Performance in the Swedish Building Code

An Inquiry into the Consequences for Architectural Design of the Formulation and Assessment of Performance Requirements

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Abstract

This thesis investigates performance-based regulation in Sweden and its consequences for architectural design. In the last 50 years, there has been a transition from prescriptive to performance-based regulation, propelled by the drive to further innovation, productivity and competitiveness by expressing the functions expected of the buildings as performances. This thesis examines the promise of freedom in design and solution that this regulatory construction offers, considering two specific performance aspects of the Swedish building code: the requirements regarding energy performance in relation to user-comfort, and the requirement in terms of daylight in relation to health and hygiene. Each case investigates the implications of the performance-based system of regulation for the synesthetic and multidisciplinary process of design, focussing on how it affects the work of architects.

This thesis also addresses the disciplinary knowledge necessary for assessing performance requirements, which in turn connects to the entry into building regulation of abstract natural science models quantifying societal goals in legislation, and to the disciplinary histories of the engineering and architectural professions.

Speculating on ways forward that address the concerns that emerge from this analysis, the thesis turns to a historical example that dealt with a similar problem to evaluate its potential for developing current architectural practice. The dual nature of design, reaching into both expressional and technical concerns, has been the subject of research and eloquent discussion within the architectural concept of tectonics. The concluding section of this thesis raises questions about the architectural discourse in relation to tectonics. It suggests that there is work to be done to reconcile the division between architectural design and technical characteristics connected to building physics that permeates systems of building regulation in Sweden and more generally. The thesis suggests that if performance-based regulation is to offer freedom in architectural design, the architecture community needs to be much more involved in both the research and critique of performance requirements and of their formulation and assessment methods when addressing this.

Keywords: performance-based regulation, performance requirement, energy performance, daylight metrics, tectonics, architectural representation, repertoire, context-dependent knowledge.
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Introduction

Over the last 50 years, Swedish building regulation has transitioned from prescriptive or rule-based (solution-oriented) regulation to performance-based (function-oriented) regulation. The initial steps towards creating a performance-based regulation system in Sweden were taken in the late 1960s to the 1970s, emerging from an ambition to rationalise and economise the building industry and to support more rapid technical development (Sigge 2017, 71; SOU 1974, 202-203). In the proposition to the Planning and Building Act in 1987, the government explicitly stated that the building code should regulate the goals through performance requirements in order to create freedom of means and solutions (prop. 1985, 100). Driving this both in Sweden and internationally are the desire to create opportunities for innovation (Knocke 1970; Foliente 2000; Meacham, 2010) and trade (Foliente 2000, 13). Whilst requirements in prescriptive, rule-based regulation systems tend to be expressed in clearly stated solutions or geometrical relations, the requirements in performance-based regulation systems are often based on abstract or complex building science metrics.

This thesis addresses a specific tension in the relationship between architecture and technology that I argue originates in the transition from prescriptive to performance-based building regulation and procurement. This tension, as it presents itself in building regulation, can be described as an unfortunate, theoretical separation of architectural solutions from technical solutions.

Design freedom is often mentioned as an intrinsic characteristic of performance-based regulation. To date however, little research has considered whether architectural design freedom really emerges from a building-design culture dominated by performance-based regulation systems. This thesis aims to consider this question, using the building design culture in contemporary Sweden as its context. In 2004, the Swedish National Board of Housing, Building and Planning (Boverket), which issues the Swedish building code, Boverkets byggregler (BBR), suggested a definition in which performance requirements should be stated so as to not limit choices in design (utformning), material, or method (Boverket 2004, 42). In the Swedish regulatory context, the word utformning relates to all aspects of building production, including architectural design.

1 This thesis thus addresses whether the ambition to generate design freedom set out in Boverket’s definition of performance requirements is being reached with regards to

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1 See the use of the word utformning in the older Planning and Building Act on building design, which relates to form, colour and materiality with consideration to the surrounding (Sveriges Riksdag, 1987, chap. 3, sec. 1-2), and in building code, where it was used for all design aspects related to architectural programming, construction, and systems such as for example heating systems (Boverket 1988). The word has been even more strongly connected with architectural programming and expression in the new Planning and Building Act, plan- och bygglagen (PBA) from 2010 (Sveriges Riksdag, 2010, chap. 8, sec. 1). In Boverkets Byggregler (BBR), utformning has been and is used for all design aspects, but also designated to architectural programming following PBA from 2010.
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architectural design.

To do this, the thesis examines both the writing and the assessment of performance requirements in the BBR in relation to their promise of freedom in architectural design and solutions. The specific regulatory examples examined here relate to two performance requirements as they are manifested in the Swedish building code: first, a requirement about energy performance; and second, a performance requirement regarding daylight. The relationship between architectural design, daylight availability and energy use is exemplary for the enquiry made in the study, as architectural form and technical criteria interlock in these parts of regulation. As in all performance-based regulation, these two objectives of societal concern have isolated requirements to be resolved within a holistic solution in the design project. In this thesis, this postulate for performance-based regulation is addressed as a general aspect of regulative requirements, where objectives and architectural design are interconnected.

To study whether or not regulation related to energy use steers architectural design, the first article of the thesis uses the Swedish energy performance requirements as a case study. This first case study is contextualised geographically; it compares what happened in 2016 in Sweden with what is happening elsewhere in Europe. To understand how the architectural community acts regarding requirements based in building science, the second article of the thesis explores the context of the Swedish daylight performance requirement. This second case study is contextualised in terms of discipline; it compares the way in which architectural and engineering culture interact with the language and methods of performance-based regulation. The building science metrics used in Sweden are versions of commonly used metrics in current legislation and standards around the globe; therefore the Swedish examples, while telling a very local story, are of interest in terms of general issues that arise internationally in relation to performance-based regulation and architectural design. Following the discussion of the second article, the section Juxtaposition of this thesis compares the challenges that architecture and engineering face today with performance-based regulation to challenges they faced when new materials entered the building sector in the nineteenth century. This part of the thesis provides a disciplinary contextualisation and uses historical examples to suggest possible ways in which the promise of design freedom in performance-based regulation might be met.

These two societal objectives can be found in performance-based building regulation around the world and in all EU member states. The energy performance requirement is motivated by a regulatory desire to manage energy resources and mitigate greenhouse gas emissions; this requirement was instigated by the EU; that is to say behind the regulation lies a broad European and Swedish governmental policy ambition about energy use in the future. The second performance requirement regarding daylight is motivated by understandings about how buildings affect users, and a societal ambition to avoid buildings being detrimental to the health of the individuals using them. Daylight requirements can be found in various forms throughout Swedish regulatory history, as in other countries.
What the first article discusses

The Swedish building regulatory interpretation of the EU Energy Performance Building Directive (EU 2010) comprises the case study context for the first article. Here, the consequences for architectural design, energy use and climate mitigation are analysed. The overarching research question for the first article is how does the section on energy in the Swedish building code condition building solutions, and what are the consequences of the framing and wording of the building code for energy use and architectural design?

The analysis shows that because of the way in which the energy system boundaries are chosen for calculating energy performance in the Swedish building regulations, office design in Sweden is often steered towards minimising the building’s external surface area, and towards the creation of deep building plans, despite the fact that these configurations require more energy use through electric lighting. This case analysis illustrates the delicate nature of the framing and wording of a performance-based regulation and highlights the fragility of the alluring possibility of design freedom through performance-based regulation. It also illustrates the need for the authority that issues the building code to perform an impact assessment of the formal consequences that emerge from their regulatory framework, i.e., the effect on the architectural design including building volume, floor plans, and façades. The article goes on to propose a new comprehensive energy section that takes all architectural design-related energy aspects into account, to support freedom in design for nearly zero-energy buildings.

To contextualise this analysis, Part I of the thesis’ exegesis, which follows the first article, considers the historical development of the Swedish performance-based model for individual technical characteristics, and how this displaced the prescription-based model, where solutions embodied design and technological choices. Here, I argue that there is a connection between the development of performance requirements in building code and the formal division between design and technology established in the Swedish Planning and Building Act, PBA, from 2010. Research on performance-based regulation as well as implementation in vanguard countries from the 1990s and onwards is used as a comparative platform to the Swedish implementation of performance requirements.

What the second article discusses

The second article highlights the relation between knowledge traditions in architecture and engineering by examining the different approaches that have been
taken historically to regulate how daylight enters buildings. These contrast prescriptive and often geometrically described explanatory models that held sway until the 1970s with the abstract building-science models that have been used since. The overarching research question addressed in the second article is what architectural knowledge is needed to assess building science metrics in order for these to contribute to, rather than limit, architectural design, organization, formal expression and creativity?

Through a series of architectural cases, the daylight metric is unfolded in the article, illustrating its basic relation of geometry and daylight. The article also shows the way in which prescriptive regulation previously informed architectural practice on daylight and addresses the issue of how to reinstate this relationship, using the geometrical relations within the traditional architectural methods to assess daylight metrics. Thus, in the second article, I and my co-writer Malin Alenius, architect and light designer at White and fellow PhD student at the School of Architecture at the Royal Institute of Technology, KTH, argue that there is a need for architects to engage with building science metrics from an architectural knowledge point of view in order to realise the potential design freedom offered by performance requirements.

Part II of the thesis’ exegesis, placed after the second article, raises questions regarding the architectural discourse on building performance and environmental control related to building physics. Fundamental concepts in building physics are articulated through building regulation and, with regards to daylight, they affect architecture in a very direct way. However, architectural practice often lacks means of analysis and a repertoire for these concepts to be assimilated into the systems of representation that architects use, and the systems of discourse in which they engage. This suggests a need for an increased architectural history and theory perspective on the correlation between architectural expression and building physics in relation to pervasive contemporary concepts such as building performance, environmental control and comfort standards.

Conclusion + discussion + juxtaposition of the two articles

In the first article and its exegesis, I criticise the established law and the lack of regulatory impact assessment regarding architectural design when the Swedish regulator, Boverket, frames and writes performance requirements for the Swedish Building Code, Boverkets byggregler, or BBR. The analysis shows how the Swedish history of constructing performance requirements has led to an ill-considered, and perhaps unintentional, division between design and the technical characteristics of a building that still exists in building regulation today. I
question the division made in the regulation between two dissociated fields of
analysis, i.e., engineering and architectural design. According to my analysis, the
regulation assumes that so-called “technical” characteristics of construction
work can be regulated without the implications of these characteristics for build-
ing form being recognised or assessed. One could say that as form has beco-
me invisible within the abstraction of building science metrics, the duality of
design, reaching both into organisational and expressional concerns as well as
technical concerns, has been forgotten.

Representational methods constitute more than illustrations of intellectual
principles: they are generative in relation to acts of intellectualisation. This the-
sis relates to two different scholarly discourses – the natural sciences and archi-
tectural history – and therefore to two systems of representational method. The
thesis suggests that bridging this duality is a representational act. A new per-
spective on building science metrics is necessary if architects are to understand
and assess them. The second article therefore argues that this new perspective
must be based in architectural representational methods, rather than in the re-
presentational methods of building science.

When juxtaposing these two sets of conclusions – the observation that the
existing system of regulation needs to address duality in design, and the con-
clusion that assessing this duality is in part a representational act – my research
looks for a historical precedent. The two-sidedness of design has been re-
searched and discussed eloquently within the architectural concept of tectonics,
which was developed at a time of revolutionary change in materials technology
during the nineteenth century and enabled a discussion of the relationships
between material, structure, construction and expression in architecture. Em-
bracing building physics in an architectural discourse could enhance the archi-
tect’s awareness and interest in experienced comfort and the architectural poten-
tial of tectonics regarding building physics, as well as give the architect a direct
relationship to the metrics used in performance requirements in building codes,
thus creating a possibility for architects to draw design conclusions based in an
architectural knowledge tradition. In the concluding juxtaposition of the thesis,
I therefore suggest the need for tectonics to be researched with a focus on the
relation between geometry, material, construction, energy, comfort, daylight and
architectural expression; i.e., with a focus on the relationship between building
physics and architecture. This is intended to strengthen the duality of design in
relation to performance requirements regarding health, comfort and resources
in buildings. There is a need to develop knowledge related to building physics
and building science metrics from an architectural point of view.
The purpose of inquiry

There is an interesting relationship between the societal ambitions of performance-based regulation, its constitution, framing and wording, and the practitioner’s understanding of how to fulfil the requirements of regulation. This correlation is evident in all regulatory forms, but becomes particularly complex in the case of performance-based building regulation. Performance requirements aim to identify how building performance should achieve goals defined as significant by a governing body (Meacham et al. 2005, 92), rather than stating a specific solution to reach that performance. They reverse the logic of prescriptive requirements that present a particular solution that embodies one or several societal expectations (Meacham et al. 2005, 92) and which require designers and builders to reproduce this solution in their work. The historic turn from prescriptive to performance-based regulation in the twentieth century was not only connected to politics and the entry of abstract natural science models quantifying societal goals in legislation, but also to the history of the engineering profession and the architectural profession.

