Disaster risk management approaches in construction and built environment: A research collaboration networks perspective

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Abstract

Purpose: Currently there is no analysis of the development of disaster risk management literature in the construction and built environment context, the changes in its research paradigms over time and the role of different key players in the advance of its current body of knowledge. This article tries to fill in this gap by investigating the longitudinal data of disaster risk management literature over three decades, from its first available publication in the ground of construction and built environment research until now.

Methodology: A social networks analysis approach was used in this study to show the overall progress of this scientific field and the role of research collaborations among different organisations and countries on research productivity.

Findings: The results indicate that the focus of disaster risk management research in the built environment context is heavily biased towards the reactive approaches (response and recovery) over the proactive approaches (mitigation and preparedness). The findings also show that the way disaster risk management researchers collaborate with each other has significant influence on their research productivity.

Value: The findings from this study should be of value to researchers, policy makers and academic strategists. This study for the first time shows the ability of the social networks paradigm to reveal frailties in research connections in the field of disaster risk management in construction and built environment and highlights where networking strategies are needed.

Keywords: built environment; construction; disaster risk management; research collaborations; social networks analysis; risk management

1. Introduction

Disaster Risk Management (DRM) is a broad field covering design, implementation, and evaluation processes for the measures, strategies, and policies to better address disaster risk (IPCC, 2012). Disaster risk is best addressed through the disaster risk reduction and transfer that comes from a continuous improvement in disaster mitigation, preparedness, response and recovery activities. The main purpose of DRM is to decrease the exposure and vulnerability of society, the economy and the built environment, while also increasing our security, well-being, quality of life, resilience and sustainable development in a cost-effective manner (IPCC, 2007, IPCC, 2012, UNISDR, 2011). DRM typically involves two relatively distinct approaches (Moe and Pathranarakul, 2006), namely: (i) a proactive approach; and (ii) a reactive approach. A proactive approach refers to activities such as mitigation and preparedness that are planned and conducted before a disaster occurs. A reactive approach refers to activities such as response and recovery carried out during and after a disaster event (Moe and Pathranarakul, 2006).

Many DRM scholars and practitioners associate disaster risk management primarily with disaster response and recovery activities, and not with mitigation or preparedness activities (Mojtahedi and Oo, 2017). This imbalance has contributed to the view that the proactive and reactive approaches are essentially discrete (IPCC, 2012, Lavell, 2011, Mercer, 2010). Nevertheless, proactive behaviours (whether by the community, government, NGOs or insurers) can directly impact the long-term consequences of various disaster events (Hu et al., 2017, Bosher and Dainty, 2011). Resilient buildings and infrastructure depend on proactive measures to promote the adaptive management, critical learning, leadership and innovation needed to respond and recover to/from disaster risks and uncertainty more effectively. The research to date has tended to focus on planning for immediate response to disaster events ahead of a more holistic approach to include more proactive options. Whilst the need to promote a stronger culture of prevention is well recognised, progress has been slow (Hellmuth et al., 2007, IPCC, 2012). A key question is whether the established network and power structure within the DRM research community has contributed to this relative meagre representation of proactive approaches in the literature.

Currently, there is no scoping review of DRM studies which shows how the relevant literature has developed over time, what approaches different researchers have taken at different periods, or how various key players have contributed to the development of the body of knowledge. To address in this gap, the present study examined the longitudinal data of DRM studies over the past 30 plus years. One critical dimension of this study is that while the overall status of DRM research and the approaches taken are explored, particular attention is also paid to the interconnections between researchers in this field and how those connections, measured using social network analysis (SNA), could affect research productivity.

Researchers regularly interact with the purpose of successfully delivering research projects and reporting on the findings. These professional interactions among individual researchers and external organisations are known as research collaborations (Tavakoli Taba et al., 2015). Research collaborations, in this sense, facilitate the transfer of information and knowledge among researchers and between organisations, and are based on a social fabric (Tavakoli Taba et al., 2019). A research collaboration network is constructed of a set of social 'actors' (nodes) and some 'ties' (relationships) between those actors and can usefully be scrutinised using SNA methods (Owen-Smith et al., 2002, Sonnenwald, 2007). When studying research collaborations, the frequency of interactions between two actors can be considered as the "tie strength" (Marsden, 1990, Wegener, 1991).

