Urban Tree Biomechanics Literature Review

Summary Report

Presented To
International Society of Arboriculture
Science and Research Committee

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May 16, 2013

INTRODUCTION

Tree biomechanics incorporates biological study and engineering principles to understand how plant growth leads to the ability to withstand self-imposed and externally applied loading events. As branches and stems annually increase in length and diameter, trees must build tissues and organs that are capable of withstanding static and dynamic loads. While the study of plant biomechanics began in the late 1800s, comparatively little work has concentrated on open-grown trees. Even less work has directly investigated arboricultural aspects of tree biomechanics.

A comprehensive literature of tree biomechanics was commissioned by the Science and Research Committee of the International Society of Arboriculture. The goal of this review was to learn what information is available on topics such as: biomechanical principals; adaptive growth; tree failure; decay; wind and storm related loading; branch and root strength. This summary report is an effort to synthesize the project. The assembled team included academics and practitioners which we feel brought a rounded approach to the subject matter. Members included Greg Dahle (West Virginia University), Ken James (ENSPEC), Jason Grabosky (Rutgers University), Brian Kane (UMASS) and Andreas Detter (Brudi & Partner).

COLLECTION METHODOLOGY

Most of the literature searches were conducted utilizing online library services at Rutgers University, the University of Melbourne and West Virginia University. Searches were conducted using the following databases: Agricola, A&UF, CAB Abstracts, Google Scholar, JSTOR, Scopus, Web of Science (listed in alphabetical order). The search for manuscripts was primarily conducted between July 2010 and April 2011 and included both print edition and ‘in-press’ or ‘online firsts’.

Emphasis was placed on searching and reading peer-reviewed articles. Additional inquiries were directed towards proceedings documents and book chapters. There were only limited efforts made to obtain text books and popular press articles. Citations were saved in a database either directly online via services such as Zotero, or manual collected for books, older articles and journals that did not have provide electronic metadata.

Since the number of peer reviewed articles pertaining to urban tree biomechanics is limited, we considered articles from journals concentrating in: agriculture, biology, botany, ecology, engineering, forestry, material sciences, plant sciences, soil science, tree physiology and wood science.

DATABASE

The database was collected either in Zotero or MS Excel and final deliverable was saved as in MS Excel. Most fields were automatically populated during the electronic collection of the citation. In the case of journals such as A&UF which did not provide a downloadable citation, the data was manually entered.

FINDINGS

A total of 782 citations were collected during the literature search (table 1). The citation can be grouped into 9 categories, ranging from peer-reviewed articles (Journal) to secondary (books, chapters, proceedings, forest service documents, dissertations), to tertiary (popular press, fact sheets, government documents). Over 80% percent of the citations collected were primary peer-reviewed articles.

Table 2 details the most commonly cited journals, a full list can be found in appendix I. Trees: Structure and Function and American Journal of Botany had the highest number of citations, yet these journals have not historically emphasized urban forestry or arboriculture. A&UF/JOA was the most commonly cited journal with an emphasis on urban forestry or arboriculture, followed by Arboriculture Journal and Urban Forestry & Urban Greening.

Table 1. The number of citations by publication type.

Article Type	#	%
Journal	629	80.4%
Book	76	9.7%
Book Chapter	38	4.9%
Proceedings	26	3.3%
Popular Press	4	0.5%
Forest Service Document	4	0.5%
Fact Sheet	2	0.3%
Dissertation	2	0.3%
Government Document	1	0.1%
	782	

Biomechanics appears to be growing in importance to botanists, ecologist, foresters, arborists, and urban foresters (figure 1). As such the number of articles published by A&UF pertaining to biomechanics has increased over the past twenty years. One difficulty during this project was collecting the metadata for citations. Many online databases provide metadata that can be downloaded into a citation database manager. Yet a few do not offer this ability, which subsequently requires manual entry if an article is to be included in a given researchers database. A&UF was one such journal and may wish to investigate developing the ability for researchers to directly download article metadata into citation managers. As this would help assure that A&UF articles are included in the databases of researchers directly or indirectly involved the fields of urban forestry or arboriculture, thus increasing the exposure of the journal.

Important findings from this review include:

- We need to understand how growth leads to changes in allometry, size, shape and material properties
- Material properties are not fully understood, especially as wood transitions from juvenile to mature growth.

- Little empirical scientific evidence to support 30% strength loss rule of thumb
- Static pull trials need to incorporate dynamic approaches
- Primary literature on urban trees and wind is almost non-existent
- Dynamic studies often used small trees that are difficult to scale up to larger trees due to allometric differences
- Urban tree wind studies used a semi-static approach using a constant wind rather than the ebbing flow of a typical wind gust
- Researchers need to address how trees re-align during wind loading, rather the consider trees as structures with a bluff body.

