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Incident Report and Analysis of the 2021 Cox's Bazar Rohingya Refugee Camp Fire in Bangladesh

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Abstract. According to the UN Refugee Agency, roughly 980,000 people live in the Cox's Bazar region in Bangladesh, making it the largest and most densely populated refugee camp in the world. The number of fires in this settlement rapidly increased in 2021. On 22 March, a large fire event occurred, where 15 fatalities and 560 injuries were reported, and more than 9500 homes were affected leaving 45,000 homeless. This work seeks to reconstruct this incident based on firefighters' statements, information found in the media, and satellite imagery. The study shows that (a) the fire spread extremely fast, with linear spread rates between 79 and 310 m/h and an average areal spread rate of 92,850 m^2/h estimated, (b) the firefighters performed two main operations, firefighting and the creation of fire barriers, (c) the residents self-evacuated, deciding when and where to evacuate, and (d) the residents' actions were similar to what has been observed in residential fires, with several people mentioning looking for missing family members. Fire spread is analogous to wildland fires where conflagrations spread across large areas of combustible material. This work can be used in planning for future large-scale fire incidents in tented camps, and proactively seeking ways of mitigating their impact. This is the first detailed documentation of such a large-scale refugee camp incident in the academic literature.

Keywords: Fire investigation, Refugee camps, Fire spread, Fire incident reconstruction

1. Introduction

According to the UN Refugee Agency [1], at least 89.3 million people around the world have been forcibly displaced. From those, around 27.1 million are living in refugee camps. Roughly 980,000 people live in the Cox's Bazar region in Bangladesh, making it the largest and most densely populated refugee camp in the world [2]. Data from 2018 indicates that the average usable area per person in certain areas was less than 10 m^2 and for most of the camps is less than 22 m^2 (the rec-

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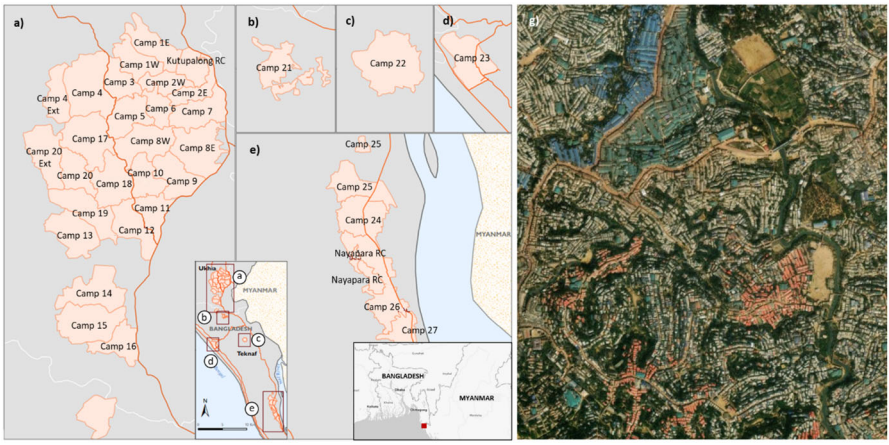

Figure 1. Rohingya refugee camp. Left: location of the different camps. Right: aerial image of the camp [73].

ommended surface area is 45 m^2) [3]. Figure 1 presents the refugee camp's configuration, it can be seen the total area was divided in more than 30 camps, which are usually very dense. It is estimated that there is an average population density of 25 m^2/person, which is less than that suggested by the UN of 45 m^2/person [4]. The density varies for each camp going from as little as 9 m^2/person in Camp 15–80 m^2/person in the newest camps such as Camp 4 Ext [5].

With fire events occurring more and more often in refugee camps [6], understanding these incidents becomes critical. The International Organization for Migration[1] (IOM) in Bangladesh has been keeping track of the number of incidents that affect the Rohingya refugees in Cox's Bazar since 2019. Between April and November 2019, 35 fire incidents were reported, affecting more than 80 shelters [8]. In 2020, during the same period, 47 fire events were reported which affected 3146 people from 700 shelters [9]. According to Fortify Rights (non-profit, nongovernmental organization), between January and April 2021, there were already 86 fires [10]. The increase in the number of fires indicates that fire safety should be a major concern in these settlements. However, as indicated in [11] fire safety is far from being a priority. Similar to informal settlement (IS) fires, fire incidents in refugee camps are usually not investigated. Due to the construction materials used (discussed below), layouts and high density seen in the camps, a fire investigation in a refugee camp would present similar challenges to the ones mentioned in [12], such as rapid-fire spread (where one incident will probably

[1] The IOM is part of the United Nations System as the leading inter-governmental organization promoting since 1951 humane and orderly migration, with 175 member states and a presence in over 100 countries. IOM works on the development of policy guidance for the field; the formulation of global strategies; standard-setting and quality control; and knowledge management relating to "mainstream" migration sectors, including labour and facilitated migration, migration and development, counter-trafficking, assisted voluntary return, migration health, assistance for vulnerable migrants, immigration and border management and overall capacity-building in migration management [7].