During my eighteen years of practice in an architectural office, I have seen an obvious struggle in project teams between the architects and the consultants in charge of the energy calculations connected to the energy performance requirement. The origins of the conflict have puzzled me; the struggle undoubtedly relates to multiple factors, including the ages of those on the design teams and the nature of their training, but also to how that training prepares them to enter a design conversation in which decisions that affect aesthetics, organisation and form must be discussed in terms of abstract, often math-based formulae, and vice versa. This in turn relates to what kind of knowledge tradition can assess a performance-based building code, especially regarding the two areas of energy and daylight. Thus, this study asks questions regarding what can be found in the different disciplinary and educational traditions for seeking knowledge in relation to the way the building code is formulated and therefore possible to assess.

An initial goal of performance-based regulation was to encourage innovation and to create a space for non-prescriptive design solutions, stating what the building should do, rather than how the building should do it (Foliente 2000, 12-13; Sigge 2017, 181-187). The anticipated result was that this way of organising things would grant the design team a broader field for decision-making. But has this been the case? Are designers more free and solutions more innovative than they were under previous regulation regimes? Based on my eighteen years
of experience in an office I find this question worth asking, if the question itself can be formulated, and the writing as well as the interpretation of performance requirements might be scrutinized in relation to the range of freedom it creates. The same goes for assessments of compliance with the performance requirements.

In this thesis, I attempt to gain entry to this very broad research question by focussing on two typical performance requirements relating to energy and daylight, respectively, to see how this freedom plays out, and to understand the ways in which performance-based regulation interacts with a multidisciplinary design context. The study is carried out using examples drawn from a specific regulatory context, provided by the Swedish Planning and Building Act (PBA) from 2010. The two different areas – energy and daylight – are used to ask questions in slightly different ways. The enquiry into how energy-related performance regulation works is confined to looking at the regulation itself and analysing its internal logic in terms of the control of design. The conclusions drawn are true regardless of the complex culture of interpretation that any building project would put on such a regulatory performance requirement. The second enquiry, into how daylight-related performance regulation works in practice, begins at the other end of the project process and focusses specifically on the context of interpretation and assessment of compliance with the daylight performance requirement. Thus, the conclusions from this second enquiry are strongly related to questions of interpretation and the ways in which various actors in building project processes relate to the specific daylight performance requirement, through the ways of understanding, representing and enquiring into designs’ compliance with code.
Research design and research questions

Before delving into these two cases, the relevant research questions must be pinpointed, the field must be delineated, existing knowledge must be reviewed in a literature overview, and the implications of the choice of methods for the inquiry must be addressed.

Research questions

The research aim of this thesis is to unfold hidden mechanisms within building performance requirements and interpretation of the same in relation to the prerequisites for architectural design and programming, formal expression and creativity as well as a critical stance on architectural knowledge and architectural discourse.

This thesis is divided into two discussions and a juxtaposition. The first discussion relates to the issues raised by a historical and contemporary perspective on performance requirements, and the second discussion relates to the issues of architectural knowledge, building physics and assessments of societal goals expressed through building science metrics. Both of the discussions and the Juxtaposition are accompanied by research questions:

Article 1 and Exegesis Part I

How does the section on energy in the Swedish building code condition building solutions, and what are the consequences of the framing and wording of the building code for energy use and architectural design?

What can the history of performance-based regulation tell us about the current relationship between architecture and technology?

Article 2 and Exegesis Part II

What architectural knowledge is needed to assess building science metrics so that they can contribute to, rather than limit, architectural design, organisation, formal expression and creativity?

Juxtaposition

From where could one generate a discourse that, read from an architectural perspective, could help create a more vital discourse on energy, building physics and architecture?
Scope and limitations

The main interest in this thesis concerns the prerequisites placed on architecture by performance requirements based on building science. While building science is not a clearly defined concept, it will be used in this thesis to define the phenomena through which natural scientific methods are used to find define and develop metrics for the concept of building performance and other building-related aspects. Building physics relates to the material aspects of buildings, studied through a physics that is primarily connected with the exchange of heat, light, air and moisture between a building, its surrounding environment, and its occupants. The relationship between performance-based regulation, architecture and building physics will therefore be at the centre of the thesis through two case studies: in the first, regarding energy transfer; and in the second, daylight availability.

A crucial area that is not addressed in this thesis is the question of how regulation and building design processes relate to solutions for controlling air quality, temperature and humidity, and whether these utilise natural or mechanically-based systems. A second limitation is that this licentiate thesis deals with the questions of design freedom and performance regulation related to new buildings, and not related to the alteration of existing building stock. This lies beyond the scope of a licentiate level thesis.3

Method in articles and discussions

This thesis addresses the Swedish building code in relation to how building science-based performance requirements do or do not steer architecture. Although the focus is on Swedish examples, many of the problems can be considered relevant for performance-based building science metrics in general, and possibly applicable to performance-based building regulations in other countries. Two slightly different kinds of inquiry methods are used in the two articles. In the first article, a performance requirement in the Swedish code creates an analytical case study. In the second article, the case is created by an exhibition room on how building science metrics can be addressed through architectural representation and repertoire. The exhibition room was developed as a part of an exhibition called Bo.Nu.Då: 99 years of Housing questions and Answers at Sweden’s National Center for Architecture and Design, ArkDes, in 2016. The exhibition room was produced under the lead of myself and Malin Alenius, architect and light designer and colleague at White, as a research and development activity.

3 There are also Boverket’s mandatory provisions and general recommendations on the application of European design standards (Eurocodes); BFS 2015:6, EKS 10. For more information see: https://www.boverket.se/en/start/building-in-sweden/swedish-market/laws-and-regulations/national-regulations/construction-standards/ This will not be addressed in this licentiate thesis.
within White arkitekter. We later wrote the second article together for which the exhibition room creates an action research case of sorts.

In the first article, the European Directive common to all European member states is used as a comparative measure of how Sweden has interpreted the framework for energy performance in buildings (EU 2010, 2018) in relation to the other Nordic countries. The method is to provide a close reading of the code’s wording, contextualised with a historical archive-based study that explains the provenance of its assumptions.

In the exegesis, the analysis in the article is complemented with material from a semi-structured interview series conducted in Germany in 2016. I use a comparative study of Swedish, Danish and German building code wording to suggest the degree to which different national formulations of these requirements steer architectural freedom of solutions.

A system of semi-structured interviews was used to gather information about the German context. The series was conducted as a qualitative research interview following Kvale and Brinkmann (2015). The interviews were conducted with a selection of consultants, architects, and university- and industry representatives in Wuppertal, Stuttgart and Berlin. The duration of the interviews was generally one to two hours, after which they were transcribed. Only the parts of this material that relate to the national construction of performance requirements on energy are used in the exegesis. The prepared questionnaire for the interviews relating to what is addressed in this thesis can be found in Appendix II.

The second article reviews an exhibition of five cases illustrating daylight aspects. These cases were chosen to exemplify the actions taken by architects and developers under various kinds of regulative regimes between the 1920s and today. When writing the article, we revisited the exhibition cases selected in 2016 and analysed the assessment methods and the representational methods chosen to disseminate the daylight performance metric to a broader audience of architects, members of other disciplines, and the exhibition audience in general. In the article, we relate this way of approach to the daylight performance metric as an example of how architectural methods can be used to unfold building science metrics in a way that is more intelligible for architects. Malin Alenius developed the pedagogical illustrations in which the daylight factor point is indicated by a line on the plan between areas of compliance and non-compliance. In the article, the cases are compared to a numerical analysis and its representational tradition. The numerical analysis with which these results are compared was carried out and reported on by the architect, daylight researcher and asso-
ciate professor Marie-Claude Dubois and the PhD candidate Iason Bournas at the Division of Energy and Building Design, Lund University. The selection of typical architectural cases for both the exhibition and the numerical analysis was carried out by the authors of the article, in collaboration with architects and planners at their architectural firm at the time.

In the Juxtaposition that concludes the thesis, the situation that architects face today is compared to a similar situation 200 years ago. At present, regulatory systems convey political goals in performance requirements expressed through building science, which is disconnected from the architect’s traditional representational methods. In the early 1800s, new materials were introduced in a building tradition dominated by masonry, and architects were faced with a transition from geometrical and empirical construction to calculations based on material properties of the new materials carried out through engineering. This architectural history and theory section of the exegesis uses an interpretation of primary and secondary sources.

Summary of the existing context: Lines of research

In order to trace a kind of field on which the discussions in the two articles can be mapped, I have divided this review as follows. The first section deals with the literature on regulation per se, while the second section deals with the societal ambitions in relation to energy resources during the twentieth and the twenty-first century thus far. The third section deals with the broader question of how architects have conceived the relationship between building physics and architectural design. The lines of research therefore come from different research traditions or knowledge interest domains. The lines of research in building regulation reviewed are those specifically concerned with legislation and building codes dealing with deregulation and performance, whether they are based in architectural history, social sciences, or engineering sciences. Knowledge interests regarding the interrelationship between societal ambitions concerning energy, requirements in building regulation and standards, and architectural results are found predominantly in architectural history, as are the interest in building physics and architecture and contributions from an interdisciplinary focus.

Building regulation research

In 1982, the International Council for Research and Innovation in Building and Construction (CIB) defined a performance-based approach as the practice of
thinking and working in terms of ends rather than means. It is concerned with what a building or building product is required to do, rather than prescribing how it should do it (Foliente 2000, 13; Meacham et al. 2005, 92). The drivers for developing the concept of performance-based regulation were considered to be its usefulness for promoting innovation (through freedom of solutions and products), its support for cost-optimizing construction, and the facilitation of international trade whilst still safeguarding the safety, health and general welfare of building inhabitants (Foliente 2000, 12-21). Greg Foliente, a scientific researcher and the coordinator for the CIB Proactive Program on Performance Based Building in 2000, described how prescriptive building codes may hinder trading of building products over national borders. In his article Developments in Performance-Based Building Codes and Standards, he argues that in its First Triennial Review of the Operations and Implementations of the Agreement on Technical Barriers to Trade in 1997, the World Trade Organization (WTO) addressed the relevance of using performance-based code in order to enhance trade between nations:

> Wherever appropriate, Members shall specify technical regulations based on product requirements in terms of performance rather than design or descriptive characteristics. (cl. 2.8 of the Agreement on Technical Barriers to Trade, quoted by Foliente 2000, 13).

As Foliente points out, the member economies have therefore committed themselves, knowingly or not, to the use of performance requirements for evaluating a product’s fitness for purpose (2000, 13). He also posits that an internationalization of performance-based standards is needed to facilitate trade. These standards supplement regulation and are often used in building codes in relation to the technical aspects of performance requirements (Foliente 2000, 16-17). During the twentieth century, standardisation bodies recommended performance requirements in building codes to encourage industrial progress. The first such publications were from the U.S. National Bureau of Standards in 1925 (Foliente 2000, 13).

