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Structural pocket guide for architecture students

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ABSTRACT: This paper reports on the endeavour to compile a pocket guide on structural design for architecture students. The guide is oriented towards use during design assignments. The paper touches upon three topics; first is a literature review of recent practical guides for the design of structures. A lot of invaluable sources exist, but none are exactly fit for day-to-day use in architecture studios. Based on this, a very concise, easy reproducible, go-to guide is suggested. The second part of the paper addresses the choices for the guides' format and content. The link at the end of this paper gives access to the most recent version. The last section is a sample check of published rules of thumb to make preliminary estimations for the depth of structural members. The variety of such rules of thumb is very large, which asks for some thoughts when one wants to reproduce them.

1 INTRODUCTION

Although architectural education programs generally include courses on structural design, it remains challenging for students to transfer this (theoretical) knowledge to design studios. A concise, accessible guide specifically for these studios could help bridging this gap. A first inquiry in educational institutions and offices leads to the conclusion that such specific pocket guides are not easy to find.

This paper reports on the considerations to compile a pocket guide on structural design, focused on supporting architecture students in integrating structural principles into their design work, in a context where structure is often not a primary focus.

The paper touches upon three topics; first is a review of a set of existing, recent practical design guides for the design of structures, together with a discussion on their direct applicability for architecture students. Indeed, a vast number of guidelines exist for the design of structure in buildings, ranging from design guides based on Eurocodes, over applied and practical basic guides for architects to rudimentary tables and rules of thumb for preliminary design. However, this information is scattered and due to its massive amount, knowledge is required to select and translate often theoretical information to make it easily applicable during design. The review focuses on 'pocket guides'. It reveals why these valuable publications are not exactly fit for our purpose and helps to reflect on what this structural pocket guide then should entail. Secondly, a format and content for this pocket guide is proposed. In a first idea, the pocket guide should be a collection of information on structural building materials, common products and practices, show basic structural principles, propose preliminary steps for verification, collect tables for preliminary dimensioning, and point where further information, examples and inspiration can be found. Over time, more fundamental requirements came to the fore. In the first place, the guide should be as concise as possible, and the information should be as much as possible tailored to be of immediate practical use for the students.

The most recent version of the design guide can be accessed through the link at the end of the paper.

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The last section of this paper reports on a sample check of rules of thumb to make preliminary estimations for the depth of structural members. These rules of thumb are very common to be found, and an estimation of the size of structural elements is one of the main concerns students generally have on the structural aspects of their design proposal. The variety of such rules of thumb is however large, and it can be shown that they vary greatly, both in the selection of relevant parameters, as in the proposed values to dimension elements.

2 LITERATURE REVIEW: AMBITION & DEMARCATION FOR THE POCKET GUIDE

2.1 *Demarcation*

The literature review is demarcated for publications that specifically aim to be 'pocket guides'. This rules out a wide range of sources that are as well of great relevance to enhance student's understanding and help the implementation of structural aspects into their architectural design.

Without any attempt to be comprehensive, what follows serves as a very short overview of such sources. On the one side of the spectrum are theoretical manuals and coursebooks. Close to such publications are books specifically focusing on the abstract, underlying principles of structural design (Millais 2017; Salvadori et al. 2016; Hunt 2003; Gauld 1995; Lin et al. 1981). Other books contextualize structural principles with references of buildings, anecdotes and historical framing, with a varying ratio between theory and context (Möller et al. 2022; Allen et al. 2019; Sandaker et al. 2019; Salvadori et al. 2016; Evans et al. 2014; Silver et al. 2013; Muttoni 2011; Ochshorn 2010; Schodek et al. 2008). On the other side of the spectrum are publications where the ratio between theoretical principles and context tilted over in favour of the last (Macdonald 2018).

2.2 *Literature review*

A dozen recent publications that could be considered as guides on structural aspects for students will be shortly discussed. First, we'll go through material that is 'course-like'. They have an explanatory focus, which is slightly different from ours. After that, we will look into a set of publications that are specifically titled to be 'pocket guides' and show that their content is generally either 'course-like', or focused on the collection of tables and data.