Table 1
Examples of Fires That Have Taken Place in the Rohingya Refugee Camps in 2021 and 2022 (Incident in Bold Is Studied in This Paper)

Refugee camp	Date	People affected	Property damage
Nayapara [65]	14 January 2021	3500 homeless	550 homes 150 shops 1 facility
Kutupalong [25, 26]	22 March 2021	15 fatalities / 560 injuries 45,000 homeless	9500 homes 1600 facilities (hospitals, learning centres, aid distribution points)
Kutupalong [26]	2 April 2021	3 fatalities	20 shops
Camp 9 [66]	21 July 2021	5 injuries	60 homes
Camp 16 [67]	9 January 2022	3600 homeless	600 homes
Camp 5 [68]	18 January 2022	43 injuries 138 homeless	27 homes 1 facility damaged
Camp 5 [69]	8 March 2022	1 fatality (four-year-old boy) 2000 homeless	400 homes 2 learning centres several WASH facilities 1 primary health centre

involve many homes), lack of physical evidence left at the scene, and lack of resources and time to conduct the investigation.

Table 1 presents some of the fires that have occurred in the last two years in the Cox's Bazar camp. It can be seen that in the first quarter of 2022 three large fires have occurred. This work aims to investigate a large fire event that took place in March 2021, from now on denoted as the 'Cox's Bazar fire' (it has also been referred as the Rohingya fire based on the ethnic group of the majority of the inhabitants). For this investigation, the methodology proposed and applied in [12, 13] for IS fires will be used. This methodology was used as it considers the restrictions present in low-income settlements. These restrictions include (a) the lack of physical evidence and localise fire patterns, as almost everything get destroyed, (b) the limited time, as the rebuilding process starts immediately after the fire is extinguished, and (c) the difficulty to obtain witnesses' statements.

The remainder of this work presents the methodology used to reconstruct the fire, a description of the fire behaviour in tented camps, a summary of the fire event, the results, and the discussion. The results section only considers the facts that were observed during the fire event regarding the fire spread, firefighters' operations, the evacuation and the human behaviour. The interpretation and analysis of the factors that could have influenced the results are presented in the discussion section.

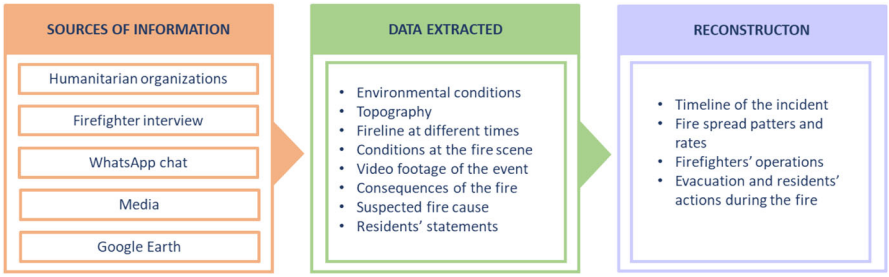

Figure 2. Methodology for reconstructing and analysing the Cox's Bazar fire incident.

2. Methodology

This section describes the methodology used in the analysis of the fire incident. Figure 2 provides a graphic representation of the methodology, which follows the one proposed in [12].

Firstly, data was collected from different sources of information. The main sources of information were (a) firefighters, (b) social and traditional media and (c) international humanitarian organizations.

In the refugee camp there are three types of firefighters, local Bangladeshi fire brigade, the firefighters from an implementing partner organization (e.g., agency that provides assistance on behalf of a larger organization) and the volunteer firefighters. The latter includes residents from different areas of the settlement, including residents that might be directly affected by fire. For this work a firefighter from the implementing partner organization was interviewed and involved in the research; additionally, he provided access to a WhatsApp conversation record from the day of the fire. The authors did not have direct contact with the local Bangladeshi firefighters or volunteer firefighters. Social valuable information such as video recordings, statements from residents, statements from local Bangladeshi first responders and authorities, and the consequences of the fire. Finally, international organizations such as the United Nations High Commissioner for Refugees and IOM, produce reports periodically to inform different stakeholders (i.e., board of directors, staff, donors) about the conditions of the camps. Furthermore, when a disaster occurs, especially one that affects several people, they document it.

After collecting data from the different sources, the information was analysed, and data was extracted. The implementing partner firefighter's statements provided information about the ambient conditions, fire lines at different times, and problems faced; additionally, this input was used to corroborate and deepen information provided by the international organizations and the media. The statements combined with the WhatsApp conversations allowed for the estimation of a timeline of the event and the identification of the main problems that affected their operations. The information provided by international organizations and the media allowed the identification of the fire scar, the camp layout (including the

location of the barbed wire fences), the consequences of the fire, the possible fire causes, and the residents' responses to the fire.

Finally, the fire scar, fire lines, ambient conditions and topography were used to analyse and estimate the fire spread sequence and the fire spread rates. Videos and residents' statements provided information that enabled the evacuation process and the residents' behaviour during this event to be studied.

3. Fire Load and Fire Dynamics of the Shelters

This section presents a short overview of the fire load and fire dynamics observed in shelters. This is based on standard shelter drawings [14] and on videos from large scale experiments [15].

3.1. Fire Load

In general, the shelters in the Camps are constructed from several materials such as bamboo, tarpaulin, ropes (polypropylene, PVC), cement and sand [14], meaning that the majority of the construction materials are combustible. Figure 3a shows homes located in Camp 8W prior to the fire. Figure 3b depicts the shelters that are provided for the Rohingya refugee camps.