Standards and their role in governance have also been addressed by Winton Higgins, a researcher in politics and ethics, and Kristina Tamm Hallström, a researcher in economy and organisation. The international standard body, ISO, is a non-governmental volunteer organisation that develops and publishes formal, written standards (Higgins and Tamm Hallström, 2007). ISO was inaugurated in

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4 CIB was established in 1953 with the support of the United Nations as an association to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on the institutes engaged in technical fields of research. Today it has 500 organisations involved in 50 CIB Commissions, and has broadened the scope to include among other things architecture and urban planning (CIB 2019).
1945 on the United Nations Standards Coordinating Committee’s third and final meeting, which included Sweden and 24 other countries. In 1970, the organization shifted from issuing recommendations to issuing international standards under the lead of its secretary general, Olle Sturén from Sweden. With this shift, ISO and its national standard bodies became major producers of the standards and attendant services that regulate international business (Higgins and Tamm Hallström, 2007). Higgins and Tamm Hallström (2007) note the intimacy between national governments and national standard bodies, where in most instances governments participated in the establishment of the national standard bodies and were well represented on boards and in committees. Higgins and Tamm Hallström (2007) also describe how, as international standards spread into new fields such as quality management and quality control, they created a relationship to governments in which the latter were increasingly dependent on standards, and as they refer to the standards, they ceased to be voluntary and instead became mandatory. Higgins and Tamm Hallström (2007) review the historical emergence of standard bodies as bearers of political rationality and its ‘action at a distance’, presenting a governance in modern society that includes both ‘public’ and ‘private’ bodies.

Brian Meacham, practitioner and researcher in fire safety, researcher in building regulatory systems and former chair of the IRCC has in several articles illustrated the development of performance-based regulatory systems and the work done in an organisation for regulatory bodies called the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC). IRCC was founded in 1997 as a forum for countries that have implemented performance-based regulation (Meacham 2010 b). It grew from 6 members to twelve in 2016 (Meacham 2016, 477). In 1976-1978, the Nordic countries agreed on a building regulatory hierarchy establishing performance-based principles that set a base further developed by the IRCC (Meacham et al. 2005, 94-95). In performance-based building regulation, the State determines a functional or performance requirement that should not steer the solution, but that should be open to several possible solutions. Performance-based regulation is intended to reflect societal goals:

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5 The initial members were from organisations in Australia (secretariat), Canada, Japan, New Zealand, United Kingdom and USA (IRCC 1998). At present, the following organisations are members: Australian Building Codes Board ABCB; Austrian Institute of Construction Engineering OIB; Institute for Research in Construction, National Research Council NRC, Canada; Chinese Academy of Building Research CABR; Ministry of Land, Infrastructure and Transport MLIT, Japan; National Institute for Land and Infrastructure Management NILIM, Japan; Netherlands Organisation for Applied Scientific Research TNO, Netherlands; Department of Building and Housing DBH, New Zealand; Norwegian Building Authority NBA; Building and Control Authority BCA, Singapore; Singapore Civil Defence Force SCDF; Scottish Government Directorate for the Built Environment DBE; Ministry of Housing MOH, Spain; Swedish National Board of Housing, Building and Planning (Boverket), and the International Code Council ICC, USA. More information about the IRCC focus can be found at http://www.ircc.info/joinus.html
A hallmark of performance-based building regulation is the explicit statement of goals and objectives that reflect societal expectations and desires, along with functional statements, operative requirements and in some cases performance criteria, which are to be used for demonstrating that goals and objectives have been met (Meacham et al. 2005, page 92).

The expectations of, or drivers for, the introduction of performance-based regulation can be framed in other ways. Meacham outlined them as “the desire to reduce regulatory burden, to reduce cost (to government, the market and consumers), to facilitate innovation in building materials and systems, to expand the application of analytical and computational tools and methods (driven in part by leaps in computer technology and computational modelling capability), and ultimately to facilitate better performing buildings – both new and existing” (Meacham 2010, 687). Meacham also points out three concurrent activities within building regulatory systems recent years:

- a relatively rapid transition to performance-based regulations, new policy objectives in the area of sustainability, some of which appear to be difficult to harmonize with traditional health and safety objectives, and a desire to address, but lack of clarity as to how; climate change impacts on buildings (Meacham 2016, 475).

Meacham states that the main motivation for the transition to performance-based regulation has been an understanding that increasing innovation and flexibility in design better positions society to address rapid change while still maintaining adequate safety and performance levels. In recent years, this regulatory accommodation to societal policy objectives has become more complex as the area of sustainability has created new challenges in relation to existing areas of regulation, such as fire safety. A particular example of this concerns climate-related change (2016, 474-477). The political agenda concerning environmental legislation that started in the 1970s has come to the fore with contemporary climate change concerns and become more intimately connected to building regulation in recent years, resulting in new pressures on building regulation from new actors both inside and outside the government (Meacham 2016, 476). Meacham writes that while stakeholders’ engagement in health and safety issues in building regulation has been quite unified, the new stakeholders that have emerged around sustainability objectives are fragmented, and their collaboration is not effective (Meacham 2016, 476).

Discussing the 25 years of transition, Meacham points out that there have been significant system failures; one of the many factors mentioned is the lack
of knowledge-transfer between regulatory regimes, i.e., prescriptive and performance-based regimes (Meacham 2016, 475). He recently conducted a survey with the 12 regulatory agencies involved in the IRCC, including Sweden, regarding challenges of the performance-based regulatory regime – both in general and regarding sustainability and resilience (2016). His general conclusions are similar to those of Foliente in 2000. He indicated three areas in need of improvement:

- mechanisms are needed to define and quantify better levels of tolerable building performance, be they in terms of health, safety, welfare, risk, sustainability or other measures;
- quantified performance metrics must be developed and incorporated into regulations, along with metrics and verification; and prescriptive metrics can sometimes still be relevant to use;
- tools and methods for enforcing performance-based regulation are still lacking. The grounds for making informed decisions of compliance are still a challenge (Meacham 2016, 477).

Another perspective on the relationship between legislation and architecture is given through social sciences, where researchers Rob Imre and Emma Street address the role of legislation in relation to architectural design and practice (Imre and Street 2011). They have argued that performance-based regulation generates sub-constructs such as standards, insurance policies and risk assessments as the responsibility shifts from state-prescription to the stakeholder’s assessment of compliance and places “the onus on architects to self-assess compliance” (Imre and Street 2011). Imre and Street have identified a dichotomy between the perception of legislation among scholars and the realities of practice in the architectural field. In the first, legislation is seen as something outside of the design process, whilst in the second, it is viewed as integral to it. The dichotomy leads to two ways of perceiving regulation: as either inhibiting creative design actions and outcomes (4), or as generative, by facilitating as well as constraining actions (23). Based on their findings, Imre and Street argue that building regulations are far more integral to the work of architects than has previously been acknowledged in research and writings. Emma Street also argues that the way in which performance-based building regulation is expressed creates a market for specialist consultants and for outsourcing responsibility from the architect to others. Street sees a risk that the whole system of governance that accompanies performance-based regulation, assessment, and compliance undermines the role
of the architect as an actor in charge of a holistic solution meeting societal objectives (Street 2018).

Katie Lloyd Thomas, professor in architectural theory and history at Newcastle University, uses historical studies of architectural specifications to show a transition from process-based clauses towards performance specifications (2012). The balance between these has shifted as manufacturing and contractual contexts have changed. The dominance of performance-based specifications today reflects enormous changes in manufacturing and testing, where “open” specifications allow the contractor to select economic solutions and make the architect less liable in litigation. Thomas uses the term “open” for performance specifications and “closed” for other specifically descriptive specifications (Thomas 2012, 233). As Thomas shows, there are links between industrial, economic and legislative contexts, and these new concepts of specification are constitutive for the architectural design that ensues. Thomas concludes:

We would do well not to relegate them [the new specification concepts] to the realm of the technical, but to take them seriously, to examine them for their social and architectural effects and to ask how we might mobilise the possibilities they offer beyond the normative prescriptions of standard specification practice (Thomas 2012, 236).

This background of specification development has also been studied in the Swedish context. In a recent PhD dissertation in architectural history at KTH, Erik Sigge showed how during the 1960s in Sweden, the industry and the State sought to “industrialize building production, standardize building systems and products, and the norming building types, materials and plans” (Sigge 2017, 71). These activities were driven by the ambition to make building construction a more efficient and cost-effective venture (Sigge 2017, 71). The quest was initiated through a governmental investigation called the Investigation of Building Economy (Byggnadsbesparingsutredningen), which aimed at cost-cutting measures to save money in the public building sector. The Investigation for Building Economy had pointed at the assessments of needs (behovsbedömning) as a fundamental activity for procurement (Sigge 2017, 65-66). This was implemented by the Swedish National Board of Public Buildings (Kungliga Byggnadsstyrelsen, abbreviated KBS), the main government institution for building, planning, and preservation in charge of issuing building codes until 1967 (Sigge 2017, 65-71), in the transformation to more open requirements in building regulation (Sigge 2017, 78-83, 181-184).
KBS also conducted research and development work on building types and technical aspects such as lighting, heating, ventilation and architectural programming (Sigge 2017, 76-77). The features of KBS’ work shifted from assessing “the quality of making” to assessing “the performance of function” (Sigge 2017, 42). Performance aligned with a “new” understanding of function as “character requirements” (egenskapskrav) and “functional analytic requirements” (funktionsanalytiska krav), the equivalent of performance requirements and performance specifications (Sigge 2017, 43). As Sigge suggests, the work at KBS should be understood as a systematic search for rule-based design methods and systems, reflecting a general shift from what architecture is to what architecture does, and scientifically and technologically, to what the building can do in relation to its users (Sigge, 2017, 18).

Compared to the earlier practice of writing specifications that described the form and material of an object, the performance specification explains “what a designed object should do” (Sigge 2017, 43).

Along with the transition to the practise of thinking in terms of means to ends, this shift has permeated procurement, specification, standards and building regulation. Today it is implicit in the complex landscape of governance in which architects find themselves. In line with Thomas, Imre and Street, Sigge illustrates how building code requirements are intertwined with architectural prerequisites.

Building regulation research regarding energy and its architectural implications

In the early twentieth century, access to energy produced from burning fossil fuels was seen as a potentially liberating factor for architecture. Architectural research scholars have examined the changes to this in a series of articles throughout the last century (March 2017; Oldfield et al. 2009). These articles show the lasting effects of the interrelations between legislation and trends in construction, technology, architecture and knowledge as presented in standards and regulations. There is a consensus in these historical analyses that there was a fundamental change in how energy was viewed after the oil crises of the 1970s and once again after the late 1990s – the second time in relation to a broader environmental consciousness (March 2017; Oldfield et al. 2009).

Philip Oldfield, Dario Trabucco, and Anthony Wood, respectively from the architectural faculties in Nottingham, UK; Venice, Italy, and Chicago, USA, ex-
amined the interaction of architectural technology with energy performance by looking at shape and form, façade, natural lighting and ventilation strategies and material properties in historical case studies on tall buildings in America. The historical analysis leads to a categorization of tall buildings from 1885 to the present into five chronological “generations” based on their energy consumption characteristics: the first energy generation, from the birth of tall buildings in 1885 to the 1916 Zoning Law; the second energy generation, from the 1916 Zoning Law to the development of the glazed curtain wall in the early 1950s; the third energy generation, from the development of the glazed curtain wall to the 1973 energy crisis; the fourth energy generation, from the energy crisis of 1973 to the present, and the fifth energy generation, from the rise of environmental consciousness after 1997 to today. All of them created different prerequisites for architecture. In the work of Oldfield, Trabucco and Wood, architectural form and detailing are presented in the context of extensive data on building physics properties, illustrations and pictures. The research shows how a societal view of energy consumption at different times is embedded in the use and appearance of architectural technology. The trio’s work is significant in that it reveals interrelations between novel technologies, building code regulations, standards, and architectural design, and the effect of these interrelations on the characteristics of indoor climate and energy consumption. As trends have changed, there have been lasting effects on the architecture of the high-rise (Oldfield et al. 2009).