Accordingly, for the first time in the context of construction and built environment, this study examines the research collaborations in the DRM literature using SNA. The analysis is undertaken at two levels of scale; between countries and between organisations. The study investigated how the structural position of organisations and countries in the overall research collaboration network influences their performance in the DRM research community. The aim is to provide researchers and stakeholders involved in DRM research with a new perspective on, and new opportunities for, the role that their networks play in giving impact to their publications.

2. Methodology

2.1 Social network theories and measures

In network theories, one especially important concept is the notion of "centrality". Centrality refers to the position of an actor in a network. "Degree centrality" is the number of ties a focal node has in the network. Degree centrality is typically considered as a measure of immediate connectedness, and thereby a measure of the influence of an actor and their capacity to directly impact other actors (Wasserman, 1994, Borgatti, 2005). It is commonly agreed that degree centrality is positively associated with actor performance, particularly in knowledge work domains (Tavakoli Taba et al., 2016). Mathematically, degree centrality is the count of direct contacts a focal node has in the network (Freeman, 1978):

$$S_i = \sum_j a_{ij} \quad (1)$$

where i is the focal node, j is any other actor and $a_{ij} = 1$ when a direct tie between i and j exists.

Another measure of centrality which also describes the power and influence of an actor on other actors, is "betweenness centrality" (Freeman, 1979). Betweenness equates to a bridging role that connects otherwise disconnected actors. Theoretically, actors who play this form of bridging role are seen to be more critical to those otherwise disconnected actors and are able to exercise more influence on them (Freeman, 1977, Goh et al., 2003). Borgatti (2005) refers to betweenness centrality as the capacity a focal node has to control the "network flow", when network flow represents the circulation and movement of information across the network. Betweenness centrality is expressed here as the proportion of the shortest paths between any two actors that a given focal node is part of (White and Borgatti, 1994, Borgatti, 1995):

$$B_i = \sum \frac{b_{jq}(i)}{b_{jq}} \qquad (2)$$

where i is the focal node, j and q are any other two actors, b_{jq} is the total number of shortest paths from j to q, and $b_{jq}(i)$ is the contribution of i to those paths.

The network size of a focal node is not unlimited in the real world. This is largely due to the time and cost required for the social actors to maintain each relationship. Further, there is no guarantee that the potential benefits an actor receives from such contact will be realised, rendering the link "redundant". Redundancy in the context of SNA might be in the form of: (i) where a focal node is connected with other actors, but those other actors are more strongly connected with each other; and (ii) a focal node is connected with other actors who are not connected directly, but share a stronger common secondary contact (Burt, 1992). In view of that, Burt (1992) defines "effective size" to measure the number of non-redundant contacts of a focal node. Effective size is then a measure of the network size of the focal node, minus the average tie strengths of connected actors when ties to the focal node itself are discounted (Burt, 1992, Borgatti, 1997):

$$E_i = \sum_j \left[1 - \sum_q p_{iq} m_{jq}\right],\ q \neq i,j \qquad (3)$$

where $p_{iq} = \frac{z_{iq}}{\sum_j z_{ij}}$, $i \neq j$ and $m_{jq} = \frac{z_{jq}}{\max_k z_{jk}}$, $j \neq k$ and i is the focal node, j and q are any other two actors, and Z is the weighted matrix of network ties (z values are tie strengths).

Network "constraint" is another important measure that has been defined by Burt (1992) to quantify the extent to which the time and energy of an actor is invested in contacts who are themselves connected to one another. In social networks literature, constraint is the best summary measure of lost benefits by an actor in the network (Burt, 2000, Burt, 1992). Accordingly, constraint and performance should be negatively associated.

$$C_i = \sum_j c_{ij},\ i \neq j \qquad (4)$$

where $c_{ij} = \left(p_{ij} + \sum_q p_{iq} p_{qj}\right)^2$, $i \neq q \neq j$ (dependence of i on j) and i is the focal node, j and q are any other two actors, and p is as defined in the effective size (Equation 3).

The constraint can sometimes result from the presence of one (or a limited number of) highly central actor(s) in the network. "Hierarchy" is a network parameter that measures the extent to which the constraint of a focal node is imposed by having a limited number of mutual and central contacts in its immediate network. The hierarchy measure has been shown to be positively associated with constraint (Burt, 2000). In that light, the greater the value of hierarchy, the lower the likely performance of that focal node (Burt, 1992):

$$H_i = \frac{\sum_j r_j \ln r_j}{N_i \ln N_i} \qquad (5)$$

Where $r_j = \frac{c_{ij}}{\frac{c_i}{N_i}}$, i is the focal node, j is any other actor, N_i is the number of focal node contacts, c_{ij} is the dependence of i on j and c_i is the constraint of i as defined in the constraint (Equation 4).