Table 2 presents details of the materials used for the standard shelter including the quantities, fire load and fire load density. The standard shelter details from [14] were used to identify materials and quantities. To determine the fire load density the following values were used: (a) a density of 660 kg/m^3 for the bamboo, which is the average from the five types of Indonesian bamboos presented in [16], (b) heat of combustion 18.4 MJ/kg [17] for the bamboo, 47.3 MJ/kg [18] for HDPE and 43.3 MJ/kg for polypropylene and polythene [19] (also called polyethylene).

Figure 3. (a) Camp 8W 2 weeks before the fire [46]. (b) Standard shelter for fire response showing the bamboo frame and structure clad [14].

Table 2
Determination of the Fire Load of a Standard Shelter

Item	Description	Quantity	kg	Fire load (MJ)	Fire Load density (MJ/m^2)
Borak bamboo	Length: 20 ft. Diameter: Upper side minimum 45 mm & bottom side minimum 78 mm. Thickness 18 mm	12 pieces	9.7	2150.8	159.3
Muli bamboo	Length: 15 ft. Diameter: Upper side minimum 30 mm & bottom side minimum 40 mm. Thickness minimum 6.5 mm	420 pieces	1.7	13,357.7	989.5
Tarpaulin	Size: 4 × 6 m +/−1% weight: 190 g/m^2 ± 20 g under ISO 3801	4 pieces	4.8	909.9	67.5
6 mm rope	Polypropylene or similar, diameter: 6 mm. Average 50mt length	8 bundles	10.5	3638.0	269.5
3 mm rope	Polypropylene or similar, diameter: 3 mm. Average 50mt length	12 bundles	2	1039.4	77.0
Polythene roll	Thin plain polythene,26 lbs per roll	0.4 roll	11.7	202.6	15.0
TOTAL					1577.7

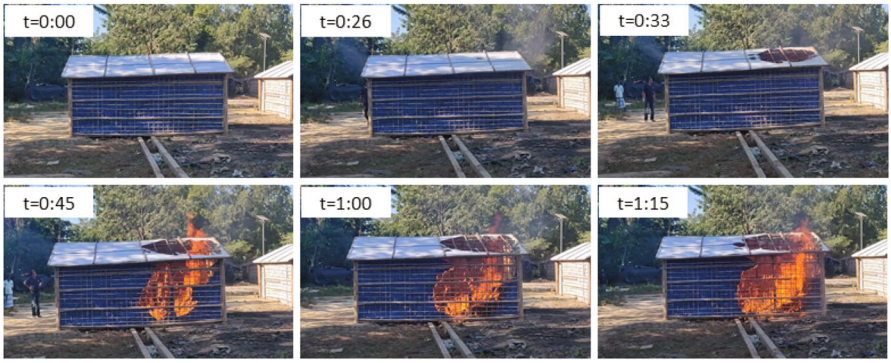

Figure 4. Screenshots from [15] showing fire development during a tented shelter burning experiment.

3.2. Fire Dynamics

This section is based on a video recording of one a fire experiment conducted on the tented shelters by firefighters from the implementing partner organization. The aim of the experiments was to observe the fire behaviour and to determine how effective different interventions are, and to come up with suitable ways to fight fires. Figure 4 presents the fire development at different times. After ignition (at t = 0:00) the fire starts to grow and at t = 0:26 the tarpaulin on the roof begins to melt. A few seconds later (t = 0:33) almost half of the roof has burnt out and

small areas of the wall have also been affected. By t = 0:45, a large part of the plastic sheet located at the wall has also melted. After this the fire size remains virtually the same. The large openings produced by the fire do not allow the build-up of the smoke layer; hence, the heat is not contained in the dwelling. This is an important difference in comparison to the fire behaviour seen in informal settlement dwellings [20, 21].

For a typical enclosure fire the stages of a fire are: (a) the growth phase which occurs after ignition, where flames spread across the fuel leading to temperature increases and rising heat release rates. (b) The fully-developed phase which follows a rapid transition from a localised fire to full room involvement, where the transition is typically referred to as flashover. During this phase the heat release rate is typically limited by the amount of available oxygen based on the size of ventilation openings. (c) The decay phase where heat release rate and temperature decrease due to the fuel having been consumed. Such behaviour is shown by the red line in Figure 5. For detailed discussions on fire dynamics refer to works such as [22, 23].

Based on Figure 4, it is hypothesised that when a fire starts in one of these shelters the fire behaviour resembles the blue curve shown in Figure 5. The fire will grow rapidly, but when the roof burns through the fire will behave as a free burning fire, rather than a typical enclosure fire which is typically ventilation limited. This topic should be further studied in order to understand in detail the complexity of these fires on an individual dwelling level, and furthermore how it would influence large scale fire behaviour.