Deliverable during this project include a citation database that was delivered to ISA, two manuscripts (part 1 – statics, part 2 – dynamics) have been submitted for review and two arborist news articles (part 1 – statics, part 2 – dynamics) are being prepared. In addition oral summaries of the findings were presented at ISA Annual Conference in Portland OR in August 2012, as well as the Tree Risk Symposium Seminar and Summit at the Morton Arboretum in September 2012.

IMPLICATIONS

Before we can successfully understand how a tree of a given size reacts to loads like ice, snow or wind, we need to understand how growth leads to changes in size, shape and material properties. Understanding differences in allometric growth over time is important as the application of biomechanical techniques utilized the shape (diameter and length) to help prediction stability, or instability.

The shift from lower material properties to higher as trees transition from juvenile to mature wood may be important, yet it appears that stem/branch shape and allometry may be a more prominent factor in stability. Beam theory has been used to demonstrate that annual elongation must slow over time or a stem/branch is likely to become un-stable yet the importance of diameter cannot be over emphasized. During bending, the amount of load that can be resisted is directly tied to the amount and shape of the wood at a given location.

The use of static analysis to model tree growth and stability has been used with some success. Yet statics does not include the dynamic inertial forces that occur when a mass accelerates or the damping forces that dissipate energy and cause motion to slow down and eventually stop. When analyzing the dynamic response of trees in winds, static methods are not enough to explain the complex sway response. Simple models used for forest and plantation trees and are useful for dynamic analysis of slender trees with few branches. Yet more complexity is needed for urban trees with many branches. A multi-modal approach is needed for a dynamic analysis of urban trees because the dynamic coupling of branches has an influence on the response of the tree. The complexity of dynamic analysis is likely to increase in the near future but will need to be condensed into some simple methods for practical use. Implications of how branches influencing dynamic response of trees may influence future practices on how to prune. Tree form and shape appears to be as important in dynamic responses as species and material properties.

Energy transfer from the wind, and dissipation (damping) of the energy are likely to be for future investigation.

Finally, a thought on utilizing the internet for to search for articles and collect metadata during this review. In order to fully complete the citation database, some older and current documents needed to be manually input. A&UF was one such journal in which this team needed to manually input information. A&UF may wish to investigate the allowing direct downloading, via the journal's website, of article metadata into citation managers. This will help assure that A&UF articles are included in the databases of researchers directly or indirectly involved the fields of urban forestry or arboriculture, thus increasing the exposure of our journal.

Table 2. The most common peer-reviewed journal in the Urban Tree Biomechanics literature review database.

Journal	# Articles	%
Trees - Structure and Function	57	8.8%
American Journal of Botany	50	7.7%
Arboriculture and Urban Forestry / Journal of Arboriculture	42	6.5%
Tree Physiology	39	6.0%
Forestry	25	3.9%
Forest Ecology and Management	25	3.9%
Annals of Botany	20	3.1%
Canadian Journal of Forest Research	18	2.8%
New Phytologist	15	2.3%
Plant and Soil	13	2.0%
Comptes Rendus Biologies	11	1.7%
Wood Science and Technology	11	1.7%
Arboricultural Journal	10	1.5%
Journal of Theoretical Biology	10	1.5%
Journal of Experimental Botany	10	1.5%
Functional Ecology	10	1.5%
Annals of Forest Science	8	1.2%
Holzforschung	8	1.2%
New Zealand Journal Forest Science	8	1.2%
Wood and Fiber Science	8	1.2%
Canadian Journal of Botany	7	1.1%
Urban Forestry & Urban Greening	7	1.1%

