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To what extent is electricity central to resilience and disaster management of the built environment?

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Abstract

Purpose:
This paper aims to establish two key points. Firstly that there is a gap in the resilience literature, and to show that electricity needs to play a more central role in all the academic research fields associated with 'disasters' and 'resilient cities'.
Design/methodology/approach:
Two approaches were used, database interrogation and establishing areas of expertise in the resilience and disaster case study literature. Firstly a database search was carried out, and the 'keyword' and 'abstract' fields searched for electricity related words. Then academic papers, and reports by public bodies were analysed to establish which academic disciplines are most active in this area of research.
Findings:
This paper shows; that only 3.9% of the 4127 papers analyzed, had key words connected to electricity, and that there is not a specific discipline within the resilience literature looking explicitly at how electricity effects the built environment.
Research implications:
This paper implies that the role of electricity, in the academic literature associated with resilience, is under represented. A future research agenda should be developed that more adequately reflects the importance of electricity to the resilience of the built environment.
Practical implications
With more focused research, into how the loss of electrical energy affects all aspects of life during and post disaster, better approaches to disaster risk reduction and management can be formulated.
Originality/value
This paper is the first to analyses the literature to understand how important the continuity of electrical supply is to the resilient-cities and disaster management academic communities, and has highlighted this theme as a gap in the literature.

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Keywords: Distributed electrical generation, Direct current voltage, Electrical resilience, Renewable energy, Power outages, Energy independence, Disaster risk reduction and management

1. Introduction

Electricity is the lifeblood of all modern societies, yet its continual flow is taken for granted. It is only when there is a power cut that we start to appreciate and realise how dependent our daily living standards are on the continuity of its' supply. Interruptions of supply can be caused by human actions and natural events. Many of these interruptions are localised, of a very short duration, and are looked at as a minor glitch of no consequence. But when there is a widespread blackout due to a major incident, then the media and policy makers become vocal, and responses are initiated to make the system more robust. Currently, about half the worlds' population live in urban areas, and it is estimated that by 2050 the global urban population is expected to approach 6.4 billion, (Gea, 2012 Section 5.2.2). This makes the robustness of the urban electricity system and the continuation of electricity supply, critical to the future resilience of cities and to the continuation of the standard of living of the population. By categorising the damage caused to a major city from a disaster, it will be possible to understand the important role played by electricity in all aspects of the city's resilience.

Almost all electricity generation systems are centralised, with consumers accessing the system via a national grid. Therefore any failure in the national grid system can have far reaching indirect consequences, and at a very long distance from the actual point of failure, I.e. a failure chain can ensue. "*A **failure chain** is a set of linked failures spanning critical assets in multiple infrastructure systems in the city. As an example – loss of an electricity substation may stop a water treatment plant from functioning; this may stop a hospital from functioning; and this in turn may mean that much of the city's kidney dialysis capability (say) is lost. This failure chain would therefore span energy, water and healthcare systems*." (UNISDR., IBM., & AECOM., 2014). As the urban population grows an electrical failure will have a larger and increasing impact on the daily lives of more and more people.

The inspiration behind the research in this paper is wider research aimed at changing the electrical system from a centralised alternating current (AC) voltage system to a distributed direct current (DC) voltage system. Besides increasing a city's resilience, it will also provide, in normal times, an electrical system that can provide a high degree of energy independence and energy security for all its' citizens. Part of the discussion to ascertain if a distributed energy system has some advantages over a centralised system is to test how a city will be affected by a major blackout. Usually a blackout is only an electrical fault than can last from a few minutes to a few hours maximum. However in a disaster situation, where there has been severe infrastructure damage, blackouts can last for many days or even weeks. Therefore being able to distinguish between, the effects of the direct loss of electricity due to damage caused by the incident, and the effects in the failure chain which are secondary or indirect consequences, is very important to the centralised verses distributed electrical system topology debate.