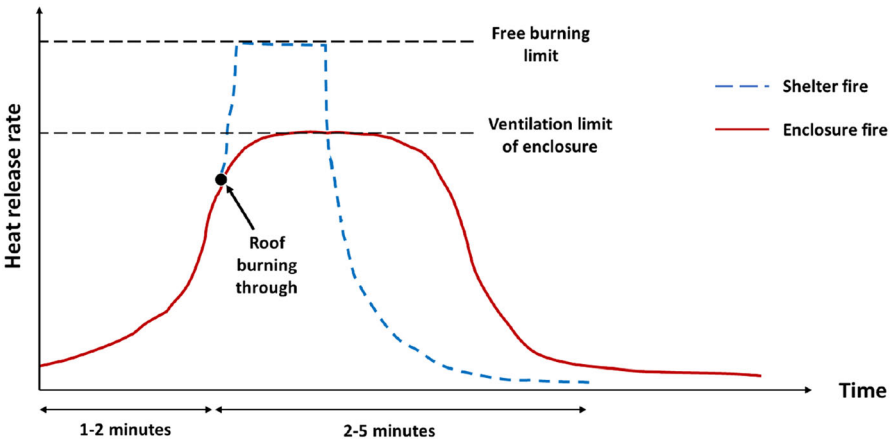

Figure 5. Hypothesised fire curve for enclousure fires (red curve) and for tented shelter fires (blue curve) (Color figure online).

4. Results

This section presents the results of the analysis conducted. A summary of the fire incident and the factors influencing the incident is firstly presented. This is then followed by the analysis of the fire spread, firefighting operations, evacuation and human behaviour in fire.

4.1. The Cox's Bazar Fire Incident

The fire event that is the focus of this paper took place on 22 March 2021 in the Rohingya refugee camp located in Cox's Bazar, Bangladesh. Figure 9 illustrates the area that was affected by the fire, which corresponds to roughly 0.65 km^2. Following the fire, 15 fatalities (from those at least three were children [24]) and 560 injuries were reported. More than 9500 homes were affected leaving 45,000 homeless [25, 26]. Furthermore, many other homes had to be knocked down to create fire breaks. Altogether the incident affected an estimated 47,000 inhabitants [27]. Figure 6 shows the intensity of the fire and the aftermath. Similarly to what was seen in IS, most of the combustible material was burnt and there is almost no physical evidence left at the scene [13, 28–30]. Although the fire cause was not identified it has been mentioned that it could have been due to an LPG cannister explosion [31], or possibly arson considering the large number of fires in the previous months [32]. Besides the 9500 homes destroyed, multiple other facilities were affected including: six health facilities [33], two nutrition centres, 141 learning cen-

Figure 6. Photos of Cox's Bazar showing [46]: (a) fire incident, (b) fire aftermath, and (c) 2 days later where people are starting to rebuild.

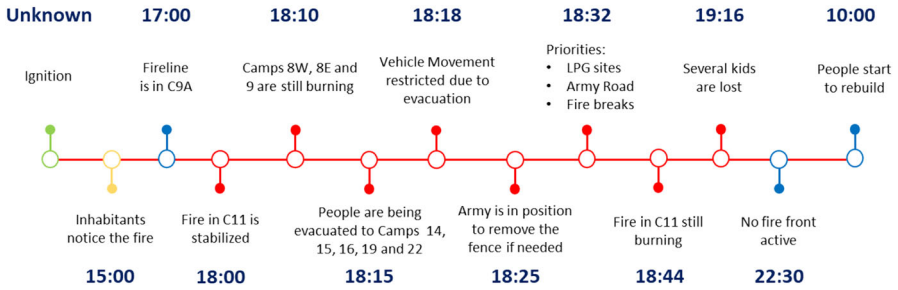

Figure 7. Timeline of the fire highlighting important happenings.

tres, and two child protection centres [34]. In addition, 1600 latrines and 630 bathing spaces, markets and other critical infrastructure were destroyed [34].

4.1.1. Timeline Figure 7 depicts the timeline of the fire. This was constructed based on official statements published in the media (events in yellow), WhatsApp conversations from the implementing partner organization firefighters chat group (events in red), and a firefighter's statement who was at the scene from 17h00 to 22h30 (events in blue). The fire started around 15h00 in Camp 8W, thereafter quickly spreading to Camps 8E, 9 and 10 [35]. According to a firefighter that attended the scene, by 17h00 the fire had reached Camp C9A (which is located near the southwestern boundary of C9). Simultaneously to this fire other fires were reported on Camp 11 and in the Turkish Hospital (according to the WhatsApp conversation). By 18h15 many people had evacuated to neighbouring camps. Due to the large movement of people the roads were congested, and vehicle movement was restricted. The impact of the barbed wire fencing in the evacuation of people became a concern, and at 18h25 members of the army were prepared to cut the fences if needed. As the fire kept spreading the firefighters were worried about the fire reaching critical areas such as the LPG site in Camp 9 and in Army Road. For this reason, their efforts concentrated on creating firebreaks there. Additionally, they were still worried about the fire in Camp 11. The locations of the aforementioned areas can be seen in Figure 9. After burning for 4 h, many children had become lost, and strategies were developed to facilitate their reunification with their families. Around 22h30, when the interviewed firefighter left the scene, there were no active fire fronts. The next morning, when he came back to the scene, he saw people starting to rebuild their homes.