TUDelft recently published 'Vademecum voor de Bouwkunde' (Arends et al. 2024). The document serves as a tool for design projects and exercises. The publication is clear and visually accessible and elaborates both on practical and theoretical knowledge. It is an invaluable introduction to structural design. It however rather reads as a course book and is with its little less than 200 pages too elaborate to be easily accessible.

'Basic Concepts of Structural Design for Architecture Students' (Khodadadi 2022) is similar. Explanations are clear, extensively illustrated and the text contains numerous links to further and up-to-date information. The focus is on theoretical backgrounds of formulas and structural principles, which is different from ours.

'Simplified engineering for architects and builders' (Ambrose et al. 2016) was first published in 1938, claiming that 'to the average young architectural draftsman or builder, the problem of selecting the proper structural member for given conditions appears to be a difficult task.' Since - as is written in the introduction - 'the numerous books on engineering which are available assume the knowledge of fundamental principles, they are useless to a beginner'. The book has a clear educational focus; it has considerable amount of text and contains exercises. It however remains mainly theoretical. The publication counts over 700 pages. It can be seen as a reference book with a focus on completeness, rather than conciseness.

'The structural basis of architecture' (Sandaker et al. 2019) has a different approach; the book as well treats 'simplified engineering for architects', but the theory is laced with illustrations and pictures of recent buildings and is made accessible by adding narrative on context and history. All these sources are very relevant for architecture students, but deemed too elaborate for the kind of pocket guide we have in mind.

In 2023, a new edition of the 'Architect's pocket book' (Hetreed et al. 2023) was published. The first edition was published in 1997, on the initiative of a practicing architect. The book 'brings together a wealth of useful information that architects need on a daily basis', and treats a wide range of issues related to the architect's profession. The chapter on 'structures' counts 66 pages and is in that sense concise. The content is however explanatory and mostly textual, which makes the information difficult to access. The documentation as well clearly focuses on British housing construction: mainly wood and steel construction is discussed.

Fiona Cobb's 'Structural engineer's pocket book' (Cobb 2004, 2015) was compiled because the author found it was difficult to source basic design data as a student or graduate engineer. It is a useful, easily accessible document, that finds good balance between conciseness and completeness. The focus is mainly on verification guides, as they can be found in building codes. Aspects such as basic design configurations etcetera are less present in the book.

When working in the Dutch-speaking area, there is no way around 'Polytechnisch zakboek' - 'Polytechnical pocket guide' in English - (van Herwijnen et al. 2010). The book aims to unify and bundle graphs, formulas, tables, etc. that 'technicians' use daily. This most recent edition has biblical proportions. Practitioners appreciate the practical tables, such as the elaborate moment diagrams, span/ratio rules of thumb and the maximal loading of steel columns as a function of their buckling length. The book evidently asks for considerable knowledge and selection to be of practical use. Similar sources exist in other language areas, such as Smith's Engineer's practical databook (Smith 2018).

'The architect's studio companion: rules of thumb for preliminary design' (Iano et al. 2022) specifically focuses on rules of thumb. This publication aims to be 'a technical advisor for the earliest stages of building design', by reducing complex code information to simple formal and spatial approximations. The section 'designing the structure' counts 108 pages. The pages 'will help you select a structural system for the preliminary design of your building'. It mainly focuses on the choice of the structural system, configuration and on graphs to size structural elements. No basic theory or formulas are included. The authors mention that content of the book has been 'interpreted' from sources that include building codes, industry standards, manufacturer's literature and personal knowledge and contacts.

At last, both the publishers Routledge (McMullin et al. 2016) and Birkhäuser (Meistermann 2017) (originally in German) recently published a series of pocket guides on structural design. The Routledge series consists of 6 guides, published between 2016 and 2019. The books contain worked examples, references and tables. Publications related to structural design in the Birkhäuser 'Basics Series' are similar. These guides are very useful reference guides, but the complete sets are again rather elaborate, and therefore as well too complex to be easy go-to sources for practical use in a design studio.