The subjects of these studies were in the main commercial spaces, e.g. office buildings and the like. In a similar study, Rob Marsh, a researcher at the Danish Building Research Institute at the time, examined the relation between architecture, cultural and regulative paradigms in new housing in three Nordic countries, this time for the period 1975-2020. Denmark, Sweden and Norway share cultural, regulative and architectural traditions, and like Oldfield et al., Marsh defines various paradigms that characterise this period. Through the use of historical, empirical and theoretical studies, Marsh observes a historic transition from prescriptive energy conservation building code regulation in the 70s, through regulation based on winter-oriented space heating energy modelling, towards environmental performance-based regulation in 2000. He relates each time period’s knowledge-related limitations to consequences for energy use and architectural end-result. Marsh uses headlines to present the three time-periods: 1975-1985 (the energy crisis and the fabric heat loss paradigm); 1985-2005 (passive solar architecture and the space heating paradigm); 2005-2020 (broader approaches and the environmental paradigm). He concludes that broader
performance-based approaches can give greater design freedom for choosing appropriate solutions that benefit spatial quality, improve indoor comfort and reduce environmental impact. Marsh shows how regulation leads to low daylight levels in the first paradigm, to overheating in the next paradigm, and can give both a greater design freedom and a better energy balance in the last paradigm. Marsh concludes that there is a need for a critical stance on the possible existence of regulative straitjackets through energy and environmental paradigms (2017).

Two decades ago, architecture researcher Susanna Hagan presented the concept ‘sustainable’ as the new ‘ethical’ in architecture, suggesting how the conventional constituent parts of architecture – which she listed as the tectonic, the topographical, the symbolic and the social – might be shaped by environmental goals (1998). Hagan divides environmental concerns into two parts, one concerned with energy use during operation of the building, and the other concerned with the energy embodied within the materials of which the building consists. Hagan points out that the relation to embodied energy is driven by a common notion in architectural practice that the material dimension of architecture, together with architecture as a whole, is not being valued (Hagan 1998). At a time when architecture began to be assessed environmentally and new types of audits were being introduced, Hagan compared the quantitative assessment of emissions from energy use to architecture discourses in history on tectonics and truth, from Viollet-le-Duc, to Ruskin, to the modernist architectural rhetoric. For Hagan, “…the new ‘truth to materials’ is not ‘telling the truth’ about them, as in ‘what you see is what you get’, but weighing up the effect of their production on the well-being of the community.” (Hagan 1998, 111).

In 2014, Anne Beim, a professor of architecture and head of the Centre for Industrialized Architecture (CINARK) at the Royal Danish Academy of Fine Arts, identified how international political agendas concerning the reduction of greenhouse gas emissions have primarily focused on energy in operation by improving insulation standards and airtight constructions and thus abolished proper empirical construction solutions and building technologies. She also criticised the energy discourse that does not suggest a comprehensive ecological perspective that addresses the heterogenous character of environmental challenges (Beim 2014, 21). Research dating from the same year, 2014, carried out by the Australian researcher in building science Stephen Berry and his research colleagues Kathryn Davidson and Wasim Saman from the University of South Australia, concluded that a broader perspective on greenhouse gas emissions’ life cycle through life cycle analysis methods (LCA) incorporating materials was
still too immature to be used in legally contestable performance-based regulations with reliable verification methods. When the time came, they stated, this would be the most appropriate way to address net zero boundary issues. A shift from the concern for operational energy of the building to include embodied energy in materials in building research has since become more visible. The Research Centre on Zero Emissions Building (ZEB) at the Norwegian University of Science and Technology, NTNU, led by the architect and professor emeritus of Building Technology Anne Grete Hestnes, has presented research and pilot projects addressing emissions from the life cycle of the building, including materials in construction, alterations and, if necessary, demolition (Hestnes and Eik-Nes, 2017). A number of important lessons have been learned from the centre, where the most novel question concerns the embodied energy and embodied emissions in materials and construction and saving existing structures and reusing materials to lower emissions (Hestnes and Eik-Nes, 2017). A researcher from the centre, Anne Gunnarshaug Lien, lists the common features among the pilot projects for zero emissions in new buildings as: compact building volumes; careful design of fenestration in relation to energy conservation and energy in operation and with regard to embodied energy; the use of wood when possible, and ventilation and cooling systems integrated in building designs to meet comfort demands with low material resource use. Another researcher at the centre, Barbara Szybinska Matusiak, also emphasizes the need for a conscious focus on daylight very early in the process, as some typical features of ZEB are restrictive in terms of daylight, limiting for example the total area of glazing and advocating thick walls and roofs and low transmittance of glazing (Matusiak, 2017).

In summary, these researchers point at the intimate relationship between architectural design, energy use, and climate impact, as well as the development towards an interest in how resources are used in architecture. At the same time, intricate and sometimes adverse relations become apparent between daylighting for wellbeing and an energy focus, as well as between a focus on operational energy and a focus on climate emission. This shows a historical movement from narrow energy focus towards an ambition to grasp architecture and its environmental and resource implications – and vice versa – more holistically.
Research on the relationship between building physics and architecture

Architecture, climate, building physics, indoor climate control and the view on comfort are closely intertwined; at the same time, this is an underrepresented area in architecture history research. In 1969, Reyner Banham – who was trained in mechanical engineering and art history and considered one of the most influential writers in architecture between the 1950s and the late 1980s – pointed at the absence of service technology as a topic in architectural research and attempted to summarise the historical relationship between mechanical services, building physics, climate, comfort and architectural design through case studies in *The Architecture of the Well-tempered Environment* (Banham [1969] 1984). In the second edition he noted:

> a vast range of historical topics extremely relevant to the development of architecture is neither taught nor mentioned in many schools of architecture and departments of architectural history. Some are external to the building (patronage, legislation, professional organisation), others are internal (changes in use, changes in users’ expectations, changes in the methods of servicing the user’s needs) (Banham [1969] 1984, 14).

Nigel Whiteley, who wrote an intellectual biography on Banham and interpreted his position on architecture and environment, among other things, wrote that the two tasks that Banham undertook when tracing the historical development of key mechanical services in buildings and assessing the implication of those services and their architectural values was innovative (2002, 193). While *The Architecture of the Well-tempered Environment* may have been radical in seeking to expand the field of architecture, Banham was still operating within concepts of “modern architecture” (Whiteley, 2002, 200). An example that shows both sides of this tendency is Banham’s celebration of Frank Lloyd Wright, who “by any standards, must be accounted the first master of the architecture of the well-tempered environment.” (Whiteley 2002, 198). Banham praises Wright for his ability to create equally radical improvements in “the art of environment” with simple and already established technologies, but also celebrates the “spectacularly novel” technology of the Larkin Building (Banham [1969] 1984, 92). Banham praises Wright’s writing, which directly relates mechanical equipment, plan and section to aesthetic pleasure (Banham [1969] 1984, 105). Banham used both positive and negative case studies to show the importance of building design and services to comfort with building physics analysis of cases in relation
to the climate in which they are positioned (Banham [1969] 1984). Banham outlines two basic methods of environmental management in *The Architecture of the Well-tempered Environment*. One is the heavyweight, slow-responding massive construction solution, and the other the lightweight, highly responsive, mechanically-managed solution ([1969] 1984, 19); he associates the former with European architectural traditions and the latter with the American developments of the twentieth century (Whiteley 2002, 200-201).

In texts such as “A Home is not a House”, Banham develops the thoughts of the “unhouse” based on “the American way to spend money on services and upkeep rather than on permanent structure as do the peasant cultures of the Old World” (Whiteley 2002, 204, 208). Architecture “as ‘built enclosure’ or ‘rigid volume’ was being superseded by the ‘formlessness’ of ‘environmental management’ as a manifestation of “‘the technological art of creating habitable environments’ in order to produce ‘fit environments for human activities’” (Whiteley 2002, 207). In an article called “The Science Side” in *Architectural Review* in March 1960, Banham argued that:

> The Science Side” […] ”could sweep away architecture as we know it now and leave in its place, precisely, that other architecture produced by the team-work of specialists in colour, heating, lighting, acoustics, market-research, group psychology – an architecture comparable to other aspects of creative technology – such as aircraft design or television – that are neither encumbered nor ennobled by a great tradition such as architects carry with them everywhere they go. (Whiteley 2002, 160)

Reviewing Banham’s contribution to the study of the technologies of environment, Nigel Whiteley writes that the idea that architecture would be transformed and radicalized by embracing new thinking from adjacent disciplines appealed to Banham (2002, 160). In another article, he stated that the architect must either become a member of an integrated team or receive a comprehensive, scientific education (Whiteley 2002, 160-161). This echoed both Buckminster Fuller’s belief that the architect’s education should include the natural sciences (physics, maths, chemistry, psychology and economy) and Hannes Meyer’s prediction from 1928 that the architect’s role would shift from that of an artist to that of a specialist in an organization as buildings became industrial products (Whiteley 2002, 159-162). Banham’s views were shared by Cedric Price, who famously created facilities responsive to “whatever the user was going to do next” (Whiteley 2002, 212). Price and Banham shared the view of the role of the architect as an enabler rather than a form giver (Whiteley 2002, 211-217).

In *The Architecture of the Well-tempered Environment*, Banham expressed criti-
icism of Le Corbusier’s quest for a uniform environment, a comfort or “respiration exacte” that maintains a temperature of 18 degrees centigrade at all times (Whiteley 2002, 206). He was more attracted to buildings that interacted with the user, offering a varied space or responsive solutions (Whiteley 2002, 200-210).

In 1979, the architect and researcher of energy performance and daylighting Lisa Heschong published the book *Thermal Delight in Architecture*, which included analyses of architectural history from the perspective of thermal experience and its relation to the cultural associations in the built environment. It is a critique of the disconnection of mechanical methods to control thermal environments from the human senses. Heschong shows how ‘thermal delight’ related to variation: in air velocity, in temperature, in relation to traditional fires, baths, and saunas. She contrasted this beneficial variation with the comfort standards of the building technology of the period, which aimed at completely normalised thermal environments. Her take on comfort suggested humans’ sensitivity to thermal experience, where the body sensed changes in the thermal surroundings as pleasurable, and where delight related to variation, rather than to a consistently maintained standard temperature range (1979).

Dean Hawkes is a British architect and researcher, active within environmental science and theory from 1965 at Cambridge University, who was later RIBA-awarded for his significant contribution to architectural education. In his books on architecture, environment and climate, published in 2008 and 2012, he uses an architectural historical case study method to connect the description of architecture, humans, and senses. Starting with Sir John Soane (1753-1837) as an example of an architect whose practice was deeply informed by an understanding of the effects of daylight, Hawkes traced an arc showing how architects had been inspired by an awareness of climate throughout the nineteenth and twentieth centuries (Hawkes [2008] 2014). Suggesting a binary opposition between approaches he defined as “humanistic” and based in “architectural science”, Hawkes questioned the reading of buildings as representing a “logical” response to a pre-existing climate and suggested that the relationship between architecture and climate is as much a question of history and culture as a question of technology. Buildings respond to, but also in some respects represent and interpret, the ideas about climate of the people who shape them. Using examples from a variety of periods between 1600-2000, he connects an architectural analysis of buildings with contemporary accounts on climate and weather, as well as accounts of the use of the building (Hawkes 2012). Hawkes is critical of the dominant role of building science in the framing of contemporary systems.
There is” […] ” a critical dimension of the experience of architecture that this approach fails to represent. The interaction of light and air and sound with the form and materiality of architectural space is of the very essence of the architectural imagination. The complex sensory experience that we enjoy in buildings implies a wholly different dimension to the idea of the architectural environment from the pragmatic and mechanical processes of climate modification and comfort engineering (Hawkes [2008] 2014, xvi).

Hawkes emphasizes how architects have imagined “the elements of space, form, material, and the mechanical systems for heating, ventilation and lighting”. He calls these elements and systems the technics of architectural environment and suggests that they can be used by the architects for poetic ends. He challenges historians and theoreticians to develop a parallel to that of the architectural historian Kenneth Frampton and his poetics of construction regarding the poetics of environment, criticising Banham for what he calls an instrumental approach. Hawkes lists studies after Banham that have begun to fill in the gaps between the developments within architecture and environmental technology (Hawkes [2008] 2014, 4).

When Hawkes mentions the discourse of applied sciences, he also points at Torben Dahl and his colleagues at the Royal Danish Academy of Fine Arts School of Architecture, who published the book Climate and Architecture in 2010. Here, the relationship between different climates around the world, human comfort experiences, building physics principles and architectural history is systematically presented through specific case studies. The editors aim was to provide an overview of climate as one of the primary generators in giving form to architecture at its most fundamental level (Dahl 2010).

