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Abstract. With the emergence of advanced Internet technologies, access to scientific literature is evolving at an unprecedented pace. While the number of peer-reviewed publications is growing exponentially, unpublished technical reports, dissertations and other forms of grey literature are becoming increasingly accessible for researchers across the world. Research organizations and universities are capitalizing on this opportunity, actively making their research available on the Internet. At the National Research Council, the Institute for Research in Construction ensures that all fire-related literature produced is stored in an Institutional Repository and posted on the Web in a freely available manner. In doing so, this system has provided fire researchers with a vehicle to improve visibility of their research, having pronounced advantages. For the fire community, the material is an excellent source of scholarly articles, reports, technical data and conference papers. A close examination of the Institute's fire-related literature in Google Scholar reveals citation patterns which illustrate the value of open-access, free literature to fire researchers.

In civil engineering, as with most scientific disciplines, the concept of peer-review is a vital component of the scholarly publishing cycle. The review process ensures that articles undergo rigorous commentary and revision before they are accepted for publication and distribution to the scientific community at large. Within the fire research community, the peer-review process is a well-established part of scholarly communications. Over the past 50 years, most of the valuable fire science research has evolved within the pages of core journals such as *Fire Technology*, *Combustion and Flame*, *Journal of Fire Protection Engineering*, *Fire and Materials*, *Journal of Fire Sciences*, *Fire Safety Journal and Combustion Science and Technology*. Today, these peer-reviewed journals continue to have a significant impact by publishing much of the breakthrough research in the field. At the same time, however, grey literature in the form of research reports, dissertations and other forms of unpublished documents are appearing on the Internet at an exponential rate and garnering considerable attention among researchers.

Currently, open-access initiatives throughout the world seek to make all forms of scientific literature, published and unpublished, freely available on the Internet. To fulfill the goal of creating this truly open–access environment, universities, colleges and research organizations across the world have responded by making their research publicly available via Institutional Repositories (IRs). At the National Research Council Canada, the Institute for Research in Construction (NRC-IRC) has a firmly established IR, which is the primary tool for disseminating web versions of the Institute's peer-reviewed and grey literature. The *NRC-IRC Publications Database* is an exceptional example of a comprehensive Institutional Repository in the field of fire sciences and, by examining some of its' content, it becomes clear that open-access initiatives and the availability of grey literature are making a major contribution to the field of fire science.

Institutional Repositories and Open Access

Institutional Repositories are defined as centralized information systems which organize, archive and make accessible, all research output of an organization [1]. While they vary in size and functionality, IRs are a fundamental tool for accelerating the progress of science by providing global access to electronic versions of reports, articles and other forms of literature. The guiding principle

behind IRs is the concept of open-access (OA), the online available of both peer-reviewed and unrefereed literature without fee or copyright restriction. In accordance with the open-access model, most scholarly publishers now allow for a preor post-print version of an article to be archived in an IR [2]. Additionally, OA literature includes the variety of unpublished technical reports, white papers and other ''grey'' publications.

Over the past decade IRs have grown exponentially and achieved a great degree of success and the reasons for this are obvious. First, in terms of content, the only requirement is a digital version of the publication. Secondly, the Internet provides an unlimited and ever-evolving platform for researchers to build worldwide collaborations in the name of science. Finally, IRs and open-access literature offer scientists unprecedented visibility for their work and, in doing so have changed the nature of scientific communications [3].

Background on NRC-IRC Fire Research and the NRC-IRC Publications Database

The *NRC-IRC Publications Database* is the central bibliographic database of the research produced by NRC-IRC. Currently, it hosts more than 14,000 bibliographic records, the full complement of research written since the Institute's inception in 1949. It is searchable from the NRC-IRC website and contains over 9000 full-text links to conference papers, journal articles, product reviews, trade publications and technical reports. Organizationally, the responsibility for the administration of the database at NRC-IRC falls under the control of *Library and Internet Services* (*LIS*). Recent studies suggest that such IRs are more successful when administrative and maintenance tasks are allocated to people other than the researchers themselves [4]. At NRC-IRC, the LIS staff enters all bibliographic information, creates standardized PDFs for the Web, ''alerts'' clients to new material available and verifies that new publications are indexed by Internet search engines. The procedures implemented at NRC-IRC can be characterized as fully mediated, allowing researchers to focus on their work, rather than disseminating their research. This serves to enhance the reputation of the system within the institute.