"Density" is another relevant network measure that describes the overall connectedness in a network (Scott, 1991). Cassi et al. (2012) argue that frequent and reciprocal connections in a dense network increases the opportunity for actors to cross-check information, which leads to improved trust among them. Conversely, a high level of connection between all actors in such a network tends to reduce the dependency on any particular focal node. Additionally, the excessive bonds present in a dense network tends to limit the access of a focal node to the potential benefits available beyond those immediate contacts (Cassi et al., 2012). Thus, network density and performance are generally negatively related to each other. Density can be calculated as the average tie strengths across all possible ties in a network (Wasserman and Faust, 1994):

$$D_i = \frac{\sum z_{ij}}{N(N-1)} \qquad (6)$$

where z_{ij} is the tie strength between any two actors of i and j, and N is the total number of actors in the network.

Burt (1992) shows that the constraint is not only dependent on hierarchy but also network size and density. Larger network size results in a focal actor receiving more diverse benefits, which ultimately renders that actor less constrained. At the same time, higher density around an actor translates into similar benefits for the immediate contacts who are also more likely to enjoy larger network sizes, which then increases the constraint on that focal actor.

2.2 Scientific performance

Performance and productivity in research projects can be defined in various ways. Nevertheless, it is commonly accepted that one of the most important factors for evaluation and comparison of researchers and research organisations is the quantity and quality of their publications (Abbasi et al., 2014). Publishing a high number of papers (increasing quantity of publications) and receiving a high number of citations for publications (increasing quality of publications) is a major objective for all researchers (Uddin et al., 2012). In this paper, both parameters are used to measure scientific performance at country and organisational levels.

Firstly, publication score (the number of papers by an actor) can be calculated by:

$$NP_i = \sum_j n_{ij} \qquad (7)$$

where i is the focal node, j is the number of all publication, and $n_{ij} = 1$ for any publication that i is an author.

With regard to citations, it is generally considered that older publications have a higher propensity to be cited in the literature. The DRM papers considered in this study have been published over the past 3 decades. Consequently, to obtain a comparable citation score, the citation counts for each have been normalised. Uddin et al. (2012) propose that normalising of citation counts can be done by dividing the total number of citations that a publication has attracted by its duration in the literature:

$$NCitation_j = \frac{paper\ j\ total\ citation\ counts}{paper\ j\ years\ of\ publication} \qquad (8)$$

The citation score of any actor can be then calculated as the sum of all their normalised citation counts:

$$NC_i = \sum_j NCitation_{ij} \quad (9)$$

where i is the focal node, j is the number publications, and $NCitation_{ij}$ is the normalised citation counts of paper j when i is an author.

2.3 Data collection and data analysis

With the purpose of analysing DRM research within the built environment context, complex lexical search methods were used to extract bibliographical data from Scopus. Scopus is the largest database of peer-reviewed literature available. All the extracted papers for the analysis satisfied specific conditions, as follows:

(i) Has the word "disaster" in the title.

(ii) Has at least one of the words "preparedness", "prediction", "response", "recovery", "before", "after", "during", "mitigation", "reduction", "warning", "rehabilitation", "reconstruction", "emergency relief" in the title.

(iii) Has at least one of the words "build", "built", "building", "construction", "architecture", "civil engineering", "infrastructure" in title, abstract or keywords.

(iv) Is either a journal article or a conference paper.

(v) Is published in any of the subject areas: Engineering, Earth and Planetary Sciences, Social Sciences, Environmental Sciences, Business and Management, Energies, Art and Humanities, Material Sciences, and Economics.

No exclusion criteria were applied to the search strategy in addition to the inclusion criteria. After extracting the dataset, affiliations of individual authors were used to determine which research organisations and countries have collaborated in each publication. Because some certain affiliation data was missing in the original extracted dataset, a manual data cleaning was applied, and the dataset completed by extracting the required information from Google Scholar. The co-authorship relations among actors was then took out from the dataset at both country and organisational levels. If an author had more than one affiliation in a publication, only their first affiliation was used in the analysis. UCINET software (Borgatti et al., 2002) was used for analysing the research collaboration networks and calculation of the network parameters, i.e, degree centrality, betweenness centrality, effective size, constraint, hierarchy and density. As shown in the social network theories and measures section, most of these values were calculated using a "weighted tie" (as opposed to a "binary tie) to determine tie strength. It should be also noted that all parameters have been considered within an "ego network" rather than the "whole network". With "ego" it is meant any individual "focal node". Each ego network includes only the ego itself and those actors that are directly adjacent/tied to it.