4.1.2. Ambient Conditions and Topography One of the authors is a fire fighter who had attended the scene. He arrived there at around 17h00 and took temperature and wind measurements. The temperature was 30 °C and the wind conditions were 20 km/h in the N/NW direction (See Figure 8b). After 18h30, when it got dark, the temperature and the wind speed decreased. It was the end of the dry season, without any substantial rain since December 2020 and the Relative Humidity was very low.

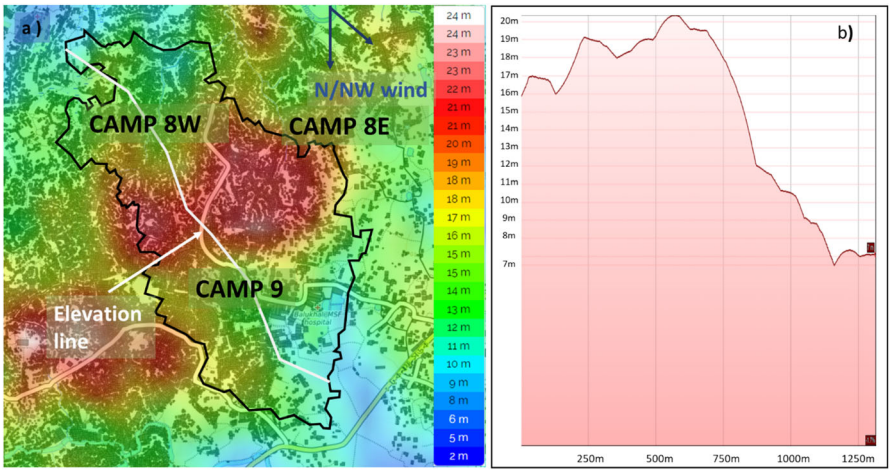

Figure 8. (a) Topography of the area [62]. (b) Elevation line.

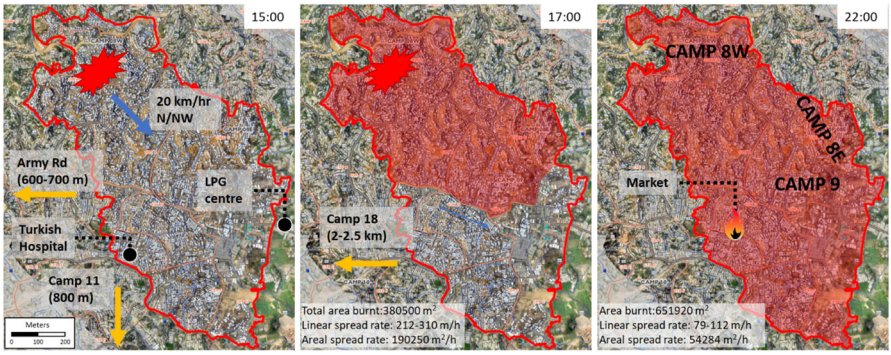

Figure 9. Estimated fire spread.

The topography of the affected area is shown in Figure 8a with the elevation line shown in Figure 8b. It can be seen that towards Camp 9 there are steep slopes that could influence the fire spread and the evacuation.

4.2. Fire Spread

Figure 9 depicts the estimated fire origin, fire spread direction, fires line at different times and critical areas. There were certain locations that were mentioned several times in the WhatsApp conversation. Those are shown in Figure 9a. Spot fires were seen (a) near Army Road, located approximately 700 m to the West of the burn scar, (b) Camp 11 located approximately 800 m to the South of the burn scar, and (c) near the Turkish hospital. According to eyewitnesses [36], there were multiple fires in different parts of the camps, leading them to believe that the fire was intentional. "First, we saw only one fire in block C, then another one, and

then one at C18, the fire was started from all sides of our camp''. ''We never thought our house would be on fire, the fire was far away, but suddenly I saw a fire burning behind us''. Army road was particularly important since it is one of the main roads (7 m wide) that go through the camps. The firefighters from the implementing organization were concerned that if the fire got there it could spread to many other shelters. Figure 9a also shows the location of the LPG centre in Camp 9, which was one of the places that was permanently monitored. Figure 9b and c illustrate two fire lines, one for the afternoon and one for the evening. In the first two hours of the fire the estimated area affected was 380,500 m^2, with linear spread rates ranging from 212 to 310 m/h. In the following 5 h, the fire burnt another 271,420 m^2, with linear spread rates ranging from 79 to 112 m/h. According to residents, the fire spread was extremely fast. One resident mentioned ''The heat was unbearable, and the air thick with black smoke.'' [16, 17]. By 22h00 there was no active fire front; however, in some areas, especially in the markets, the fire kept burning.

4.3. Firefighters' Operations

It is important to distinguish between the resident volunteers, local firefighters, and firefighters from the implementing partner organization. In this work, interviews, and a WhatsApp conversation from the latter were used. From these, two main operations were identified: firefighting and the creation of fire barriers. All three organisations participated in the firefighting activities, and residents were also seen throwing buckets of water to the fire. However, according to the interviews conducted, due to the magnitude of the fire and the lack of water supply, the firefighting efforts had little influence on the fire spread (e.g., meaning that fire was only controlled once there was no more combustible material left to burn). The creation of fire barriers in strategic locations seemed to have a bigger impact. Critical areas such as the LPG distribution centre and Army Road were constantly being monitored and fire barriers were put in place to protect them. This means that shelters located near these areas were dismantled and removed from the vicinity.