As mentioned in the beginning of this section, case studies in architecture that include an understanding of theories of comfort and the technical analysis of building physics are few and far between, especially compared to the vast number of handbooks or research articles which explore building physics and building science through maths and abstract descriptions. One example on daylight from a building science perspective directed at architects is the work done by Peter Tregenza and Michael Wilson (2011). An example that lies between handbook and architectural reflection is Norbert Lechner’s book Heating, Lighting and Cooling, which combines pedagogic sections on solar and daylight natural science with principle drawings and sections, as well as historical descriptions of daylight (2014). Perhaps not surprisingly, architects also write more frequently
about daylight, both from an architectural history and an environmental science perspective related to studies of perception as for example Michelle Corrodi and Klas Spechtenhauser in 2008. The focus on the relation between building design, service design, comfort and senses has developed from an overtly technologist view to a critique of an exaggerated emphasis on building design formed by building science comfort standards. At the same time, local climate has come to the fore in relation to architectural design for researchers such as Hawkes and Dahl.

The above authors and themes form an essential background for the analyses that follow, from the charting of the development of performance-based regulation, to the discussion of the historical and present relationships between views on energy and emissions in relation to architecture, to the schism between humanistic and technical concerns in building cultures. In the end of the exegesis, the historical analysis of the final juxtaposition and its discussion of tectonics reconnects to the lines of research, but also presents yet another line of research within architectural history and philosophy.
Lundgren, Marja S. 2016. "Energy and architectural consequences of Swedish building code", *Smart and Sustainable Built Environment* 5, no. 2: 125 - 142

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The first article can be discussed through four themes: firstly, contextualised within the history of performance-based building regulation and within the current legislative hierarchy for regulating buildings; secondly, in relation to other comparable cases and in terms of the kinds of critique that this suggests; thirdly, in light of the alterations in the recent recast of the EU Energy Performance Building Directive (EU 2018) to determine whether the findings in the article still bear examination; and fourthly, to discuss the inherent challenges in performance-based building regulation and what actions can be taken to address them. In relation to the first of the four themes, a complementary research question is *What can the history of performance-based regulation tell us about the current relationship between architecture and technology?*

**Performance-based building regulation from the 1970s till today**

As early as 1964, the Nordic Committee for Building Regulation (*Nordiska kommittén för byggnadsbestämmelser*, NKB) stated that “the building code requirements should as far as possible be expressed as functional requirements”.¹ How to formulate functional requirements had not only been a discussion for the NKB, but also for the Nordic building engineering organisations (Knocke 1970, preface). Three years later, the ambition to shift from prescriptive regulation to performance-based regulation was codified for the first time in Sweden. In the introduction to the Swedish Building Code, *Svensk Byggnorm 1967* (SBN 67), the authorities’ ambition was explicit:

> An attempt has been made to give the regulations the form of functional requirements, connected to general and objective test or calculation methods, and to co-ordinate all rules in the field of building design and construction. (SNB 1967, English version page 519).

In 1976, the Nordic “five-tier system” for defining a hierarchy in building regulation was established. This was fundamental to the development of a performance-based approach, both in Scandinavia and in other countries (Foliente 2000, 17; Meacham et al. 2005, 94-95; Meacham 2016, 475-476). The first and uppermost tier expresses explicit and overarching objectives, stated in parliamentary acts in Sweden. The second tier expresses the so-called functional statements for a building or for building parts, in Sweden stated in the Acts, Ordinances, and in introductory paragraphs to the performance requirements in the building code (*Boverkets byggregler – föreskrifter och allmänna råd*, BBR). On the

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¹ The term functional requirement used by Jens Knocke in the 1970s is interchangeable with performance requirements used in this thesis.
third tier, the operative performance requirement is expressed in terms of performance criteria or expanded performance description, stated in the Swedish building code BBR. In the model by NKB, these three tiers of binding provisions are supported by two lower tiers of non-binding guidance.

NKB hierarchy of binding and non-binding tiers (Meacham et al. 2005), illustrated after the Swedish model.

When performance requirements were introduced into the Swedish building code in SBN 67, a basic system for drawing up building regulations based on the performance concept was still lacking. The National Board of Urban planning commissioned Jens Knocke to research how to write performance requirements, who duly filed a report on “A building standard expressing performance requirements – draft” in 1970. Knocke presented a performance analysis (funktionsanalytisk byggnorm) based on three concepts. These were user requirements, such as for example thermal comfort; contingencies, such as the conditions under which a performance requirement had to operate, and a system of verification. The two first concepts constitute the performance analysis to which the verification system is subordinate. For Knocke, the performance analysis, which created the basis for a performance-based building code, could only deal with technical design (that was, the choice of materials and the structural design), technical problems and technical solutions (1970, 15):

Non-technical matters, on the other hand, are not dealt with (finance, allocation of space, architectural design).” (Knocke 1970, 1, English summary). Knocke suggests that a comprehensive qualitative list of user requirements based on the existing or pending building code could be “developed by physiologists, psychologists and sociologists, possibly complemented with a consulting engineer” (1970, 51). This list was to be developed in a second phase into

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2 Original title in Swedish: "En funktionsanalytisk byggnorm – förslag till principer". An alternative translation could be “A building norm based on functional analysis – a proposal of principles".
quantitatively expressed user requirements (Knocke, 1970, 51). If the user requirements and the contingencies were quantified in a performance requirement, the system of verification could be defined. Knocke presents three ways of verifying performance requirements: a natural science verification system; a technological verification system, and empirical verification by testing (Knocke 1970, 30-32). The natural science verification system is bound by known physical laws; this can be verification by calculations, such as predictions of room temperatures or lighting levels. The technological verification system makes use of empirical knowledge from existing building techniques in combination with calculations, for example, verifying the structural properties of a brick pillar, which combines hand-craftsmanship and the physics of various materials. The empirical verification system, finally, would be carried out through full-scale testing of prototypes or in testing scaled models, to measure things such as sound reverberation or material strength (Knocke 1970, 30).

Distinguishing between the three concepts in the building norm was paramount for Knocke. He argued that it was necessary from a democratic perspective, as well as to ensure that the building code would allow innovation through new building solutions (Knocke 1970, 11-12, 50). A parallel separation of building parts and construction, material properties and testing methods had already been carried out within standardisation in close connection to research and building code developments (Sigge 2017, 78-87).

As mentioned in the literature review of this thesis, the international standards supplement regulation to facilitate trade. Accordingly, in 1989 the European Union issued a directive on construction products with the objective of minimising barriers for trade (EU 1989). This delineated essential requirements on buildings and construction works for which these products must be suitable:

the essential requirements constitute both the general and specific criteria with which construction works must comply (EU 1989, 185).
These essential requirements were later implemented in a Swedish act complementary to the Planning and Building Act, called the Act of Technical Characteristics of Construction Works, ATCCW (Sveriges Riksdag 1994). Before an act is issued by parliament, the government presents a proposition stating the purpose of the act. In the proposition for the ATCCW, a differentiation was made between locally related requirements, covered in the Planning and Building Act, and general (and thus not locally variable) requirements, derived from the European Directive on construction products (CPD) and covered in the ATCCW (prop. 1993, 93-95).4

The first type of requirements – the local – regulates the placement and volume of the building and controls aspects of building design relating to form, colour and materiality. These require professional and local political judgement to be made at the local level and in relation to the local conditions. The second type of requirements, CPD-derived general requirements, were to regulate safety, health and the use of energy and water. These were placed along with national requirements on functional suitability and accessibility in the ATCCW. According to the proposition, these can be objectively assessed (prop. 1993, 93-95). Boverket was designated to detail these general requirements, and since 1994 Boverket has issued operative performance requirements in the building regulations (BBR).6

Thus, the proposition of 1993 distinguished between requirement types in terms of how and where they could be assessed. This in turn led to a ‘divorce’ in subsequent pieces of legislation and guidance that defined the responsibilities of the assessors and the requirements for compliance that these assessors would set. Yet both the local requirements, where compliance is assessed through the judgement of individual design proposals, and the general requirements, called “technical characteristics” in the ATCCW (Sveriges Riksdag 1994), affect architectural design. Regardless of whether they are seen as “technical” and quantitatively measured using a general system, or “cultural” and measured on a case-to-case basis, these requirements form prerequisites for designing and constructing individual buildings. Thus, although they may be divorced in terms of the systems of measurement involved in ensuring compliance, they are interrelated. Within the context of architectural design, demands made within one

4 A third category of requirements was also mentioned in this differentiation and related to alterations that need to be weighed in relation to the prerequisites of an existing building. Some national requirements were also incorporated in ATCCW together with requirements listed in the CPD.

5 The Planning and Building Act states that the Building Committee must include at least one person with architecture training for assistance, and otherwise have access to staff to the extent and with the particular skills needed for the committee to carry out its tasks adequately (Sveriges Riksdag, 2010, chap. 12, sec. 7).

6 In Sweden, the acts are issued by the parliament, defining the objectives of societal concerns. This can be further detailed by the government in an ordinance. In the ordinance, the government also designates the authority that is to write the building code.
set of requirements affect decisions made in relation to the other. There is an overlap between the architectural design consequences of a general requirement and the local requirements relating to form and architectural expression.

This condition creates problems that are seldom addressed when one reads about performance-based regulation. Questions regarding quantification and verification, as illustrated in this section and the literature review, have been crucial for the development of performance requirements since the 1970s (Knocke 1970; Foliente 2000; Meacham 2016, 477). However, that discussion has focussed almost entirely on how to make such systems effective within their own terms of reference, and hardly addressed the tensions created by the need to mesh systems of regulation based on case-by-case judgements with systems based on generalised performance criteria. In 2002, the Swedish government gave Boverket the assignment to develop verifiable performance requirements in line with the European harmonisation and Swedish national environmental goals, that lead to good quality in construction (Regeringen, Miljödepartementet 2002). In response, Boverket produced a report about how to formulate performance requirements in the BBR (2004). In Sweden as elsewhere, the drive to introduce performance requirements was a desire to generate innovation and competition in the building industry (prop. 1985, 95, 99-100). It is therefore interesting that Boverket’s report stated that a performance requirement expressed in the BBR should also explicitly address design (utformning):

Performance requirements: demands on characteristics of a building, construction work or part thereof or a product for a certain use expressed in terms, more focused on the end result than on the way to reach an end result, that does not limit the choices of design, material or method. A performance demand can be verifiable or not verifiable. (Boverket, 2004, 42).

The verification methods of the performance requirement listed in the report were calculation, judgement, and comparison with proven solutions. These methods were primarily exemplified in relation to engineering or building science knowledge, although one example of a verification method addressed requirements through judgement, with the example of a scenario test of usability and flexibility in a dwelling plan (Boverket 2004, 50).

In conclusion, one can say that the main difference between the principles drawn up by Knocke in the 1970s and those developed by Boverket in 2004 was that Boverket addressed the issue of design in general. Knocke limited the performance requirement model to technical analysis of materials and structural
design, which he specifically differentiated from architectural design. The idea introduced by Knocke in the 1970s that performance requirements are technical and do not account for artistic expression reflected a divide between building science and architectural design. From the above analysis of the subsequent history of how regulation was legislated, it is clear that Knocke’s report and introduction of performance-based thinking into the construction product directive during the 1980s increased that divide. The recurrent ambition to quantify performance requirements and the thought of objective control of compliance for the requirements in the TCCW suggests an unresolved relation between quantifiable metrics and non-quantifiable judgements. In general, performance-based regulation aims to promote innovation and design freedom in technical areas, but rarely does it explicitly set out to create architectural design freedom. Reconnecting to the definition by Boverket, one can discuss performance requirements in relation to both technological and architectural design freedom. In the following texts, the current Swedish building regulation will serve as an illustrative example.