2.3 *Observations*

This literature overview left us in a somewhat schizophrenic position; a large amount of qualitative manuals, (pocket) guides and course material exists, with a range of different focuses, even within a narrow demarcation. Yet none of those seemed to exactly fit. This clearly poses the question what should be different, and what kind of guide would be a useful addition.

What is common to the reviewed publications is that they give a kind of summary of the theory used in structural engineering, be it in a collection of data, or in a rather textual format supplemented with examples and/or exercises. As a result all these publications are rather elaborate. All this information needs selection and translation in order to be applicable for students while designing architecture projects, and thus asks for a certain engagement that might be too large in the context of demanding design exercises, where structural aspects are only of secondary importance. If we want to encourage students to make considerations for the structural aspects of their design by default, we believe the threshold between the guides and their practical information should be kept as low as possible.

This brings us to a somewhat counterintuitive, but equally evident conclusion. For an easy to use pocket guide, conciseness should be chosen over completeness and guides should be as much as possible tailored to immediate use in the specific context of the development of an architectural design (in an educational context). By definition, it will be reductive. Our defence is that this guide is only complementary to the knowledge students acquire in their courses. Additionally, this can be bypassed by making the guide a reference point on where to find further information.

3 STRUCTURAL POCKET GUIDE FOR ARCHITECTURE STUDENTS FOR USE IN ARCHITECTURAL DESIGN STUDIOS

The most recent version of the document can be downloaded through 'bit.ly/structuralpocketguide'

3.1 *Format*

The guide is limited to both sides of an A3-sheet. This makes it an extremely concise guide, that can be grasped visually in its entirety, that allows the guide to be easily updated and broadly circulated and has a very low threshold to use.

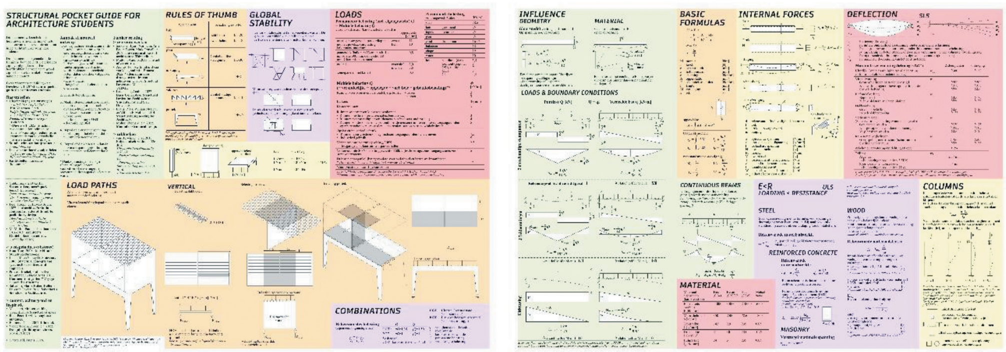

Figure 1. Impressions of the double sided A3-pocket guide.

3.2 *Content*

The guide is made up of 14 'chapters', organized in boxes with various sizes with coloured background. The boxes are puzzled on the pages in a sequence that mirrors the sequence of a structural design procedure. These steps are as well made explicit in the introductory chapter. This idea of giving an overview of the general structural design procedure, as well informed the selection of the information.

The guide aims to be of use for students in architectural design studios. This is why the content specifically focuses on the influence of choices on structural behaviour. For example; for beam formulas six basic cases for a single span beam are organized in a table which allows to compare the influence of the boundary conditions and loading patterns (based on (Lin et al. 1981, A36)). A seventh case informs on the influence of continuous beams. Another example: the selected formulas, depicted in the chapter on verification, are go-to formulas for preliminary dimensioning and checks.

As mentioned, another strategy is to limit information in the guide itself, but to add plenty of references that guide to more elaborate sources, collections of rules of thumb, beam formulas, – this paper is part of that strategy.