This research is interested in how to make the electrical system more robust. However to do this the vulnerability of the system, and how a long term blackout affects the living standards of the population must be known. The only way to record and assess how the lack of electricity effects the daily lives of a city's inhabitancy would be to turn the electrify off and record how the living standards of the whole society are affected, which is not acceptable. But in times of a national disaster when there is a sudden and long term loss of electric power, it is possible to record the consequential multiple failure chains, and all aspects of how people's lives are affected. With this knowledge it is possible to identify which aspects of modern living are affected by the loss of electricity and work towards mitigation solutions. To this end many papers are direct to what is coined 'resilient cities' projects around the world, and the United Nations Office for Disaster Risk Reduction has a global reach in coordinating, campaigning, advocating and informing on the International Strategy for Disaster Reduction, (UNISDR, 2014a). This research therefore focused on the disaster/resilience literature to identify the direct and indirect consequences, of a large scale loss of electric power. The way to distinguish between direct and indirect consequences is to have accurate data. The data should for example provide statistics about how many houses, schools, shops, health facilities, public building, etc. were non-functional due to physical destruction, and how many were non usable due to the loss of electricity. Aggregated values like the total number of building etc. that lost electric power, tells us nothing about what difference a distributed electrical system would have made, or knowing that five months after the disaster many shops had not reopened (DRAP, 2012), tells us nothing about why this has happened and whether a distributed electrical system would have negated this situation.

The initial literature search showed the diversity of research disciplines associated with resilience/disaster research and is set forth in section 2. However it was hard to find specific details on the direct impact of power outages on the usability of the build environment, or on the living standards and conditions of the survivors. This lead to the question: 'to what extent is electricity recognised by the academic community as being central to disaster resilience'? To answer the question 'is there a gap in the resilience literature?; a second wide-ranging literature search was carried out to see how prominent electricity was in the disaster literature. The methodology and results of this literature search are set out in section 3. A tentative discussion about the focus of electricity in the disaster/resilience literature, and some suggestions about what can be done to further the discussion are set out in section 4. Conclusions and further work is in section 5.

2. Initial Literature search

2.1. Introduction

The three stages in the lifecycle of disaster management are, firstly mitigation against future disasters, then resilience to the disaster in progress, and finally post disaster recovery. At each stage many actions can be put in place to reduce the risk, mitigate against harm, and to speedup post disaster recovery. This research recognises how important it is to focus on the role that the electrical system plays in the quality of peoples' life, during and post-facto a disaster. The Global Energy Assessment (GEA) report (2012) was the first document used to try and understand the effects of the lack of electricity have on the built environment. Its many hundreds of citations became the catalyst for the beginning of our research into how electricity or the lack of it, affects peoples' lives.

This report led to the first literature search which was to find citations that would help build a picture of the importance of electricity in the built environment. As more and more papers were read it became apparent the lack of mention of any correlation between the subject-matter under discussion and electricity. This is not a criticism, as one would not usually expect researchers from the Humanities or from the Social Sciences to focus on electricity which is an engineering subject matter. This literature search helped to build a picture of the different subject areas involved with disaster resilience and disaster management. Some of the different subject areas are as follows; logistics, human geography, sociological and psychological effects, flooding, healthcare, heating and lighting, post disaster reconstruction, economic effects, and resilience of the built environment. Each discipline highlighted important questions about the difference electricity may have made to mitigate the particular problems associated with their area of the disaster, but provided little evidence or solutions of the effects of the loss of electricity.

2.2. The different subject areas in the resilience literature and what questions were highlighted

2.2.1. Economics, the effects of power cuts

The economics of electricity and how its proliferation affects the growth of a country's gross domestic product is a three way discussion. In section 6.4.2 of the GEA the research shows that for developing countries the effect energy has on GDP is ether a little effect (Wang, 2008), depends of the industrial development of the country, (Soytas, 2006), or energy causes GDP growth (Lee, 2005). These correlations between GPD <u>growth</u> and electricity thus imply that cutting the energy supply will have a negative impact on the economy. In fact when a power cut occurs, whether for a few seconds or a few hours, there will be an associated economic cost (The NextGen Energy Council, 2008). Estimates of such economic costs can be very high for industry, (Balducci, 2002) as well as for domestic customers (Praktiknjo, 2011). There are also the social costs (see later sections). Work has been carried out to ascertain peoples' willingness to pay a premium to avoid domestic power outages (Carlsson, 2008; Leahy, 2011).

These papers look at the aggregated economic effects of the loss of electricity supply, but the question that is not discussed is, 'in light of the massive economic loss due to the power cut, what can be done to make the domestic electrical system more robust so that the negative economic impacts due to a national disaster are minimised ?'.