**Contemporary Swedish building regulation: Act, ordinance and BBR**

The general requirements on buildings and construction works in the ATC-CW from 1994 were inserted in the new Planning and Building Act in 2010, PBA (Sveriges Riksdag 2010) under the heading “Technical characteristics of construction works” (chap. 8, sec. 4). The 2010 PBA also incorporated the requirements on buildings from the previous legislation (Sveriges Riksdag 1987). In the chapter on buildings in PBA 2010, the provisions on new designs or construction works are divided into two categories of requirements, namely those relating to the design of construction works and those relating to the technical characteristics of construction works (chap. 8, sec. 1 and 4). In this separation, the shadow of previous divisions between “technical and general” and “local and subjective” assessment criteria is visible.

The organisation of the requirements on buildings in PBA 2010 relates to the process of planning and constructing projects, from comprehensive and detailed planning requirements, (detaljplan) described in the second chapter, to the issue of a building permit to a developer (bygglov; equivalent to Detailed Planning Permission in the UK, which covers the use, detailed appearance and material articulation of the particular project proposed for the site), to commencement of works (startbesked; Building Regulations Approval in the UK) and
finishing clearance (*slutbesked*, Building Regulations Construction Sign Off in the UK) in the eighth chapter. The provisions on *design of construction works* seek to control the following at the stage of issuing the *bygglov* or building permit:

- suitability for the building’s purpose
- form, shape, external colour and materiality\(^7\) and,
- accessibility and usability for individuals with limited mobility or orientation capacity (chap. 8, sec. 1-3).

The provisions on *the technical characteristics of construction works* regulate the following at the stage of commencement of works and finishing clearance:

- structural safety
- fire safety
- protection with regard to hygiene, health and the environment
- personal safety
- protection against noise
- energy management and heat retention
- suitability for the intended purpose\(^8\)
- accessibility and usability for individuals with reduced mobility or sense of direction (orientation)\(^8\)
- economical management of water and waste (chap. 8, sec. 4).\(^9\)

In this system, all of the ATCCW requirements are presented under the heading

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\(^7\) My translation of the Swedish word *materialverkan* in PBA to materiality differs from that of Boverket (2018b). The word material is used by Boverket.

\(^8\) As is apparent here, this organisation in PBA of 2011 has led to a duplication of requirements. The requirements on suitability and accessibility and usability (noted with an\(^*\)) that come from the ATCCW are mentioned twice and controlled twice. According to Boverket’s web-education, these identical requirements are differentiated in scale in (Boverket 2019 b).

\(^9\) There is yet another requirement on broadband access, but as it has no consequence for BBR.
Technical Characteristics, and they are detailed in the building regulations, BBR. The BBR do not address the requirement that the building must demonstrate a good effect of form, shape, external colour and materiality related to its site; this requirement is instead a part of the planning process decisions.

One can ask why a dichotomy between design and technical characteristics is introduced in PBA; the answer appears to be part historical and part operative. On one side, it is a consequence of incorporating the ATCCW into PBA in 2010. It can be added that the history of division goes further back. As seen already, the habit of separating design from technical parameters is already a trope in Knocke’s early work on developing performance-based regulation criteria in the 1970s. At the same time, PBA 2010 aims to steer the control process of assessment via the very organisation of the requirements in the act. Arranging these requirements – firstly so that the design characteristics are to be assessed when granting the building permit, and secondly so that the technical characteristics are to be assessed at the commencement of the work – also says something about how a requirement is thought to impact design. As can be deduced, technical characteristics are not to impact the building scale or the design features assessed in granting the building permit, i.e., issues such as form, shape and materiality. Whether this could become a real risk depends on if the requirements are formulated with such a mindset or not.

The two performance requirements studied in the article, i.e., energy performance and daylight performance, are addressed in BBR following the technical characteristics of construction works in chapter 8 of PBA 2010. Thus, continuing the logic of the previous paragraph, it is assumed that all energy and daylight issues will not impact the form or individual design of a building, and they are to be controlled at the end of the design process before starting and finishing clearance (Sveriges Riksdag 2010, chap. 8, sec. 1-3, 4). The findings in the article show on the other hand that the energy requirements are not neutral in relation to form and façade, neither in terms of overall morphology nor in terms of building exterior. This results, I suggest, in a sub-optimal culture with regard to designing buildings with architectural ambition with nearly zero-energy performance in the Swedish context. Without claiming that the organisation of the Building Act exclusively creates this tension, it is possible to say that the

10 With the exception of the two characteristics that are marked with an asterisk, all of these are from the construction product directive, the essential characteristics for construction works that products need to fulfill, listed in the EU Product Directive (CPD) from 1989. With the recast in 2011 to the directive, the construction product regulation (CPR) adds another essential characteristic regarding sustainable resource use (EU 2011). This has not been added to the PBA (Sveriges Riksdag, 2011).

11 The performance requirement on energy is directly stated in the PBA as energy management and heat retention; it is detailed by the Swedish Government in the Planning- and Building Ordinance (PBO) and there is a section for it in the BBR. Daylight is addressed by Boverket in the BBR as an interpretation of the overarching requirement on Hygiene, Health and Environment in the Act. Thus, the two performance requirements appear in slightly different places in the code.
The legislative role of the Planning and Building Ordinance

The Planning and Building Act (currently PBA 2010) identifies the requirements placed on buildings. In the Planning and Building Ordinance (PBO) from 2011, these requirements are further detailed by the government, such as for example when introducing national requirements and definitions to comply with the EU Energy Performance Building Directive. Thus, in the PBO, Boverket is designated by the government to write the mandatory provisions for these identified and defined building requirements, which then form the basis for the BBR regulations (Boverket 2018). Building regulatory framework in Sweden still uses the NKB five-tier hierarchy, with the three uppermost mandatory tiers articulated in the national acts, ordinances and mandatory provisions of the Swedish building code, BBR. The two non-binding, lowest tiers consist of general recommendations for verification methods and accepted solutions (Stadsrådsberedningen 1998, 172). These are only detailed in the BBR. The performance requirements are stated through mandatory provisions accompanied by the general recommendations in the BBR. The developer (byggherre) is responsible for fulfilling the Act, Ordinance and BBR requirements (Sveriges Riksdag 2010, chap. 10). If the developer asks the design team to meet the mandatory provision with a solution that deviates from the general recommendation, it must be established that this solution meets the general recommendations in terms of complying with the purpose of the provision. Boverket is explicitly required to develop verifiable...
performance requirements and to follow up on and analyse the use of these (Sveriges Riksdag 2012, sec. 3, cl.10). In the following, the energy performance requirement – formulated as a quantitative mandatory provision – and the daylight requirement – quantified first in the general provision – will be further discussed, both individually and in relation to one another.

The Swedish Building Code: Context

This section of the discussion expands on the article’s findings in comparison with how other countries have implemented the EU Energy Performance Directive (EPBD). A concept for nearly zero-energy buildings was introduced in the recast for EPBD in 2010. The aim was to mitigate climate change and to change the course of energy use (EU 2010). The directive is implemented in each European member state in the national building regulation. The comparison will be of the Swedish implementation of EPBD and the corresponding implementation in Germany and Denmark. A new concept of nearly zero-energy buildings is introduced in the directive:

‘nearly zero-energy building’ means a building that has a very high energy performance [...] The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby (EU 2010, Article 2, 18).

The framework for expressing the very high energy performance requirement is detailed in an annex to the EPBD 2010; this was altered to some extent in the revision done in 2018 (EU 2010, Annex I, 29; EU 2018, 90). This EU energy performance framework determines what will be included in the national requirement, as well as the methodology to be used for assessing the requirement. The performance requirement, its assessment and its premises are thus what outlines nearly zero-energy buildings.12

The main take-aways from the above article can be summarised very briefly. It shows how so-called technical characteristics impact architectural design, exemplified by the design rationale given by the energy performance requirement in the BBR compared with the design rationale given in the daylight performance requirement in the BBR, and it suggests that there are cases in which the regulation’s overall aim is thwarted by this impact. The overall energy performance requirement impacts choices about building volumes, plan layout and envelope through the designated energy balance boundaries, i.e., what energy

12 In Sweden, the EPBD is implemented in the technical characteristics of construction works in the PBA (Sveriges Riksdag 2010, chap. 8) and PBO (Sveriges Riksdag 2011, chap. 3) and as energy performance requirements in the code, BBR, section 9.
Because the requirements do not relate to user lighting, windows are the envelope’s Achilles heel, contributing with solar gains (generally undesired in office buildings) and causing energy loss; i.e. a windowless building will be estimated to use the least amount of energy. Based on these boundaries, the most energy-efficient building system tends to be a completely artificially-lit building.
use in the building is included in the fixed target limit of the requirement. Consider the illustration to the right. The left-hand column shows that the perimeter of an office plan will be assessed in relation to energy transfer (losses and gains) through the building envelope (ground, façade, roof). The area enclosed by this perimeter will also be assessed in relation to the real estate’s energy use for ventilation and other installations, except the lighting. The assessed areas of built-in or fixed lighting are those for stairwells and technical equipment areas, shown in light beige. The second column shows the areas where the workplace is assessed with regards to the daylight requirement, illustrated by the dark beige areas. These areas also have built-in or fixed lighting, but the latter is not included in the energy performance of the BBR. This exclusion is most probably because the use of real estate energy and the use of tenant energy have traditionally been kept separate: the energy use in the dark beige areas is defined as user-related electricity and is paid for by the tenant, and is thus not the responsibility of the building owner. Although the amount of energy used in the building to facilitate a thermal indoor climate and the amount of energy used by the tenant to facilitate visual indoor climate are related, and although both add up to the energy use of the building operation, the BBR separates the two and includes only one in the assessment that conditions the form of the building. Surplus heat gains from the lighting are however included in the energy performance balance boundaries. The article’s findings show that the design of the form, plan, and façades will be steered by the energy performance requirement in a direction that competes with the form-related aspects needed to comply with the daylight performance requirement.

As the requirement does not include electric lighting or natural light, the windows are the ‘Achilles heel’ of the envelope, contributing with solar gains (mostly undesired in office buildings) and causing energy losses. With this design rationale, a building with no windows may result in the lowest energy rating.

Thus, the findings in the article indicated that the formulation of the overall energy performance requirement in the BBR impacts design in an architecturally undesirable way. The BBR creates competing sets of performance requirements, steers building organization towards compact volumes, optimizing surface-to-volume design to reduce heat-transmission-losses, and encourages buildings with lower levels of daylight and higher electric lighting needs, which in turn can result in higher primary energy use.

An obvious question emerges: is this an inevitable consequence of implementing the EPBD? To examine that, the design rationale created by the
Swedish BBR can be compared to that created by other building codes among member states of the EU who have incorporated the EPBD requirements into their building regulations. While this aspect is discussed in the article, it can be complemented by a comparison between the Swedish BBR and the Danish and the German codes as they were in 2016. The differences in implementation philosophy are best observed by the overall energy performance requirements in the codes. A summary of this comparison follows.

The Swedish regulatory model steers architectural design on a morphological scale, relating to design choices regarding building volume and envelope, but also façade design.

The German regulatory model uses a reference building, meaning that the architectural design is carried out first, in relation to the program of the office, school, or other use, and the energy efficiency is then optimised on the level of building components and installation systems. The German requirement includes lighting for both the user and real estate holder. This model has a design rationale with no form-related consequences, although it is notable that the system is still extremely sensitive to detailed wording and its relation to standard references.

The Danish regulatory model for non-residential buildings has an overall performance requirement, as the Swedish BBR does, but deals with all aspects of form related to energy simultaneously, including all forms of lighting, creating a
balance of formal aspects from an energy perspective.

Several countries, including Sweden, Denmark and Germany, introduce additional requirements to the overall energy performance requirements in their code. In the Swedish BBR, this additional requirement is set out, again, in terms of building morphology. A mean overall value for the designed heat-transmission losses from the envelope is calculated by adding up the losses through opaque (walls, roofs etc.) and transparent (window glass) parts of the construction and dividing this figure by the indoor areas. This is a general requirement applied regardless of a building’s size or form. One can say that this requirement steers design towards low overall heat-transmission losses by steering the surface-to-volume ratio and the window-to-wall ratios towards a fixed limit. In this regulatory system, glass can only be seen as a less effective façade material (as it loses more heat than opaque insulation), and no allowance can be made for offsetting solar gains. Side effects of this requirement include that compliance is harder to achieve for tall buildings, with more façade surfaces than roof and basement surfaces than for single-story buildings. Again, deeper buildings are favoured by the additional requirement, as was the case with the overall performance requirement. Daylight is neglected in this additional requirement.