3.3 *General applicability*

The guide is made for a Belgian building context. Although most content is generally applicable, some information is inevitably related to the local context. This is the case for nationally specified values such as imposed loads or limits to deflection, for often used buildups of construction elements and even for generally used material qualities. It is a choice to include these in the guide, since it largely facilitates its use in practice. These chapters are coloured in red.

However, in other contexts, the selection of the chapters themselves might be questioned as well. In Belgium for example, earthquakes are very rare, so they are no main concern for structural design. The format of the guide allows to be easily adapted when deemed necessary. We imagine that over time, a large set of slightly locally adapted guides, can be generated by the international community.

4 RULES OF THUMB TO ESTIMATE THE DIMENSION OF STRUCTURAL ELEMENTS

4.1 *Problem statement*

'A question I am commonly asked by students of architecture is: How far can I span and how deep would the beam have to be? If only it were that simple.' (Garrison 2005, 256)

In general of course: the larger the span, the greater the depth. Most of the publications mentioned above contain rules of thumb to estimate dimensions of structural elements. They are time-honoured, widespread and broadly used.

However, when one looks a bit closer into these rules, important questions rise. First of all, the parameters taken into account largely varies, which makes rules of thumb hard to compare. Secondly, it is invariably completely unclear where these rules of thumb come from. Where they derived from several theoretical hand calculations, based on an analysis of sizes of elements in real constructions, based on estimations made by experienced practitioners or simply reproduced from previous publications, as if they are inalienable truths?

These questions lead us too far for the scope of this paper. Nonetheless the reservations that can be made, it is deemed relevant to include some rules of thumb into the pocket guide. To make a preliminary evaluation of the variance of the rules, and in order to make an informed selection of rules of thumb for the time being, a comparison based on a sample from literature was made.

List of sources for comparison*:* (Gauld 1995; Van Tol et al. 1999; Cobb 2004; Verburg et al. 2004; Garcia 2005; Garrison 2005; Schodek et al. 2008; van Herwijnen et al. 2010; Allen et al. 2012; Silver et al. 2013; Ching et al. 2014; Innovative Engineering Inc. 2015; McMullin et al. 2016; Meistermann 2017; Ollivier 2017; Khodadadi 2022; Möller et al. 2022; Hetreed et al. 2023; Arends et al. 2024)

4.2 *Overview*

In general, two categories exist: rules for which loading is a main parameter, and rules for which loading is not. Loading fundamentally influences the size of the elements. Taking the parameter into account, implies that students should estimate the loads and load paths. Since this asks for more engagement, this category of sets of rules of thumb will not be considered here. For rules of thumb where the load is not included as parameter, the span is taken as the main variable to estimate structural depths.

The rules in this category come in three formats, or a combination of those. In one format the ratio of a span over its height given. (For example: a steel beam will have a height of 1/20 of its span.) These are often combined with an average or a range of common spans. The third format is an average or a range of common thicknesses.

The sets of rules of thumb proposed in publications vary largely in amount and in how they nuance or generalize over different parameters such as materials, structural elements, configuration and direction of spans etcetera. In some of the more elaborate tables, columns are added for illustrations or additional information and remarks. (van Herwijnen et al. 2010; Silver et al. 2013). The most elaborate tables were found in the chapter 'sizing the structural