In order to distinguish proactive and reactive approaches in the research paradigm of the publications, three categories were used:

(i) Proactive publications were those with any of the words "preparedness", "prediction", "before", "mitigation", "reduction" in their title.
(ii) Reactive publications were those with any of the words "response", 'recovery", "after", "during", "warning", "rehabilitation", "reconstruction", "emergency relief" in their title.
(iii) Combined proactive and reactive publications were those with at least one word from both categories in their title.

SPSS software (version 22.0) was used for all statistical calculations in this study. All social network parameters and performance scores were continuous variables. Because the performance scores had a non-normal distribution, Spearman rank-order correlation test was used to examine the relationship between the network parameters and the performance scores.

The 95% confidence intervals of all variables were calculated using 1,000 bias-corrected and accelerated (BCa) bootstraps (Field, 2009).

3. Results and discussions

A total of 763 research publications were identified and accessed in the relevant literature. The extracted papers were published between 1983 and 2016 and were the outcomes of research collaborations between 1,894 researchers, representing 801 organisations and 69 countries.

3.1 Disaster risk management approaches and descriptive statistics

Fig1 shows the frequency of these research publications and their DRM approaches over the past 3 decades. A significant growth in the number of publications can be seen over that time. A particular, substantial research development has occurred since 2006, which can be linked to the increase in devastating natural disasters occurring post 2005. For instance, Hurricane Katrina in 2005 had an estimated economic damage of USD$200 billion (Dolfman et al., 2007) and the Japanese earthquake and tsunami of 2011 had an estimated economic damage of USD$240 billion (Cooper et al., 2011).

Fig1: The count of publications per year and by approach

It is of note that the first paper with a proactive approach was published in 1989. With minor exceptions (around the Mozambique National Policy on Disaster Management launch in 1999) the reactive approach has been the dominant practice of research publications in this context.

Table 1: Top 10 countries with the highest publication scores in DRM research

Table 1 shows the top 10 countries with the highest number of publications over the study period (1983-2016). United States, China and Japan published the largest number of relevant papers in DRM. United States, Japan and the United Kingdom received the largest number of citations. Table 2 shows the top 10 organisations with the highest number of publications over the same study period. At the organisation level, Harbin Institute of Technology (China), University of Illinois (United States) and University of Salford (United Kingdom) had the largest publication counts in DRM. Of these top 10, Texas A&M University (United States), Kobe University (Japan) and University of Auckland (New Zealand) have achieved the greatest number of citations. Texas A&M University (United States) being the stand-out in this regard. Cornell University (United States), whilst not represented in the top 10 for publication score, actually achieved the second highest citation score overall with a score of 50.0.

Table 2: Top 10 organisations with the highest publication scores in DRM research

Overall, 64% of the publications had solely a reactive approach, 33% had solely a proactive approach, and the remaining 3% a combined approach (proactive and reactive). These results confirm that despite an increasing volume of literature, the representation of research particular to proactive approaches still remains poor. This under-representation overall is despite the increased attention given to disaster mitigation planning in recent years. The under-representation is also more acute in key instances. For example, in Australia (a top 5 country by publication number and top 10 country for citation score) well over 75% of publications consider only a reactive approach in their research paradigm. That lack of consideration for proactive approaches in DRM research in Australia plays out through the limited and ad hoc building and planning regulations. Relevant regulations are especially limited for flood and hailstorm hazards in a country prone to such disasters, and one which is highly regulated for such low probability hazards as earthquakes (Blong, 2004).

This broad finding of a lack of consideration to proactive approaches in the DRM literature is in keeping with Bosher et al. (2007). Bosher et al. (2007) shows that despite the construction industry being a key stakeholder and potential resource, the knowledge and awareness of proactive approaches is poor, and the sector is not being consulted adequately in preparing mitigation plans. Further, Freeman (2004) demonstrates that the vast portion of post-natural disaster financing is allocated to building reconstruction, with comparatively minimal financial support going to develop future mitigation and risk reduction strategies. Given the strong tradition and continuing flow of funding to reactive approaches, it is perhaps not surprising that response and recovery research continues to dominate.