2.2.2. Logistics of post disaster recovery

Much work is done in the field of Post-Disaster-Humanitarian-Logistics (J. Holguin-Veras, Jaller, Van Wassenhove, Perez, & Wachtendorf, 2012; J. J. Holguin-Veras, M. Taniguchi, E. Aros-Vera, F.), however logistics needs electricity to operate an effective communications systems, refrigeration etc. The fact that the lack of electricity negatively impacts on Disaster Plans is well documented, what is not understood is details as to how the lack of electricity came about, what the direct consequences were, how the continuity of supply would have presented a less impacted disaster and to what extent its loss hampers the rescue efforts.

2.2.3. Human geography –The social costs of a national disaster

Living through a major incident can be very traumatic, however living through evacuation, temporary shelter, and eventually going back home or resettlement has repercussion on the physical and mental state on the refugees. Hurricane Katrina was in a developed country that has a very good demography collection system and therefore the knowledge about who was evacuated, for how long, and where they now live is well documented, (Groen & Polivka, 2008, 2010), also the physiological effects on the evacuees, especially the children has been studied (Norris, 2002). However the question remains, what was the actual reason for their evacuation? How many of them were not allowed home due to the fact that the authorities deemed the local as being uninhabitable until the electricity system was fully up and running, even though their houses were habitable? How many schools were closed due to the power cut and not due to physical damage? The answers to these questions was not found in the literature, but they will help to understand the far reaching impact of the loss of electricity when a major incident occurs, and perhaps whether a distributed electrical system would be more robust thus mitigating some of the suffering, and allowing more people to quickly resume normal live again.

2.2.4. Healthcare and disasters

When tropical storm Allison stuck the Memorial Hermann Hospital in Houston Texas in 2001 it caused a total meltdown of its functionality and lead to its closure for 38 days (Nates, 2004). Nates gives a rare insight into the impact of the loss of electrical power to a level 1 trauma hospital. The objective of his paper was to inform clinicians about what can go wrong when a total power cut occurs due in a disaster situation. Similarly the hospital system in New York was put out of commission due to Hurricane Sandy in 2012, (DRAP, 2012). Tropical storms and Hurricanes are forecasted event, thus giving time for contingencies to be put into operation. However there are many instances where total blackouts in hospitals occur for only a few hours, and where ICUs have to go into manual mode to keep patient alive. In the literature found between 1992 and 2010 at least 7 instances are documented of total electrical failure, where even the emergency backup system failed. (Carpenter & Robinson, 2010; Fawcett, Blowers, & Wilson, 2001; Maxwell & Oneil, 1993; Mitchell, 2001; Ohara, 1993; Ohara & Higgins, 1992). The only solution provided by these papers is for better maintained emergency generators and the use of more battery powered devices including for lighting. These papers are quite detailed and do provide a rare glimpse into the direct consequences of the loss of electricity. These papers are recorded facts given by the clinicians who lived through the loss of electrical power, however what is not known is how the electrical systems could have been designed to be more robust.

2.2.5. The infrastructure

There are many dedicated research units in many universities around the world that work on the resilience of the build environment to natural disasters, (Bollinger & Dijkema, 2012; Chang, 2009), and much good work is carried out through the auspices of the UNISDR. The UK government have an infrastructure resilience plan (The-Cabinet-Office, 2011). Research into the electrical infrastructure was carried out after Hurricane Katrina (Reed, Powell, & Westerman, 2010), but this was about the robustness of the national grid system and not on the electricity system of the consumers. They do not provide data that would help in the centralised - distributed debate.

2.2.6. General reports

There are a number of UNISDR reports that only mention electricity as a minor item in the larger picture, (Southgate RJ, 2013; UNISDR, 2014b), there is the reconstruction report for New York, (DRAP, 2012), to name but a few. Doing a word search on these documents reveals the total lack of discussion about the electricity system.

2.2.7. Discussion from the initial literature review

This literature review highlighted the complexity of different subject matters that deal with all aspects of a city affected by a disaster. However it was very difficult to find accurate data about the direct and indirect effects of the loss of electricity, so that this research could formulate a targeted action plan of how to make the electrical system more robust. The question was asked, perhaps as the subject matter across the resilience literature is so vast, the initial literature review was not far reaching enough? It was therefore decided to carry out a wide-raging literature review to identify the traction that the discussion of electricity has in the the disaster resilience literature.