4.4. Evacuation

To understand the evacuation process, it is necessary to provide context regarding what activities people are normally doing at the time of the fire. The fact that the fire occurred on a Monday at 15 h contributed to the families being separated. Women would be at home, men would be in the shops or markets, and the children at the Madrassa or playing outside (in March 2021 the educational facilities were closed due to COVID). The magnitude of the fire, the dense smoke, the narrow roads, and the barbed wire fences, among other factors, all impacted the evacuation process. There was no evacuation plan; people decided when and where to evacuate on their own. According to the WhatsApp conversation people were moving towards Camps 14, 15, 16, 19 and 22. Figure 10a depicts the location of some of these camps in relation to the area affected by the fire (Camp 22 is located below Camp 16). The physical capabilities of the residents also played

Figure 10. (a) Area affected by the fire and fence location [63] (barbed wire fencing, approximated location based on [10]). (b) Man trying to evacuate through the wire fencing [50].

an important role in evacuation, as some people were not even able to walk [18, 19]. During the evacuation injuries were reported [16, 17, 37], and people got lost [19, 38–41]. One of the inhabitants stated [34], "My wife and I lost our son when everyone rushed to escape from the fire in camp 9… Everyone was rushing to the main entrance of the camps, which is the only exit route. Other sides are surrounded by fencing… When my son got lost, he tried to go back to our shelter searching for us. This is where we found his burned body… If there had been no fence, people could have escaped using different routes". In the WhatsApp conversation it was seen that there was a concern about the fences, for this reason from very early on the army was cutting the fences to allow people to evacuate. A detail of the location of the fences is shown in Figure 10a, it can be seen that fire came very close to the fence in the Southwest part of the burn scar. Figure 10b shows a man trying to evacuate through one of the fences.

4.5. Human Behaviour in Fire

According to one of the camp leaders, during the initial stage of the fire the residents tried to control the fire; however, they were not successful, and the fire continued spreading [31]. Then they continued with the evacuation of the block where the fire started [31]. Although it is unclear what cues were available that allowed for the identification of the fire, once it started to grow, people from neighbouring areas could see the flames and smoke and hear people screaming [38]. Nevertheless, the fire spread so rapidly that some of the residents were not able to evacuate or save their belongings before the fire reached their homes. "The fire spread so quickly that before we understood what happened, it caught our house … people were screaming and running here and there" said one of the inhabitants [16]. On the other hand, a young mother indicated that everything happened so fast she could not do anything to protect her children [38]. Some of the testimonies found reveal that some of the actions preceding evacuation were to: dress the children

Figure 11. Human behavior during the fire. (a) and (b) Evacuation[41]. (c) Firefighting attempt [19]. (d) Looking after their belongings [64].

[17], look for family [19, 38, 39], help others [17, 19, 39, 41], save belongings [39], and fight the fire. [19, 41]. A re-entry behaviour mentioned by one person was to collect valuables [39]. The firefighter interviewed mentioned that several people were standing at the vicinity of the fire, using their cell phones to record what was happening. He mentioned that this situation created congestion in the area (Figure 11).

5. Discussion

Based on the technical and reported details of the fire presented above, this section analyses and discusses important factors that influenced the incident. In addition, a general discussion about the benefits and limitations of conducting this type of study is presented.

5.1. Fire spread

From Figure 9 it is possible to see that the fire spread in the evening was much slower than in the afternoon, this can be associated with an improvement in weather conditions and also with the fire spreading downhill due to the topography (see Figure 8b). Similarly to what has been seen in large IS fires, the fire scar resembles ones seen in wildland fires, in which topography and weather conditions play an important role. The fact that there were multiple fires occurring at the same time could be attributed to spot ignitions due to firebrands or hot metal fragments being carried by the wind. From what has been seen in this and previ-

Table 3
Comparison of Large-Scale Fire Incidents Considering Spread Rates and Wind Speeds

	Fire event or experiment	Wind Speed [m/s] (km/h)	Area affected [m^2]	Fire duration [min]	No. of dwellings affected	Linear spread rates [m/min] (m/h)	Avg. Areal spread rates [m^2/min] (m^2/h)
1	Cox's Bazar (This paper)	5.5 max (20 max)	651,920	420	9500	1.3- 5.2 (79–310)	1552 (93,131)
2	12 dwellings[a] [70]	0.7–5.7* (2.5–20.5)	110 out of 160		6	0–0.5	
3	20 dwelling experiment[a] [5]	4.2–6.9(15–25)	310	16	16	3.6 avg	19.4 (1162)
4	2017 Imizamo Yethu[b] [30]	7.8–12.8 (28–46)	76,600	810	> 2000 destroyed	0.5–2.3	94.6 (5674)
5	2016 Itoigawa[b] [71, 72]	9 average 27 m/s max	40,000	660	120 destroyed, 27 damaged	1.7 avg	60.6 (3636)
6	2019 Langa[b] [29]	1.7–3.1 (6–11)	550	50	42 destroyed	0.4–2.3	11 (726)
7	2020 Masiphumelele [13][c]	9.7–13.9 (35–50)	31,000	600	> 1000 destroyed	0.5 avg	51.7 (3100)