Despite the limited research specific to proactive approaches, the potential value of mitigation and preparedness in reducing the adverse impacts of disasters and enabling a more resilient future response is well recognised (IPCC, 2012, UNISDR, 2011). Changes in the funding policies of governments and the insurance sector are shifting to disaster risk reduction and proactive risk transfer (Gurenko, 2004, Kreimer and Arnold, 2000, Linnerooth-Bayer et al., 2005). Increasingly, a more resilient built environment is being advocated (IPCC, 2012), leading the way to greater consideration of proactive DRM approaches. The lift in DRM research activity more broadly is also generating increased and improved empirical evidence for the various roles the built environment can play in reducing the deaths, injuries, damage to property and broader economic hardships associated with natural disasters (IPCC, 2012, Lavell and Mansilla, 2003, UNISDR, 2011). Research in both proactive and reactive approaches is required, but the need is most keenly evident in the proactive context.

3.2 Social network analysis

The collaboration networks in DRM research, as evidenced by the collaborations in the publication of scholarly research articles and papers, are presented in the form of sociograms in Fig2 and Fig3. Figure 2 demonstrates the collaboration networks between the various countries. Figure 3 demonstrates the collaboration networks between the various organisations. In each of Figures 2 and 3 the country/organisation affiliation for each author is shown as a node. The structure of the network is indicated by the presence and strength (width) of the ties linking each node. Whenever two authors from different countries/organisations jointly publish, the strength of the tie is increased (appears more solid). The more frequent the author collaboration, the more solid the tie in the sociogram. Countries and organisations with no collaboration between their authors are listed separately (to the left of each Figure).

Fig2: A sociogram of the collaboration network in DRM research between countries.

Fig3: A sociogram of the collaboration network in DRM research between organisations.

Figure 2 shows the existence of two principal collaboration networks: one largely based in Europe and comprising primarily the Czech Republic, Germany, Italy and the Netherlands; one more global based around the United States and comprising key collaborations with Egypt, Japan and United Kingdom.

Whilst the scale of reproduction does not allow individual organisations to be identified, Figure 3 shows how relatively discrete and sparse the research collaboration at the organisational level appears. The presence of so many isolated sub-networks with no or minimal frequency of co-authorship demonstrates the possible lack of coherency or interaction between organisations. The two standout exceptions to this are, on the one hand a very strong and otherwise isolated network comprising six principal organisations shown in the top left quadrant of Figure 3 (ETH Zurich, Switzerland; Czech Technical University, Czech Republic; Delft University of Technology, Netherlands; Sapienza University, Italy; Fraunhofer Institute for Intelligent Analysis and Information Systems, Germany; and German Research Centre for Artificial Intelligence, Germany), and on the other the large number of interconnected organisations present in the centre of Figure 3.

In order to determine the relationship between collaboration (networking parameters) and performance (in terms of publication scores), Spearman correlations are calculated based on a bootstrap sample size of 1,000. The results for publication scores are shown in Table 3. All values of P are less than 0.001 (statistically significant), and the results are consistent at both the country and organisational level: publication score is positively associated with degree centrality, betweenness centrality, effective size, and hierarchy; publication score is negatively correlated with constraint and density.

Table 3: Spearman correlations of social network parameters and publication scores

In order to determine the relationship between collaboration (networking parameters) and performance (this time in terms of citation scores), equivalent Spearman correlations are calculated based again on a bootstrap sample size of 1,000. The results for citation scores are shown in Table 4. In this case all but one of the values of P are less than 0.001 and even then still less than 0.05 (statistically significant). The correlation results are also consistent at both the country and organisational level: citation score is positively associated with degree centrality, betweenness centrality, effective size, and hierarchy; citation score is negatively correlated with constraint and density.

Table 4: Spearman correlations of social network parameters and citation scores

Results from the social network analysis is in general accord with the expectations determined in the literature. The greater the number of co-author connections with researchers in other countries or organisations (degree centrality and effective size) and the more influential those connections (in terms of betweeness centrality) then the higher the publication score and the higher the citation score. Some previous research has explored the relationship between network measures and scientific performance in other research areas. For example a study by Abbasi and Altmann (2011), in the area of “information management and systems”, showed that degree centrality and effective size were positively correlated with performance but they did not observe a significant relationship between betweeness centrality and performance, as it was the case in our study.