While LIS staff manages the technical and administrative aspects, success of the IR relies upon the participation of researchers to submit

full-text versions and associated bibliographic information of their research. For researchers to participate there has to be an incentive to ensure that all research written at NRC-IRC makes its way to the *NRC-IRC Publications Database*. Within NRC-IRC's current system, the motivation is quite substantial. When a researcher is eligible for promotion, only official bibliographies generated from the *NRC-IRC Publications Database* are accepted for review by the promotion committee. It is to the researchers' advantage to have all material entered into the database therefore, they make every effort to keep their list of publications up-to-date and complete. The publications database has become part of the research culture at NRC-IRC. In doing so, it has also created the ancillary benefit of providing access to a comprehensive set of documents for the worldwide research community.

For the NRC-IRC researcher the benefits are numerous. Since all works are archived in the *NRC-IRC Publications Database*, researchers are not required to maintain their own private bibliography. Researchers can obtain a list of their publications at any time in a variety of citation formats, which may accommodate their changing needs. Additionally, by providing full-text access, NRC-IRC research becomes more widely available within the international community. White papers, technical reports and unpublished research papers receive additional visibility providing a valuable source of ''grey'' information, which has not traveled the traditional route of peer-review.

The full-text features of the publications database also provide an added layer of access to peer-reviewed journal articles. While subscribers to high-impact journals peruse publisher versions of the articles, non-subscribers can download an open-access archived version via the Web. The advantages are twofold. First, researchers having limited access to high-priced journals gain access to critical information and, secondly, for the author there is all likelihood that the article itself will be more heavily read and cited. Literature suggests that journal articles, which have equivalent full-text versions, enjoy a marked citation and readership advantage within the academic community [5, 6]. Both readership and citation rates for journal articles available in Institutional Repositories have been estimated to be appreciably greater than those without [7]. By providing full-text access, the *NRC-IRC Publications Database* offers

key benefits to NRC-IRC fire researchers: a citation and readership advantage. By creating a medium to give research literature more visibility with the probability of greater scholarly impact, the IRC Pubs Database has proven to be an indispensable tool for researchers. To get a clear picture of the specific impact that NRC-IRC's repository is making on scholarship, it was necessary to examine some of the fire-related publications housed in the *NRC-IRC Publication Database*.

For the study, eight prominent scientists were selected as a representative sample of the Fire Research Program at NRC-IRC. The expertise of this particular group included fire detection and suppression, fire resistance of structures, risk assessment and human behavior during fire. After examining all options it was determined that Google Scholar would provide the majority of citation information for this study. While Scopus, Web of Science and Google Scholar all have their advantages, Google Scholar is the only citation tool which indexes not only journal articles and conference papers, but a host of grey literature which is more reflective of the open-access era [8].

As a first step, the authors were searched in Google Scholar, resulting in a total of 494 individual journal articles, conference papers and technical reports. Of the 494 publications, 350 had been cited on Google Scholar at least one time; the other 144 were not cited at the time of the study and are not part of this discussion. The set of 350 cited publications received a total of 2217 citations in Google Scholar and while peer-reviewed journal articles received the majority of the citations, a large proportion of the total cited conferences and grey literature. Of these citations 58% cited NRC-IRC peer-reviewed journal articles, 22% cited NRC-IRC conferences and 20% of the citations referenced technical reports, practical guidelines, newsletter articles or other forms of grey literature (Figure 1). As a comparison, these same authors were then searched in Scopus, a citation tool which focuses on peer-reviewed journals and contains little conference and grey literature. The same eight authors yielded 223 total references, a number significantly lower than the list of 494 documents retrieved in the original Google Scholar search. Similarly, these 223 documents were cited 672 times, far fewer than the 2217 citations received in Google Scholar.
The absence of grey literature is a startling omission and reveals the weakness of exclusively using peer-reviewed literature to understand

the nature of citation patterns in fire research. Peer-reviewed journal articles are still the most credible form of scholarly communication. This fact notwithstanding, open-access initiatives combined with advanced citation tools such as Google Scholar highlight the emerging fact that grey material is becoming a force in the field of fire literature.

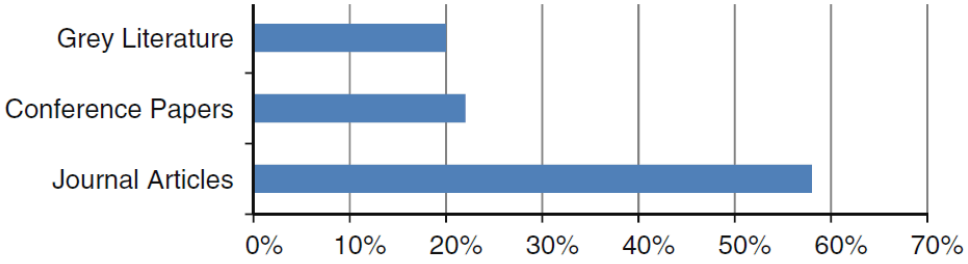

Figure 1. Type of NRC-IRC publication cited in Google Scholar.