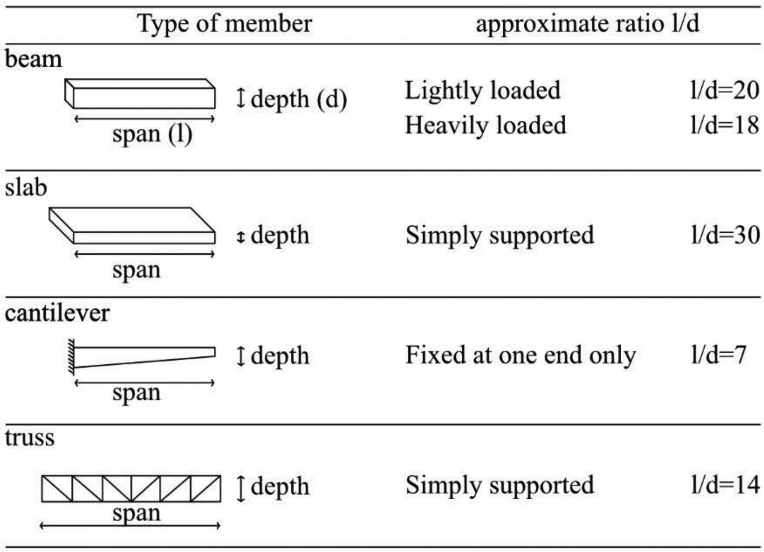

Figure 2. Approximate sizes of structural members, based on (Gauld 1995, 10).

Table 1. Parameters and tags for comparison of rules of thumb.

Parameter	Tags
material	concrete, composite: concrete/steel, steel, wood
structural typology	beam, slab, truss, portal, space frame
type of structural element	rectangular, T/ ribbed/TT, flat, waffle, hollow core, mushroom, corrugated steel plate + concrete, wide flange, IPE - UNP, triangulated, vierendeel, open web, plate girder, I-joist, cassette/stressed skin panel, etcetera
production	cast in place, prefabricated, plywood, timber, Glulam, LVL, laminated
reinforced/ prestressed	reinforced, prestressed
configuration: span	single span, cantilever, continuous, one-end continuous, two-end continuous
Direction of spanning	One-way, two-way
hierarchy	Primary, secondary
(intermediate) supports	linear - beam, column
Hint of loading	light, heavy, floor, roof, point load, surface load, several floors, one floor, light floor, light roof

system' in (Iano et al. 2022), which was already mentioned in the literature review. The chapter counts 77 pages with 44 chapters on structural elements, such as wood beams, brick masonry walls or open-web steel joists.

The rules of thumb are depicted as graphs (spans on the x-axis, and depths on the y-axis), in which either bars or areas (of applicability) indicate ranges of preliminary dimensions.

The advantages of the most elaborate tables seem evident: the information is probably more precise. The disadvantages are however similar to those of very elaborate pocket guides:

the amount of information probably has an optimal point, after which the amount of information asks for a higher engagement to access. Another disadvantage is that these elaborate guides tend to become more regionally and product specific and thus less generally applicable. The more specific they are, the more they as well result in a pick and go, menu-like list, which is inevitably limiting for all the possibilities beyond what the table entails.

The most basic rules of thumb differentiate in the least number of parameters. 'Structures for architects' (Gauld 1995, 10) – see Figure 2 - proposes span/depth ratios without differentiating for the material. According to the author these provide 'a surprisingly good 'guesstimation' as to find the most efficient depths of beams and slabs regardless of the material used'. In relation to more elaborate tables, this is a rather bold statement.

Often it is mentioned that serviceability limits are decisive. When expected deflections are the limiting factor, loading is an equally fundamental factor as the material type and the inertia of the structural element, as is evident in the formulas. The span and the structural depth (in the moment of inertia) are the only factors that are raised to a power. If we agree that large simplification is inherent to rules of thumb, and that loading can be left out as a parameter, this might as well make sense for the material and its configuration. This is why Gauld's rules are taken as the starting point for the following comparison.

4.3 *Approach and comparison*

To be able to compare all these rules of thumb, a table was composed with a total of approximately 300 entries. These entries are all the rules of thumb that have tabular values (graphs

Table 2. Average l/d values (l/d = span/structural depth).

	beam*				slab**				truss	cantilever
	all	concrete	steel	wood	all	concrete	composed	wood	all***	all****
l/d (Gauld 1995, 10)	18-20				30				14	7
Average l/d	19,0	20,0	18,7	18,3	28,0	30,2	24,5	20,0	12,1	8,2
St. deviation	5,70	8,33	4,82	3,03	8,10	8,27	4,54	3,88	3,23	2,21
# values	67	21	20	23	72	50	13	8	23	13

Stags: * single span & no specification'. **one-way & two-way/*** in practice: wood and steel ****steel