The results from this study also showed that where the immediate collaboration network is mutually (constraint) and strongly (density) connected internally then the benefit of each connection is reduced, and both the publication score and citation score suffer as a consequence.The only network parameter where results from this study did not follow the theoretical expectation is hierarchy. The impact of hierarchy is a relatively complex balance between the constraint imposed by having a mutually/internally connected immediate network and the vicarious influence derived when certain of those immediate network connections are central figures more generally. Hierarchy has been shown to be most positively associated with constraint, and so a reduction in performance was expected (Burt, 2000). The results of this study show a relatively weak, but nevertheless positive association between hierarchy and performance across publication score, citation score, at country level and organisational level. The results indicate that further consideration of hierarchy is warranted. It may be, for example, that the balance of negative constraint and positive centrality influences tip the overall impact of hierarchy under particular structural or relative weighting situations. The results of this study indicate, given the current structure of the DRM networks, that collaboration with a key figure in the research community is a positive influence on publication performance. It would appear that, for the DRM community, collaboration with a central/key researcher is not excluding broader, direct collaboration with others across the network.

The most significant network parameter overall is betweenness centrality, meaning the most positive thing a researcher can do to improve their publication performance through co-authorship is to position their DRM research collaborations as a bridge to facilitate information flow between otherwise separated sub-network groups. This applies across the board but is most especially the case for collaborations between countries, where the connectedness of the network overall accentuates the impact of the central figures. The more segregated network structure at the organisation level means betweenness centrality has less of an impact, but it is still the network parameter with the most positive impact potential.

The most significant negative impact network parameter is different for the publications score and citation score. For the publication score the most significant negative influence is the density of the network. Notwithstanding the overall dynamics of network parameters, this indicates in general that to improve the publication score the DRM researcher should focus on a smaller group of co-authors. For the citation score the most significant negative influence is the constraint of the network. This broadly indicates that to improve the citation score the DRM researcher is best placed when the group of co-authors is comprised of researchers who are not regular co-authors themselves. In other words, seek to publish with a group of co-authors who do not otherwise tend to publish directly with each other.

4. Conclusions

Effective DRM research is of critical significance and urgency. The frequency and cost of natural disasters is growing at an alarming rate. Central to any DRM strategy is the built environment. This study demonstrates that research activity in DRM specific to the built environment, expressed in terms of the number of scholarly publications, has developed rapidly since the turn of the century. However, the focus of DRM research is heavily biased towards the reactive approaches (response and recovery) over the proactive approaches (mitigation and preparedness), by a factor of 2 to 1. Although this study was limited to a scoping review, which makes the generalisation from the results difficult, it warrants that future research should explore the impact of policies and funding opportunities that results in such imbalance. The authors believe that the lack of research consideration for proactive approaches is being manifested through outdated policy and ineffective regulation. Given the particular and strong role that the built environment has to play in how emerging proactive approaches might translate most effectively to improved disaster response and recovery, it is important to make the most of our research productivity.

This study has analysed the influence of publication collaboration on the research productivity of built environment DRM in terms of publication score and citation score. For the first time, SNA is applied to a comprehensive analysis of the scholarly literature to examine the DRM publication collaboration at the country and organisation levels. This work demonstrates the ability of networking paradigm to reveal both strengths and weaknesses in research connections. It also highlights networking skills and strategies that might ultimately improve the benefit from research and research funding in DRM.

In broad terms, the study demonstrates that the more co-authors a researcher publishes with, and the more those co-authors themselves publish with others, then the more publications result and the higher the citation rate. This positive benefit is tempered somewhat when any given network of co-authors becomes overly self-contained and the internal connections dominate. For this reason, one of the most positive things a researcher can do to improve their publication performance through co-authorship is to bridge between authors who do not otherwise tend to publish directly with each other.

The best placed country for DRM research in the built environment is United States, followed by China and Japan. At the organisational level, the collaborations tend to be more focussed around strong but isolated networks. This may warrant researchers, research institutions and policy makers in DRM to examine their networking strategies, potentially looking for wider and more diverse collaborations. A break with traditional collaboration ties, and/or increased new ties between sub-networks or organisations has the potential to improve individual and overall publication performance significantly.