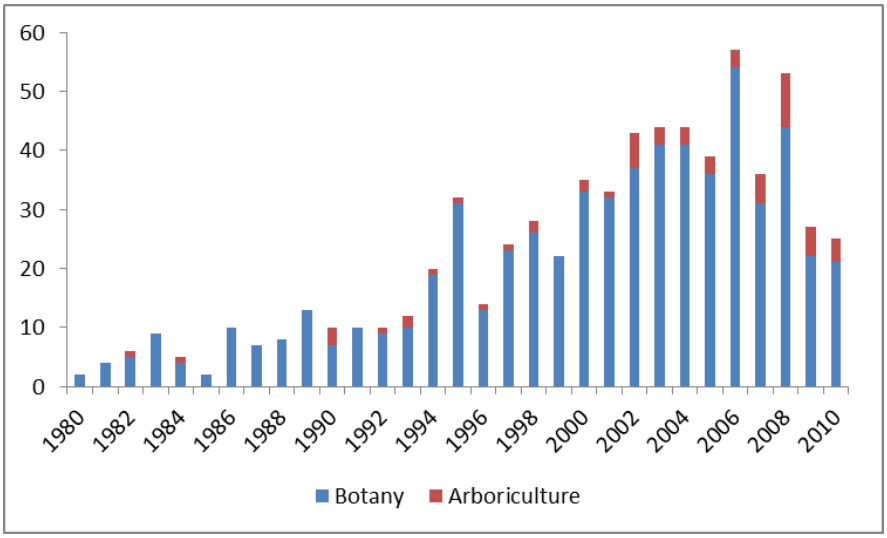

Figure 1. The number tree biomechanics manuscripts that were in botany, ecology or forestry journals (grouped as Botany) or arboriculture journals (Arboriculture & Urban Forestry/Journal of Arboriculture, Urban Forestry & Urban Greening, or Arboricultural Journal).

APPENDIX I

Table 2. List of primary journals and secondary sources, and the number of articles collected to date during searches for biomechanics of trees.

Journal Name	Number
Acta Horticulturae	1
Agricultural and Forest Meteorology	6
Agricultural and Forest Meterology	1
ALLGEMEINE FORST UND JAGDZEITUNG	3
American Journal of Botany	41
American Naturalist	1
Annals of Botany	15
Annals of Forest Science	6
Annals of Warsaw University of Life Sciences	1
Annual review of fluid mechanics	1
Arbor Age	1
Arboricultural Journal	3
Arboriculture & Urban Forestry	9
Arboriculture Journal	2
Arborist News	2
Australian Forestry	5
Australian Forestry Research	1
Biological Invasions	1
Biomimetics	2
Biosystems Engineering	1
Biotropica	3
Bois et Forets des Tropiques	1
Book	58
Botanica Acta	1
Boundary-Layer Meterol.	3
Bull. Math. Biophys.	2
Bulletin of the Torrey Botanical Club	1
Canadian Journal of Botany	2
Canadian Journal Forestry Research.	12
Canadian Journal of Agricultural Economics	1
Civil Engineering Transaction, {I.E.} Aust.	1
Climate Change	2
Comptes Rendus Biologies	10
COMPTES RENDUS B-MECANIQUE	1
Earthquake Engineering and Structural Dynamics	1
Ecological modelling	1
Ecology	4
Ecology Letters	1
European Journal of Soil Science	1
Evolution	1
Evolutionary Ecology	1
Experimental Mechanics	1
Fibre Science and Technology	1
Forest Ecology and Management	19
Forest Science	1
Forestry	18
Forestry Abstracts	1
Forestry Chronicle	1
Functional Ecology	6
Global Change Biology	1
Holz als Roh- und Werkstoff	1
Holzforschung	8
IAWA Journal	1
Integrative and Comparative Biology	1
International Journal of Forest Engineering	1
International Journal of Plant Sciences	3

Journal Name	Number
Journal of Agricultural and Forest Meteorology	1
Journal of Agricultural Engineering Res.	1
Journal of Arboriculture	14
Journal of Biomechanical Engineering	1
Journal of Bioscience	1
Journal of Ecology	1
Journal of Experimental Biology	5
Journal of Experimental Botany	8
Journal of Forest Science	1
Journal of Plant Research	1
Journal of Polymer Science	1
Journal of Structural Engineering	2
Journal of Theoretical Biology	9
J of Wind Engineering & Industrial Aerodynamics	2
Journal of Wood Science	5
Malaysian Forester	1
Native Plants Journal	1
Nature	2
New Phytologist	15
New Scientist	1
New Zealand Journal Forest Science	5
New Zealand Journal of Forest Research	1
New Zealand Journal of Forestry Science	2
Oecologia	2
Other	5
Palaeogeography Palaeoclimatology Palaeoecology	1
Philo.Transactions of the Royal Society	4
Plant and Soil	14
Palaeontgraphica	1
Plant Biology	2

Journal Name	Number
Plant Biosystems	1
Plant Molecular Biology	1
Plant Physiol.	1
Plant Physiology	1
Plant, Cell and Environment	2
Planta	4
Proceedings	23
Proceedings Cambridge Phi. Soc.	1
Proceedings of the National Academy of Sciences	3
Radiation Environ. Biophys.	1
Report	19
Rev. Palaeobotany Palynology	2
Revista Arvore	1
Scandinavian Journal of Forest Research	1
Scottish Forestry	1
Silva Fennica	3
Stadt und Grun	2
Studia Forestalia Suecica	1
The Forestry Chronicle	1
The Plant Journal	1
Transaction. {ASAE}	1
Tree Physiology	23
TREES-STRUCTURE AND FUNCTION	36
Trends in Plant Science	1
Urban Forestry & Urban Greening	4
Wind Effects on Trees	1
Wood and Fiber Science	4
Wood Science	3
Wood Science and Technology	7