The Swedish code (BBR) differs from the Danish and German codes with regard to how it articulates the additional requirement. The Danish code has two separate additional requirements: one for the opaque parts of the envelope, and one for the transparent parts. Only the opaque parts are summarised in a mean calculated value of heat-transmission losses (mean u-value). For the transparent parts, there is a specific requirement that addresses heat-transmission-losses and solar gains. Thus, in the Danish code, glass is considered not
only in relation to its heat-transmission, but also in relation to its benefits, acknowledging that transparent façades impact energy use in a different way than opaque facades. This degree of nuance is even greater in the German model, where requirements are made on a building element level. The Swedish additional requirement, illustrated on the far end of the line, has high implications for morphological and façade design choices; the German additional requirement, on the other end of the line, has low implications for design choices carried out in relation to these two things.

The German model can be compared to the Swedish model as it existed for Knocke in the early formations regarding performance-based regulation in the 1970s. In general, additional requirements closely resemble Knocke’s subsidiary requirements, as they are not pure performance requirements, but address user performance by isolating a quantifiable aspect whose optimisation can ensure the fulfilment of the user performance requirements under given prerequisites (contingencies). Knocke gives the example of calculated heat-transmission losses (u-values) of the construction as a subsidiary requirement for the user performance requirement of thermal comfort. In the case of thermal comfort, the description of performance requirements from the 1970s – when Knocke argued for the technical functional analysis – was made up of subsidiary requirements at the level of building elements. When such requirements are defined for build-

The follow-up technical requirements (building envelope)

**SWEDISH MODEL**
A maximum requirement for the design transmission heat losses of the overall envelope (opaque and transparent parts) steers towards a low overall u-value, regulating the amount of window-to-wall ratios towards a fixed limit.

**DANISH MODEL**
A maximum requirement for the design transmission heat losses of the envelope only for the opaque parts. Specific requirements for the transparent parts.

**GERMAN MODEL**
The façade design is influenced by the program regarding window-to-wall ratios and amount of facade or building envelope surfaces.

Thermal properties are regulated by each building component and as a leverage to reach an improved overall energy value.
ing elements, they provide a broad set of potential criteria that can be balanced against each other by the designers within a single composite construction. In this case, as in the German model, the requirements themselves do not steer the overall design in any particular direction. But when the additional performance requirement is defined in terms of envelope and volume regardless of scale, as in the Swedish BBR, it is no longer neutral in relation to morphology. The Swedish energy performance requirements – both the overall requirement and the additional requirement – create effects on a larger scale than the building element level. Furthermore, as the requirement operates directly on the building envelope and building volume, it limits the design conditions of volume, form, plan and façade, especially as the energy performance levels are tightened to reach nearly zero-energy.

**Theoretical implications**

In the BBR, both the overall performance requirement, with its energy balance boundaries, and the additional energy requirement for designed heat transmission losses have consequences for volume, envelope and façade design. This condition can be contextualised in relation to Foliente’s study of performance-based building regulations. Foliente claims that there is a difference between lower-level and higher-level specification in terms of performance; according to Foliente, a lower-level is more prescriptive and constraining, whilst a higher level is more open to many combinations of design choices. He also argues that although it is more open for design choices, the higher-level performance specification increases the difficulty of developing appropriate methods for verification (Foliente 2000, 14-15). My analysis in this thesis challenges Foliente’s conclusions. The case of the overall energy performance requirement, as formulated in Sweden, can restrict design choices when using a high-level – that is to say a very abstract – performance specification, if the requirement is improperly designed. I argue that the constraints for architecture have yet to receive sufficient research or attention in regulatory impact assessments.

**Implications for practice**

The Swedish case suggests that the following needs to be taken into account when formulating performance-based building regulations:
• what architectural design aspects are included in and excluded from the performance requirements,

• what limits a requirement can be given without constraining architectural freedom, and,

• where do specific performance requirements conflict, both with other requirements within the same tier of regulation (various sections of BBR, for example) and between tiers of regulation (for example between those of the BBR and those of the PBA) that identify local design requirements.

In terms of formulating a new performance-based system in the light of these concerns, performance requirements applied to building parts (as in Germany 2016) will restrict design less than setting the performance requirements on an envelope level (as in the Swedish additional requirement) or on a volume level (as in the Swedish overall performance requirement).

The literature review and the historical review both suggest that performance-based building regulations are generally biased towards quantification. A conundrum when creating a situation where abstract objectives and performances can be met through solutions freely chosen in building projects is the question of how to assess performance. An assessment or verification process is needed to enable the real-estate holder to demonstrate, and for the local building authority to approve, that a performance solution fulfils the performance requirements.

The objectives of societal concern in the first and second tiers of the NKB hierarchy are concretised in the mandatory provisions and in the BBR’s general recommendations (Boverket 2004, 39-54, 90-98). Some of these mandatory provisions are formulated as performance requirements based on quantified metrics, whereas others are more open for interpretation; thus, there is a risk that some first and second tier objectives will be valued over others. Since there is no hierarchy between different objectives in the PBA, the PBO, or in the mandatory provisions in the BBR, there is a risk that the energy management section will override the health section. The implementation of the EU performance directive in Sweden illustrates challenges in performance-based regulation and where it can go wrong, especially when it comes to architectural design, if it is not addressed with care.

The analysis in the article was made possible because the national regula-
tions interpret a common European norm for thinking about building nearly zero-energy buildings, which makes it significantly easier to identify the junctures at which, and the ways in which, the national formulation of regulations reflects a national regulatory culture rather than maximizing energy economy or minimizing climate effects per se. In a sense, the European regulatory system provides an X-ray image of sorts, against which the peculiarities of individual national bodies of regulation can be measured. The energy management section in the code conditions how Swedish designers will produce buildings “fitted” to the Swedish weather and climate. The comparative Nordic and German examples of building code reveal that the framing and writing of the code is steered by cultural factors rather than given by an EU directive design rationale.

Recent studies have also illustrated that the solutions for nearly zero-energy buildings tend to be highly standardized in Sweden; this too has implications for practice. Even for offices, the standard appears to be a “thermos” type of building, with solar shading to minimize the impact of variations in sun load (or solar gains), a highly compact form, a tightly sealed skin, a deep plan, mechanical ventilation, and often, bore-hole heating and cooling. Again, a comparison with countries with similar climates such as Denmark and Norway shows other solutions for nearly zero-energy or zero-emission buildings. In both of these countries, there are projects that challenge the compact energy paradigm and where there is a clear emphasis on design solutions that focus on the systematic exploitation of daylight, as well as the use of hybrids between mechanical and natural ventilation systems, to name but two factors which receive scant attention in Swedish examples.

I argue that the way that the way in which the 2010 PBA differentiates between design and technical characteristics is problematic. PBA has introduced a dichotomy that is invidious, in that it creates a series of problems and conflicts in the collaborative practice necessary for producing good buildings. I argue that the division is unnecessary and that it in practice often leads to a situation in which the architectural consequences of what are called “technical characteristics” are underestimated when Boverket formulates the requirements in the BBR.

The article in the light of the 2018 recast of the EPBD

In 2016, Sweden was required to change its method for assessing energy performance in line with an EU directive; the government-issued changes to the
requirement in the Planning- and Building Ordinance (PBO) took effect from April 2017 (Sveriges Riksdag 2016). A revised definition of energy performance was introduced and now also included *lighting in the normal use of a building* which:

equals the amount of energy supplied for heating, cooling, ventilation, hot water and lighting in the normal use of a building, excluding such energy from the sun, wind, land, air or water generated in the building or on its site; and primary energy: energy that has not undergone any transformation (Sveriges Riksdag 2011 [2016:1249], chap. 1, sec. 3a).

**Sound characteristics regarding electricity management** were also included:

1. a very high energy performance (nearly zero-energy) expressed in primary energy, calculated with a primary energy factor per energy carrier;

2. especially sound characteristics regarding electricity management, and;

3. a building shall be equipped with building elements consisting of one or several layers that isolates the interior of a building from the outside world so that only a small amount of heat can pass through (Sveriges Riksdag 2011 [2016:1249], chap. 3, sec. 14).

Boverket also had to supplement the assessment method for the energy performance requirements. The existing assessment method consisted of measuring the building energy usage two years after completion. Boverket now had to present a method for calculating the energy performance in compliance with Annex 1 in the EPBD 2010. Therefore, in 2017, Boverket issued a new constitution of mandatory provisions on how to calculate the energy performance, entitled *Boverket’s mandatory provisions and general recommendations on determining a building energy use during operation*, abbreviated BEN, (Boverket 2016). No changes were made to the BBR energy balance boundaries with regards to the changes in PBO. BEN thus follows the energy balance boundaries of the BBR, and as these have not changed since the article was published in 2016, the critique of them in the article remains valid.

The EPBD required a shift from energy per kilowatt hour to energy factors per energy carrier (EU 2010, 29). This change was implemented in Sweden in 2017 and is under review and revision in 2019. The critique of the BBR in the article regarding primary energy also related to the fact that office lighting and its primary energy were ignored in the energy balance boundaries of the BBR. This has remained unchanged.
In 2018, the Energy Performance Building Directive was revised in the EU, and it is now more explicit than previously with regard to the role of lighting in the calculation of energy performance:

The energy performance of a building shall be determined on the basis of calculated or actual energy use and shall reflect typical energy use for space heating, space cooling, domestic hot water, ventilation, built-in lighting [mainly in the non-residential sector] and other technical building systems. (EU 2018, 90 to compare with Thesis article I, page 129 or EU 2010, 29).

Furthermore, the revised version of EPBD from 2018 expresses the relation between the calculation of energy use and health aspects in the indoor environment:

The energy needs for space heating, space cooling, domestic hot water, ventilation, lighting and other technical building systems shall be calculated in order to optimise health, indoor air quality and comfort levels defined by Member States at national or regional level. (EU 2018, 90).

Regarding daylight and calculation, the EPBD’s earlier statement that the:

The positive influence of the following aspects shall, where relevant in the calculation, be taken into account: … (d) natural lighting (EU 2010, 29).

has been strengthened:

The positive influence of the following aspects shall be taken into account: (d) natural lighting. (EU 2018, 90).

Another addition of interest is that:

The methodology applied for the determination of the energy performance of a building shall be transparent and open to innovation. (EU 2018, 90).

Thus, the recast EPBD 2018 reinforces the basis for my criticism of the existing regulatory regime in my article from 2016: that daylighting cannot be ignored in the regulation of energy performance. The same goes for the article’s proposal of a new comprehensive energy section to take into account all architectural design-related energy aspects. This proposal introduces the use of climate-based daylight modelling, addressing both diffuse light and sunlight, in order to assess the natural light as a consequence of the design of envelope, volume, floor plan
and elevation. This also aligns with the recast of EPBD in 2018 (EU 2018), where natural light shall be taken into account.

**Concluding discussion Article I**

The performance requirements in the BBR will steer design, and the choice of parameters included in the performance requirements will relate to geometry on the scales of both the building, its elements, and details. The Swedish regulatory interpretation of nearly zero-energy buildings introduces a focus on some parts of the building design whilst ignoring others, although all of these parts impact energy use in operation. It becomes evident that the nearly zero-energy model with a deep-plan and a highly sealed, daylight-insensitive solution favoured by the culture of office building production in Sweden is to an extent prefigured in the regulatory framework for energy in the building code. Both the article and the further detailed analysis also indicate a lacking impact assessment by Boverket regarding the formal consequences given by the energy performance requirements for nearly zero-energy buildings. The relationship between form, daylight and energy has not been addressed in regulatory impact assessments in the Swedish regulatory context.

Another challenge in performance-based regulatory systems is that the objectives of societal concern expressed in the first tier of the NKB hierarchy (in PBA 2010 in Sweden) are addressed in individual performance sections in the third tier of the hierarchy (incorporated into the BBR in Sweden). This action creates the inherent risk that the regulatory system itself will create competing objectives. In the independent review carried out in the UK under the lead of Dame Judith Hackitt, competing objectives in the establishment of performance-based regulations were identified as problematic, and the recommendation was to substitute this with a systemic approach:

A package of regulations and guidance that is simpler to navigate but that genuinely reflects the level of complexity of the building work [is recommended]. This new approach will reinforce the concept of delivering building safety as a system rather than by considering a series of competing or isolated objectives (Hackitt 2018, 13).