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Table 1: Top 10 countries with the highest publication scores in DRM research

Country	Publication Score	# Publications with Reactive Approach	# Publications with Proactive Approach	# Publications with both Approaches	Citation Score
United States	588	481	84	23	585.2
China	381	217	164	0	45.9
Japan	359	212	135	12	152.1
United Kingdom	138	83	52	3	141.3
Australia	94	72	20	2	49.0
Taiwan	60	28	32	0	56.8
Germany	59	46	13	0	126.9
New Zealand	59	55	4	0	76.2
India	56	29	27	0	13.1
Italy	45	28	17	0	28.6

Table 2: Top 10 organisations with the highest publication scores in DRM research

Organisation	Publication Score	# Publications with Reactive Approach	# Publications with Proactive Approach	# Publications with both Approaches	Citation Score
Harbin Institute of Technology	44	16	28	0	2.1
University of Illinois	37	36	0	1	26.8
University of Salford	36	23	10	3	10.4
University of Tokyo	36	22	12	2	3.5
Texas A&M University	35	34	1	0	129.4
Tohoku University	33	22	11	0	16.4
Kobe University	32	3	29	0	40.8
Kyoto University	30	13	17	0	10.8
Purdue University	24	6	18	0	3.0
University of Auckland	22	22	0	0	31.3

Table 3: Spearman correlations of social network parameters and publication scores

Social Network Parameter	Country-level				Organisational-level			
	r	P	95% Confidence Interval		r	P	95% Confidence Interval	
			Lower	Upper			Lower	Upper
Degree centrality	.648**	.000	.364	.843	.310**	.000	.194	.425
Betweenness centrality	.798**	.000	.636	.891	.687**	.000	.623	.747
Effective size	.689**	.000	.432	.853	.676**	.000	.595	.747
Constraint	-.708**	.000	-.872	-.446	-.645**	.000	-.717	-.571
Hierarchy	.587**	.000	.362	.746	.378**	.000	.279	.485
Density	-.712**	.000	-.863	-.509	-.666**	.000	-.727	-.600

- ** P ≤ .001
- Bootstrap results are based on 1000 bootstrap samples

Table 4: Spearman correlations of social network parameters and citation scores

Social Network Parameter	Country-level				Organisational-level			
	r	P	95% Confidence Interval		r	P	95% Confidence Interval	
			Lower	Upper			Lower	Upper
Degree centrality	.584**	.000	.290	.795	.308**	.000	.199	.413
Betweenness centrality	.780**	.000	.593	.888	.359**	.000	.261	.456
Effective size	.695**	.000	.452	.859	.322**	.000	.214	.432
Constraint	-.754**	.000	-.894	-.532	-.434**	.000	-.521	-.344
Hierarchy	.372*	.018	.093	.610	.208**	.000	.104	.323
Density	-.728**	.000	-.857	-.528	-.339**	.000	-.433	-.236