[a]Experimental work
[b]Real fire events
[c]Case study applying a framework for fire investigations[12]
*Wind opposed to the direction of fire spread

Table 4
Comparison of Fire Spread Rates for the Cox's Bazar Fire Incident and Wildland Fire Spread Empirical Models (Extract from [42])

Model	Wind range (km/h)	Rate of spread range (m/min)
CALM Mallee	5.4–24.8	7.8–408
CSIRO grass	10.4–25.6	17.4–124
Heath	0.4–36.4	0.6–60
PortShrub	1.0–27.0	0.6–20
PortPinas	1.1–23.0	0.2–14
TRW	0.0–16.9	0.0–0.4
NBRU	0.0–32.4	0.2–23
Cox's Bazar (This paper)	20 (max)	1.3–5.2

ous fires, the shelters burn extremely fast and usually there is not much material left to create embers. However, those could be associated to the vegetation present in the area. Although the limited amount of information only allowed to identify two fire lines, the results obtained can serve as a basis for fire spread modelling.

Table 3 compares the results obtained in this work with fire spread rates for low-income settlements as provided in the literature. Due to the magnitude of the fire, it is difficult to compare the areal spread rates with other fires, as seen in [13] the fire spread rates estimated were highly dependent on the size of the fire. Nevertheless, it can be seen that the linear spread rates are somewhat similar to the ones observed in real informal settlement fires in Cape Town, South Africa, and in the 2016 urban conflagration in Itoigawa, Japan. In this current work fire spread rates of 1.3–5.2 m/min were estimated, while for previous fires upper bounds were in the region of around 2–3.6 m/min. To compare the fire spread rates obtained in this work with the ones from wildland fires, ranges from different empirical models have been used. In [42], Sullivan reviewed several empirical and quasi-empirical models for the fire spread modelling of wildland fires. Table 4 shows an extract from [42], presenting the models that are applicable for the wind conditions observed during the Cox's Bazar fire. It can be seen that the values obtained in this work are closer to the lower bounds for almost all models, meaning that wildland fires spread much faster.

5.2. Firefighters' Operations

It is important to consider that the nearest fire station was designed to only support the local Bangladeshi population when around 50,000 people lived in the area. Nowadays, there are nearly 980,000 people in the camps, so clearly the fire risk has increased, and the fire station does not have the capacity and capability to assist the community in case of a fire event. In addition to the fire brigade, there is a satellite fire station in the camps. Even though the firefighters have fire engines and water tankers to assist in case of a fire event, the camps do not have roads wide enough and bridges that can support their weight. Hence, it is difficult

for the engines and tankers to move through the camps and reach the affected area. There are also approximately 1700 "fire points", which consist of two or three buckets with water or sand. However, their availability is unknown: some of them are well maintained and others are not there anymore. Also, every camp has around 100 emergency volunteers that have received training and are given one 5 kg dry chemical powder fire extinguisher. Although this is a good initiative; during the trainings it has been found that many of the fire extinguishers did not operate correctly.

In the previous section it was mentioned there were different organizations trying to control the fire. However, they do not work together. Currently, there is no Incident Command System that allows for the management of the resources during a fire event. Furthermore, there is no radio network to communicate in the field, and that is the reason for communicating through WhatsApp.

Although in this case the creation of fire barriers proved to be useful, it is not a technique that can be applied every time. This is because once the shelters are dismantled it is necessary to remove all the combustible material from the area. A collapsed combustible dwelling is likely to still be ignited and burn, albeit possibly at a slower rate. To entirely remove material, it is necessary to have special equipment, which might have the same accessibility problems that the fire engines and water tankers do. If it is not possible to remove the material this technique is not recommended.

After the experience gained in this and other fires, members of the implementing partner organization started working on developing new firefighting equipment that considers the limitations present in the camps.

5.3. Evacuation

Most of the area affected by the fire corresponds to a residential occupancy. Hence, it could be expected that people are familiar with the area [43–45]. However, due to the magnitude of the fire and the large number of people displaced, people were evacuating to Camps that were far from the affected area, and it is likely people needed to evacuate through routes that were unfamiliar to them. Furthermore, some of the structures needed for evacuation, such as stairs and bridges, were also affected by the fire as shown in [46]. The large number of people missing could be attributed to these, and to the fact that at the beginning of the fire families were often not together. The evacuation challenges seen in this fire could be similar to the ones wildland urban interface evacuations face. Some of them are due to the lack of accurate information on where to evacuate, insufficient exit routes, and delayed evacuations that increase the risk of having casualties [47]. Furthermore, it was also seen that occupant's did not respond immediately to the cues of the fire, as they felt the fire would not spread to their homes. Due to the large areas involved in the fire and the constant changing of the fire conditions, the recognition and interpretation of fire cues has been acknowledged as a challenge in wildland fires [48].