The type of documents citing the NRC-IRC's full-text literature also reveals the impact grey literature has on the discipline. From the original Google scholar search, there were 2217 documents citing the NRC-IRC authors. Of the 2217, 47% were journal articles, 36% research/technical reports, 8% were conferences, 2.4% were books and 7% were considered other sources (websites, dissertations etc.). In the case of NRC-IRC, peer-reviewed articles accounted for less than half of all citing documents and while this number is significant, it exemplifies the diverse nature of fire literature. At just over a third of all citing documents, research/internal reports are pronounced sources for scholars in the open-access era. Historically, these types of grey literature were traditionally difficult to obtain [9], yet as universities and research agencies continue to make their unpublished reports available on the Internet, usage will continue to rise (Figure 2).

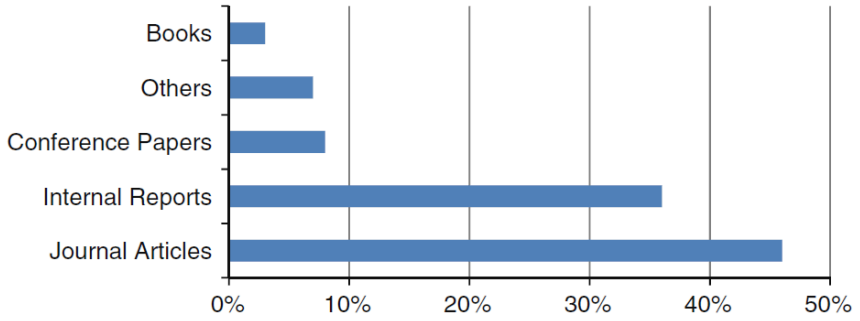

Figure 2. Type of document citing NRC-IRC publications in Google Scholar.

A specific, yet representative fire-related example will suffice to illustrate the value of grey literature in citation analysis. According to Scopus, Alfawakhiri and Sultan's 1999 article *Fire Resistance of Loadbearing Steel-Stud Wall Protected with Gypsum Board* [10], has been cited by two peer-reviewed publications. The same search in Google Scholar reveals not only the two peer-reviewed citations, but also six additional citations from grey sources. The citing documents include two Ph. D. dissertations from the University of Edinburgh and Universidade Federal de Minas Gerais, a MSc. thesis from Universidade Federal de Rio de Janeiro, two research reports and one conference proceeding. Furthermore, seven of the eight citing documents had free, full-text versions available in some form of open-access repository. The numbers alone are noteworthy, but perhaps the most revealing issue is the sheer breadth of grey literature citing NRC-IRC research. The two Portuguese theses are representative of the types of non-English materials found in Google Scholar references. With such a diversity of literature sources, Google Scholar simply offers the most comprehensive view of citation patterns in the age of open-access.

While citation numbers are revealing, the qualitative nature of the sources citing the documents offer telling insights into the way open-access and grey literature contribute to fire research. Too often researchers and information professionals focus on citation numbers within a scholarly milieu. In doing so, we may ignore other, less measurable aspects of the value of freely available material being posted in IRs. Mainstream public documents have been quick to use NRC-IRC research as the background for their fire documentation. For example, Guylene Proulx's 2000 publication *Strategies for*

Ensuring Appropriate Occupant Response to Fire Alarm Signals [11], has been cited in high visibility websites such as the New York City Fire Department and FEMA's Fire Prevention Pathfinder [12, 13]. While not in the traditional peer-reviewed literature, citations in such public domains will ensure that NRC-IRC's fire research has a long-standing impact on the public understanding of fire safety. Transferring technologies and knowledge to the public is one of the fundamental goals of fire sciences and institutional repositories are directly assisting in this endeavor.

Conclusion

At NRC-IRC both grey and peer-reviewed fire literature produced by the institute receives unimpeded web access via the *NRC-IRC Publications Database* and, as a result, substantially more visibility compared to documents not posted in an open-access institutional repository. By taking advantage of Internet technologies, NRC-IRC reports and other grey publications are now being widely circulated and cited within the community of fire researchers. Additionally, some research is even being promoted on public awareness websites in an effort to improve fire safety. As research institutes and universities continue to populate the Internet with their literature, Google Scholar is making it more accessible. Additionally, by providing citation information to both peer-reviewed and grey literature, Google Scholar has created a system which more accurately reflects the reality of open-access. With the introduction of institutional repositories and other open-access initiatives, the barriers to access are disappearing. In doing so, fire scholars will profit from this growing source of published and non-published literature.

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