- ** P ≤ .001, * P ≤ .05
- Bootstrap results are based on 1000 bootstrap samples

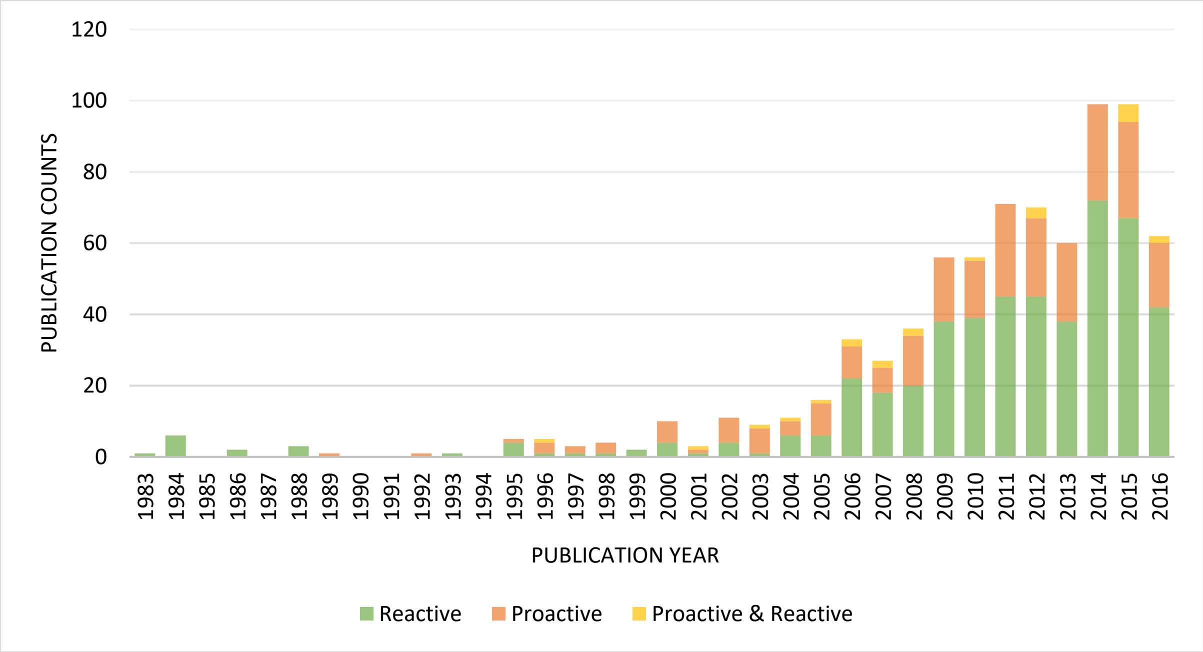

Fig1: The count of publications per year and by approach

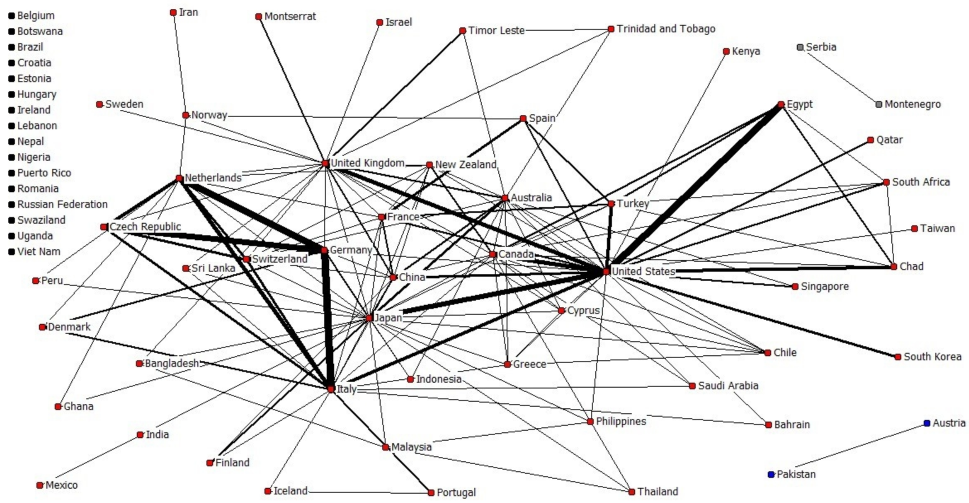

Fig2: A sociogram of the collaboration network in DRM research between countries.

319x170mm (96 x 96 DPI)

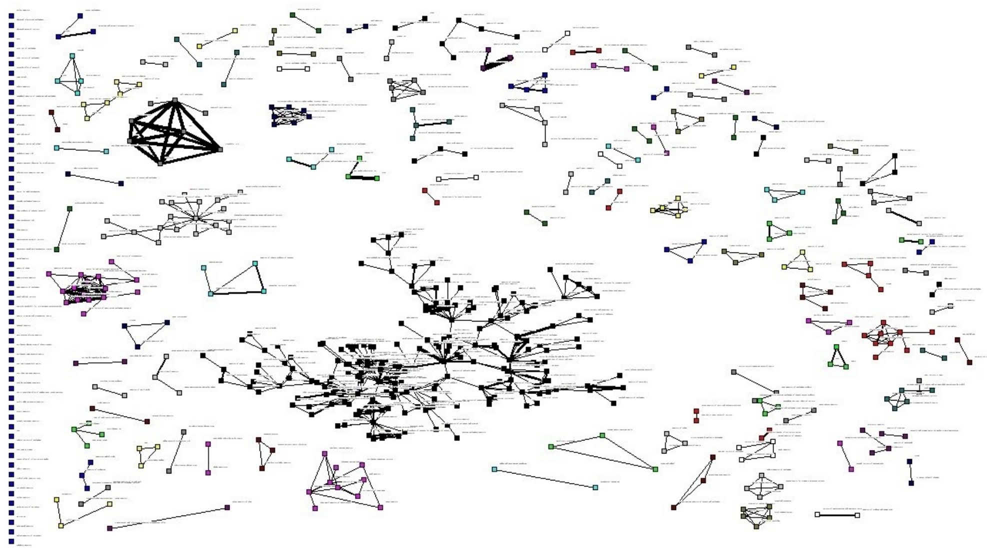

Fig3: A sociogram of the collaboration network in DRM research between organisations.

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