3. A wide-ranging search of the resilience literature

3.1. The methodology for gathering the citations

The literature search was carried out using a combination of software to gather, search, and word count the data. Endnote version X6 , which is able to search databases and build its own database of full citations, was used to build a database of citations which included the 'keywords' and 'abstract' fields where available. First Keywords then search-strings associated with disasters was used to gather the citations. Once the citations had been gathered they were exported to Microsoft Excel for word search analysis. The keywords and abstract were extracted to a separate worksheets. Key words associated with electricity were used as search strings to see how many times they appeared in the keywords and abstract fields. Microsoft Word was used to count the total number of key words in all the abstracts.

Two standard databases in Endnote X6 are PubMed and Web-of-Science. The first set of search strings and the number of retrieved citations for both databases is set out in Table 1 below. The first search string was "Resilience", which being a generic term returned a huge amount of citations. This search was made to gauge the amount of citations available however they were not inputted to Endnote as the term was too generic. To keep the search results separate a different Endnote library was used for each searched database. Also within each Endnote library as a set of citations was downloaded it was placed in its own group, this allows the tracking of how many results were obtained for each search string. It was apparent that the number of retuned results was far higher from the Web-of-Science database than that from PubMed. Therefore all further searches were only carried out on the Web-of-Science database and the results became the dataset for analysis.

3.2. Results from the literature search

Table 1 Initial search criteria and the number of results returned from each database as on 21/01/2014

Search string	PubMed	Web of Science	Search string	PubMed	Web of Science
resilience	2237	6442	disaster reconstruction	17	122
disaster Resilience	35	97	disaster recovery	138	450
disaster management	373	1009	disaster prevention	53	327
post disaster	192	391	disaster response	475	706
disaster risk	113	560	resilient cities	2	38
natural disaster	299	754	disaster mitigation	22	225
disaster impact	101	191	power blackout	5	60

Table 1 shows the initial search criteria using two different databases. More generic searches, which were not inputted into Endnote, were carried out on the Web-of science database to gauge if the search string was a good one, (Table 2) after which more specific search strings were used. The Endnote software has a feature that searches for duplicate entries. It became obvious that there would be many citations that would have in their title more than one search string. When the data base had a total of 8346 citations it was decided to stop and remove all duplicates. 1426 duplicates were removed leaving 6920 citations for analysis. These papers were dated from 1904 to 2014. Because each search string was placed into a different group in the Endnote software it was possible to see how many duplicate citations there were in each search string. The final dataset is shown in Table 3.

Table 2 The generic search strings and the number of returned citations as on 21/01/2014

Generic search terms – Citations not used in dataset			
earthquake	24553	hurricane	5348
flood	13391	cyclone	4495
Resilience	6442	tornado	1400

Table 3 The search strings and the number of citations used in dataset as on 21/01/2014

Search string	Initial Number of citations	Final Number of citations	Number of citations removed	Search string	Initial Number of citations	Final Number of citations	Number of citations removed
Bam Earthquake	106	104	2	flood UK	85	85	0
cyclone disaster	28	17	11	Haiti earthquake	216	191	25
cyclone Nargis	38	34	4	hurricane disaster	201	115	86
disaster impact	191	137	54	hurricane Katrina	1090	970	120
disaster management	1009	971	38	hurricane resilience	20	11	9
disaster mitigation	225	133	92	Hurricane Sandy	49	45	4
disaster prevention	327	266	61	Kashmir earthquake	82	79	3
disaster reconstruction	122	61	61	natural disaster	754	614	140
disaster recovery	450	355	95	post disaster	391	353	38
disaster Resilience	97	93	4	power blackout	60	59	1
disaster response	706	547	159	resilient cities	38	36	2
disaster risk	560	386	174	Sichuan earthquake	219	208	11
earthquake disaster	529	322	207	Tohoku earthquake	440	431	9
flood disaster	255	254	1	tornado disaster	33	23	10
flood resilience	25	20	5	**Total**	**8346**	**6920**	**1426**

3.3. The methodology for analysing the citations

The following fields from all the 6920 citations were inputted into Excel, the Authors names, the title, the keywords, the abstract, and the name of the journal. The 'keywords' column was pasted into Microsoft Word and a total of 49,036 words were counted. To filter out the citations that did not have any keywords a new excel worksheet was used. After sorting there were only 4127 citations that had a keywords field, which is 59.6% of the 6920 citations. Using Excel the keyword column was searched for electricity and none electricity related terms and the results are presented in Table 4. When doing a word search in Excel the results obtained indicate how many cells in the spreadsheet have the search string in them. Therefore the results obtained were not for the number of times the search string was found within all keywords, but the number of citations that mentioned the search string in their keyword field.