With regards to the barbed wire fences, there is an ongoing debate about it. Several international organizations raised their concern about their use. According

to the UN they hampered the evacuation and the rescue efforts and caused some of the injuries [37]. According to [49], many of the fatalities of this fire were people that could not evacuate the area due to the fences. This opinion was shared by other organizations such as the International Rescue Committee, the Norwegian Refugee Council and Fortify Rights [10, 40]. Some of the residents' statements also mentioned that the fence hindered the evacuation and cause several injuries [50]. On the other hand, the Bangladesh refugee commissioner defended the erection of the fences and dismissed their influence on the evacuation [51].

5.4. Human Behaviour in Fire

It is well known that prior to evacuation occupants will undertake several actions. These actions and the time occupants spend on them depend on several factors, including some of them are age, past experiences, culture, fire cues, and type of occupancy [52, 53]. The residents' actions identified in this paper correspond to those seen in residential fires in previous research [43, 54, 55]. Furthermore, those actions have also been seen in large fire evacuations, such as wildland urban interface and informal settlement fires [29, 56]. It was also possible to see the impact of the social affiliation in people's response. It is important to mention that according to the UNHCR [57], as of 30 November 2022, the average family size was 5. In most of the statements, it was found that inhabitants mentioned going back to look for their families (parents looked for missing children, young people helped elderly people to evacuate [19, 41]). Similarly to what was seen in IS [29], large numbers of people remained in the vicinities of the fire, either looking for their belongings or just looking at, or recording, the fire. Although smartphones can be very useful during large scale evacuations [58], and the recordings and pictures can provide valuable information with regards to the fire and occupants behaviour, it can also affect the evacuation and the emergency response. Further analysis is needed in order to understand the decision-making process and to determine the factors that could influence people's behaviour.

5.5. General

This is the first detailed documentation of such a large-scale refugee camp incident in the academic literature. The analysis of this fire event provides valuable information regarding such fires. It could be seen that the fire spread is analogous to wildland fires where conflagrations spread across large areas of combustible material. It showed that firefighters face similar problems to the ones seen in other low-income settlements and that residents' actions correspond to what has been observed in residential fires.

There are several limitations to this work. The main one is the many assumptions that were considered for the reconstruction of the event. This work is mainly based on firefighters from the implementing organization input, meaning that perspectives from other stakeholders were not directly taken into consideration. Nevertheless, through the analysis of social and formal media, this work tried to incorporate their views. Additionally, although the WhatsApp conversation was captured in real time, the interview was conducted months after the fire took

place. Then, critical information used to understand the fire spread, such as the ambient conditions and fire lines at different times, have an important influence on the estimated fire spread rates and timeline. Other limitations are the fact that, even though most of the residents' actions during the fire were seen on video recordings, there is no information with regards to their motivations and the cues that influenced their response. Finally, this work is only the first step in order to understand fires in refugee camps. The findings of this work might not be representative of refugee camps located in other areas. Further research should be conducted to understand the fire dynamics and the impact of fire different refugee camp configurations along with geographical and cultural conditions.

The construction materials used in the Rohingya refugee camps are very different from the ones used in other low-income settlements. The materials used had an important influence on the fire load estimations and in the fire dynamics observed. Although previous research in IS has shown that the fire load can be extremely variable [20, 59–61], in IS most of the fire load was mostly associated with the contents. However, in this case the shelter alone accounted for 1500 MJ/m^2, which is equivalent to approximately 33 l of petrol per m^2.

The findings of this work can be used to (a) plan for future large-scale fire incidents in tented camps by enhancing residents, firefighters' response and training (b) seek ways of mitigating the impact of fires in these camps, (c) develop and validate fire spread models, (d) guide the development of firefighting equipment that responds specifically to refugee camps, (e) provide input for the development of evacuation models, and (f) to promote general fire awareness in such communities. All of these will assist with the understanding of these incidents in a holistic way, enhancing the response and management of refugee camps fire incidents.

6. Conclusions

This paper has documented the 2021 Cox's Bazar fire incident which left approximately 45,000 people homeless. This is the first detailed documentation of such a large-scale refugee camp incident in the academic literature. The fire lasted 7 h and spread at rates of between 79 and 310 m/h, with an average areal spread rate of 93,131 m^2/h. Fire spread rates calculated appear higher than previous values obtained for informal settlements, although are of a similar magnitude highlighting potential similarities between these low-income communities. The fire line at different times has been identified, although due to lack of information only two specific times could be confidently defined. Factors influencing fire spread are addressed, and it is shown that the highly combustible nature of people's homes, along with the dense nature of the settlements, significantly affected fire spread rates.

It appears that self-evacuation governed community response. Individuals or families decided when to evacuate and where to go based on a variety of factors including where they had relatives or friends to visit, or where they think they may be safe. The residents' actions were similar to what was seen in other residential fires such as firefighting, saving belongings, helping others and looking for

family members. However, there was one activity that drew attention, the fact that multiple people were recording the fire. This not only creates an unsafe situation for the residents but also hinders the firefighters' operation due to the congestion in the area.

This work can be used in (a) planning for future large-scale fire incidents in tented camps, (b) seeking ways of mitigating the impact of fires in these camps, (c) developing fire spread and evacuation models, and (d) developing equipment to improve the firefighter response. All of these will assist with enhance the understanding, response and management of refugee camps fire incidents. However, further research is required before significant developments can be made in a number of these areas.

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