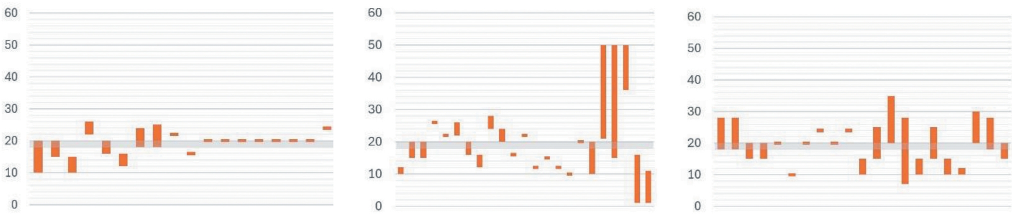

Figure 3. Graphical depiction of l/d rules of thumb for beams (single span). l/d on y-axis. Grey bar indicates 18<l/d<20 as proposed by Gauld. From left to right: wood, concrete and steel.

were excluded). Each rule of thumb was tagged with the parameters (when applicable), based on their description in the source. The ten parameters and related tags are shown in Table 1, as these are illustrative for the broad range of conditions considered. Comparisons are made by using filters in the dataset, which allows to make a variety of sensical groups. To evaluate Gauld's proposal, the different values are averaged out (Table 2) and graphically plotted (Figure 3).

When one takes the average value of all ranges of the proposed l/d-ratios together with the proposed discrete values, and derives the average of those, one gets values surprisingly close to the values proposed by Gauld for the case of single span, simply supported beams, cantilevers and trusses. The same exercise for slabs gives a somewhat different picture. For concrete slabs, the average value again comes close to Gauld's value. For composed slabs (steel corrugated plates with concrete) and wooden slabs, Gauld's value seems optimistic.

In Figure 3, plots are shown of all the l/d-ratios – both the ranges and the singular values - for single span, simply supported beams found in the series of rules of thumb. They are grouped for wood, concrete and steel. Both the l/d-values and the width of the ranges vary greatly, for the three material types. This nuances the conclusions that could be made on the validity of Gauld's statement based on the average values.

4.4 *Conclusion & further research*

The discussion and sample test above clearly show that in the sets of rules of thumb proposed in literature, little consensus exists. This does not only apply to the values, but as well to the parameters to consider and the fit degree of nuance. It can be argued that for the sake of conciseness and clarity, and to avoid the impression of precision that might result from very elaborate lists of rules of thumb, a small set of rules-of-thumb is preferable. If we agree loading can be left out to approximate the preliminary estimations, this can arguably be done as well for the material type.

The discussion on rules of thumb however shows that more research would be necessary to make more conclusive observations about the sense and nonsense of (existing) rules of thumb. One can think of several approaches; theoretical analysis by making calculations for a large variety of set-ups would allow to propose estimations for new construction techniques and materials. Another approach can be to verify these rules of thumb with a large amount of data of real-world structural elements in constructions, as there might be a theory-practice gap. With additional data such as location and/or construction date, this might as well allow to scrutinize difference in building culture and evolutions over time. Currently, a test project is started to generate large amounts of data based on tender documents of public projects (as these are theoretically publicly accessible) to investigate these values. At last, a meta-perspective on the history and context of these rules of thumb will help to properly understand their genealogy and current applicability.

5 CONCLUSION

Composing a structural pocket guide for architecture students is a balancing act in rigorously selecting and translating the right information for practical use during design studios. A lot of invaluable sources exist, but none seem exactly fit for day-to-day use in architecture studios. We suggest a very concise, easy reproducible, go-to guide and discuss its international applicability.

Secondly, this paper took a closer look at rules of thumb to estimate the size of structural elements. A sample test shows that little consensus exists in the sets of rules of thumb proposed in literature. It is argued why the simplest set of rules, in which no materials are included, is selected for the guide.

Link to the most recent version of the guide: bit.ly/structuralpocketguide

https://www.ugent.be/ea/architectuur/en/research/research-projects/all-research-projects/structural-pocket-guide-for-architecture-students

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