had after the travel experience was complete, as well as to determine whether collaborative tool completion yielded different results than the average of individual observations. Table 3 presents the results of individual post-travel results for each of the three translators, the liaison, and the local resource, as well as a collaboration of the two practitioners, two translators and community liaison. Results demonstrate a strong alignment of perception that cultural identity is a governing influence for the Panamanian community, regardless of tool-user role or of collaboration. It is interesting to note, however, that the client liaison and one translator were more attuned to political influence than the remainder of the group, not to the degree, though, that they influenced the final collaborative outcome.

4 DISCUSSION

The accidental discovery that a practitioner's perceptions of a client community may change dramatically after immersion into the client's daily life provided a basis for further investigating how strongly we rely on incomplete information about our clients' needs in designing infrastructure when we do not travel, explore, inquire, and observe. Of particular interest while pursuing this research path was examining what practitioners rely upon for client information when they are unable to draw upon their own interactions with the place and people. As the professional practitioner and student team both explained, much of the information they acquired about their clients came through local resources that may have unintentionally filtered their understandings of the village. Were those pre-travel perceptions misguided because of deliberate manipulation of information to achieve maximum support for the project, as may be assumed if one subscribes to Krause's analysis in her book, "The Good Project" (2014)? Krause's conclusion is that NGO drivers focus on organisational self-preservation rather than client need. An equally likely alternative interpretation is proposed in Witmer (2018c) that concludes perception of community context improves with increasing familiarity until it reaches a point in which the assessor begins to identify as a community member rather than an observer. Should this stage of perception, labelled "integration," occur with local contacts, they may be so familiar with a client society that they identify with a portion of it, thus shifting their own perceptions toward those of the segment itself and losing sight of the heterogeneous whole. Such an integrated perception may unintentionally result for field representatives or client contacts who have become so familiar with the community or the region that they fail to perceive the nuances that exist specific to place and time.

Regardless of how pre-travel information is gathered, the results of this study provide strong initial indications that true contextual understanding doesn't occur until the practitioner interacts with the client community directly and experiences the people, place, beliefs, and practices that reside specifically in that place at that time.

5 CONCLUSIONS

Engineering practitioners who have been educated using the EPS process are predisposed to believing they have a sufficient understanding of local context associated with an international engineering project even if they have had no direct interaction with the community or experience in evaluating values, experiences, identities, and dynamics associated with society. In reality, it is very difficult to establish an assimilative view to inform design unless practitioners experience the client location first hand and spend time gathering information and experience in examining its societal as well as physical conditions.

Resources upon which practitioners rely to provide a remote understanding of local conditions, ranging from online information services to conversations with local liaisons, may not intentionally obscure their understanding of local conditions but may not provide a complete and non-biased understanding of the client.

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