The keywords in an academic paper indicate the highest level of importance that the author/s have placed on the subject matter of the paper. The next important part of the paper that should indicate the important highlights of the paper is the abstract. There were 4467 citations with abstracts among the 6920 citations under analysis. The same search strings that were used on the keywords field were used on the abstract field. The results are shown in Table 4. Analysis was carried out on the journal field to see what the spread of publications represents the source for all the citations. Using the 'remove duplicates tool' within Excel, the 6920 citations came from 2750 different volumes of journals and conference proceedings , this number includes different volumes of the same journal. Using the same procedure there was 1787 journals that had the keyword field.

Table 4. Results from word search on the keyword and abstract fields

Search String	No. of Cells in Keyword Field	No. of Cells in Abstract Field	Search String	No. of cells in Keyword Field	No. of cells in Abstract Field
blackouts	4	11	earthquake	967	1499
communication system	3	32	fuel	0	13
distributed system	2	4	hurricane	424	864
electric	18	82	health	390	600
electrical	4	24	medical	60	285

electricity	3	29	medicine	51	68
energy	27	116	Posttraumatic stress disorder	33	92
grid	25	78	trauma	375	348
microgrid	1	2	flood	260	561
power	69	281	tsunami	174	350
power grid	2	9	water	100	359
renewable energy	4	2			
Total connected with electrical energy	**162**	**670**	Total citations not connected with electrical energy	**2834**	**5039**

4. Discussion

The aim of this literature search was to identify to what extent electricity is central to resilience and disaster management of the built environment. In an academic paper it is recognised that the keywords and abstract sections should show the most important aspects of the subject matter under discussion. Therefore if the continuation of the electricity supply is of paramount importance to researchers and policy makers, it would feature prominently in a wide range of papers. The Web-of-Science database was chosen as the source of academic papers and the bibliographic software Endnote was used as the search tool.

What can be seen is that the amount of papers that mention in their keywords terminology connected to the use of electricity is only 162, which is only 3.9% of the 4127 citations that had a keywords field. It goes up to 16.23% when the abstract is analysed. When this is compare to the amount of papers that discuss health-medical-medicine-trauma which is 909 citations, or tsunami-flood-water, which is 524 citations, electricity as the main focus of academic research is by far a very much neglected subject in the field of disaster resilience . This is not to say that it is missing from the literature, or that the importance of the loss of electricity supply cannot be found in the literature, but electricity as a central focus of how to analyse what went wrong due to disaster and to mitigate against the effects of a disaster, is definitely lacking. Those that do mention energy or electricity are looking through the lens of their particular discipline, with the loss of electricity being minor to, or a consequence of, their research.

These are papers written in English and this analysis says nothing about non English language papers. However it is believed that the 6920 papers from 2748 different volumes of academic journals over a spread of over 100 years, from a worldwide pool of academic institutions, is indicative of what one may find in the non-English language literature and should be very indicative of the overall content across academia.

5. Conclusion and further work

It is concluded that there is a knowledge gap in the disaster literature with regard to specific details on the direct impact of power outages on; the usability of the build environment, the living standards and conditions of the survivors, and on what changes are need to the electrical system to reduce the impact of loss of electrical power. Although everyone living through a disaster has first-hand knowledge about how they were affected by the loss of electricity, the research community needs to increase its efforts in firstly understanding the direct and indirect impacts, and secondly providing solutions to increasing the resilience of the electrical system.

While we were not able to identify any papers that described in detail the circumstances of how electricity affected all aspects of a disaster, it is possible to formulate a good picture of how the loss of electricity effects all aspects of daily life during and post facto a major disaster, from papers that are looking at other aspects of the disaster. Also from reports like the GEA where the discussion is about the many aspects of electricity that help towards a sustainable future, one can infer what the negative impact and the damage to society will be with the loss of electricity. Therefore future work will look at the literature that deals with post disaster reconstruction and how medical facilities cope with blackouts, to glean information about how the loss of electricity due to a disaster affects all aspects of living standards and the economic activity within a disaster zone.

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