The current suite of guidance does not take a systems approach to building work, instead setting out a series of separate objectives to be achieved. This makes it difficult to take a holistic view of building work that prioritises safety as well as other important objectives and considers the best way in which these objectives can be achieved (Hackitt 2018, 50).
The Swedish case presented in the first article shows the competing relationship between the energy performance requirement and the daylight requirement. The analysis indicates that the origins of this competition within the code lie in the choice of energy balance boundaries for the energy performance requirements. These boundaries omit the electricity need for lighting for the user, and thus neglect the energy-saving potential of natural light. Energy performance is therefore not aligned with the requirement regarding daylight availability. The inconsistency between these sections in the code creates difficulties in fulfilling both requirements in real projects. When it comes to energy, the content is steered by the EU to some extent; however, the article and the further comparison with other codes have shown that this would not necessarily be an obstacle to balancing energy and daylight.

The performance requirement of energy and daylight would align better if the new comprehensive energy section suggested in the article was incorporated into the BBR. However, as the origin of societal concern is different, competition can still exist between different objectives, and these sections will not fully align.

Boverket has set the targets in the BBR regarding energy and daylight as being equal for all buildings irrespective of shape or location, i.e., one storey or more, detached or in dense urban environments, etc. In the situation that this creates, the daylight performance requirement and the energy performance requirement must both be fulfilled, regardless of the planning prerequisites. A difficulty that is explored more thoroughly in the second article of this thesis is that the competing objectives between energy and daylight become more and more pronounced as building projects encounter dense urban situations. Urban density planned in at an earlier stage of the detaljplan for a new area, or that results from siting a new building as an addition in an existing environment, might itself work against the daylight availability on a morphological level. If the project is to comply with the daylight requirements, a dense urban context will demand more glazing in the lower parts of a building than it would in a non-dense situation. This creates even greater difficulties in relation to compliance with the energy performance requirement as it is formulated. Furthermore, the objectives of different sections may not align fully in the situation it presents. In the Swedish Planning and Building Act from 2010, all requirements for new buildings and construction works are equally binding (chap. 8). This gives the base for equally binding performance requirements in the Building Code, BBR.

Another challenge comes from the inherent risk of performance-based regulation overvaluing quantifiable end results. Meacham and Foliente’s research
indicates an increasing ambition to create quantified descriptions or metrics for performance requirements. The first Swedish Code in 1967 already attempted to connect requirements to general and objective tests and calculation methods. Quantification is the easiest way to reach an objective result of compliance, and less interpretation is required of the authority controlling the project. With their mandatory provisions and general recommendations, the requirements in the BBR are extensive; a control of every performance requirement would thus be too labour-intensive, and the building regulations do not demand such a meticulous control by the authority (Sveriges Riksdag 2010, chap. 10). Nonetheless, an appraisal of the documentation of the assessment and verification of compliance must be carried out. If some requirements are easier to assess than others, there is a risk that these will be assessed whilst others will not. The relation between the energy performance requirement and the daylight performance requirement is an illustrative example of this.

Between 1994 and 2014, the daylight performance requirement in the BBR was expressed only as a qualitative parameter; there was no quantitative metric provided against which it could be evaluated. One may assume that this affected how the authorities verified compliance with this requirement. It is fair to say that it coincided with a period during which daylight in planning, detailed planning and building design was not assessed by the municipality. At the same time, the energy performance requirements were heightened, and the quantitative result of compliance was measured two years after construction. After 2010, the compliance with the BBR was connected to obtaining a finishing clearance that assured the building developer the right to use the building; this was regulated by PBA (chap. 10). It was not until after 2014, when the daylight requirement was supplemented with a quantitative general recommendation, that these factors – energy and daylight – came to be assessed in a more equal manner. In the second article, an example of non-compliance of daylight in the year 2010 illustrates how the energy performance requirement, which was assessed – rather than the daylight performance requirement, which was not assessed – steered the sizes of the windows at that time.

The Planning and Building Act from 2010 includes a number of requirements that are based on professional discretion, concerning, for example, the suitability of the building design with regard to:

1. the townscape and landscape, natural and cultural values on the site, and in the interest of ensuring a favourable overall impression (chap. 2, sec. 6, cl. 1);

2. demonstrating a good effect of design, colour and material (chap. 8, sec. 1, cl. 1).
Systemically, a tool is needed to align such requirements with the process of assuring compliance with quantitatively-stated BBR requirements. When performance-based building regulation introduces hard quantitative limits, there is a risk that architecture is steered or undermined by building science metrics that are quantifiable in the planning process.

I propose that Boverket should address this risk in the formulation of performance requirements. Swedish authorities are required to carry out regulatory impact assessments before issuing mandatory provisions or general recommendations. These requirements are described in general terms in an ordinance for regulatory impact assessments (RIP). As a conclusion to this section, some proposals can be made about such regulatory impact assessment (RIP). The following could be taken into account to minimise the risk of steering architecture and creating a conflict between performance-based BBR requirements and judgement-based PBA requirements:

- the first requirement would be to address the formal consequences of the framing and wording in the BBR: to determine where regulation steers design (utformning), and to understand where it ignores other requirements in the PBA, such as the spatial and local requirements on placement and volume of the building or building design relating to form, colour and materiality with consideration to the surroundings;
- the second requirement would be to cross-check performance requirements in the BBR. Although performance requirements are assessed with greater ease if they are quantitative and individual, the logic of performance-based regulation indicates the need to formulate the requirements in a synthetic and holistic manner in order to address competing objectives in the BBR;
- the third requirement would be to establish genuine conflicts between objectives where they will not fully align. If these conflicts arise due to different prerequisites in locality, such as differences in density, this could either be detailed in the code (different requirements for different environments such as one-storey dwellings and dense urban areas) or left to be resolved through a hierarchy determined by Boverket that can inform the planning process (in the given example, I suggest that daylight takes precedence over energy).

In summary, while a performance-based building regulation system might appear to be free of judgement when calculated and presented numerically, the system boundaries of such a calculation involve many design decisions. The

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definition presented by Boverket in 2004, where performance requirements should be stated in a way that does not limit choices in design (utformning), material, or methods is vital, as the BBR will be assessed individually within a planning and building process for each project, alongside local and programmatic concerns. The proposed requirements given above for a regulatory impact assessment (RIP) of BBR requirements addresses the unfortunate dichotomy between design and technical characteristics that is visible and organisationally implemented in PBA 2010. Until now, the so-called technical characteristics of construction work have been formulated without Boverket acknowledging their crucial impact on building volume, form, program, façade and other architectural design features. I argue that the separation of different objectives of societal concern into sections and individual performances has obscured the relationship between abstract building science and architectural expression.
ARTICLE II
Malin Alenius and Marja Lundgren
”Architectural repertoire and daylight metrics”

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DISCUSSION II
The historic turn from prescriptive to performance-based building regulations during the second half of the twentieth century is not only connected to politics, but also to the history of the engineering profession, the architectural profession, and the entry of abstract building science models quantifying societal goals in building code. The fundamentals of performance requirements are to be found to a great extent in research of building science rather than research of architectural technology. This is a contrast to the historical situation prior to the 1960s, which was governed by prescriptive requirements in which the knowledge incorporated was often derived from several knowledge fields at once, e.g. architecture, engineering, craft and construction.

The discussion of the first article illustrated the underlying ideas surrounding the construction and formulation of performance requirements, the close correlation between a performance-based regulatory system and quantification, and the wish for objective assessment methods. It also showed how formulations in Boverkets byggregler (BBR) create a situation in which various performance requirements compete and in doing so create undesired tensions and conflicts within design processes, as well as sub-optimal results. Yet another level of competing requirements in different tiers in the NKB hierarchy was raised in the discussion; namely that between the general building requirements in the BBR and the building requirements with spatial and local considerations in the Planning and Building Act (PBA). This first discussion presented potential courses of action in order to avoid creating competing objectives and in order to promote architectural design freedom.

In the second article, the daylight requirement in the BBR is examined from the perspective of assessing a quantitative performance requirement. The analysis in the following discussion relates to two systems of assessment: one embedded in building science, and the other embedded in architectural practice. The discussion consists of two parts, illustrating a problem and a potential course of action. Firstly, it exemplifies the problem by looking at a particular example in a particular building culture, and secondly, it understands the problem by analysing how architectural and building science systems of representation differ, where they might overlap, and addressing the need for architects to find their own methods to master assessments of relevant performance requirements.

The guiding question for the following section of the exegesis is What architectural knowledge is needed to assess building science metrics such that they can contribute to, rather than limit, architectural design, organisation, formal expression and creativity?

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1 Jens Knocke notes that performance analyses (funktionsanalyser) were also carried out in Sweden and by CIB around dispositions of programme in plans in relation to activities (1970, 7).
Sweden as an example of a general problem

In the second article, five architectural cases chosen from between 1917 to 2016 are analysed in relation to the contemporary performance requirement for daylight availability in Sweden. These cases originate from an exhibition where the correlations between daylight, architectural composition and historical changes from prescriptive to performance-based regulation were illustrated. This local example represents a situation that emerges in many countries in relation to codes, standards and voluntary certification systems. In building science, daylight is described as comprising two components: direct sunlight and diffuse skylight (Boyce 2003, 28). Over the past twenty years, in performance-based regulations or in standards in countries including the UK, Denmark, Norway and Sweden, daylight availability has been assessed through a metric called the daylight factor. A daylight factor metric only accounts for diffuse skylight and its reflected skylight, equivalent to an overcast day. The metric that is generally used to assess daylight has thus neither been related to geography nor to orientation.

A description of the metric used in the BBR will follow in order to illustrate what this metric does. The daylight factor is typically calculated in points over the surface of a room, 800 mm over the floor, and then presented as an average value, a median value, or – less frequently – in the value for a given point, as is the case in the Swedish performance requirement in the BBR. This requirement is set through a mandatory provision and a general recommendation in the BBR and must be fulfilled for all rooms that are used more than occasionally. This daylight factor method was based on research funded by the Swedish State and first introduced into the building code in 1972 (Löfberg 1987, 3). Its predecessors were the British standards based on research done at the Building Research Station in England and further introduced in building science by the researchers Ralph Galbraith Hopkinson, Peter Petherbridge and James Longmore (Hopkinson et al. 1966, preface; Löfberg 1987, 18). In the general recommendation, Boverket refers to the daylight provision standard as the Swedish method (Boverket 2018, 98, sec. 6:322). This standard also offers a rule of thumb based on the daylight factor. This rule of thumb is only valid for obstructions from other buildings or obstacles lower than 30 degrees (SIS 1987). The standard does not provide guidance for higher obstruction angles, and planners and architects have thus required simulations for cases in which the obstruction angle is above 30 degrees. Between 1994 and 2014, the daylight factor metric was omitted from the BBR, and only the rule of thumb valid for obstruction angles below
30 degrees was mentioned. As urbanisation has led to higher buildings and denser areas, a requirement for these situations became critical, and the daylight factor metric from 1975 was reintroduced into the revised BBR in 2014.

**Representative systems from building science in performance requirements**

It has been clear in practice that some design team members have difficulty interpreting the representative systems traditionally used in building science and exemplified by the daylight metric factor. Indeed, the metric’s inner logic is often only understood by specialists working with digital daylight modelling. Nor has Boverket provided any guidance on a design level regarding the design parameters that interact to create the daylight factor result. This was the context for the inception of the exhibition analysed in the second article. The article suggests that there is a disconnect between planners, architects and the use of the daylight factor-based performance requirement, and that this causes problems. Making predictions about possible changes to a synthetic building design based on individual numerical results requires significant engagement and understanding from all parties in the system and within the design process. When intuitive representational information that a numerical metric – e.g. daylight factor – offers a planner or architect trained within another representational tradition is lacking, there is also a risk that planners will not understand the basics of the geometrical relationships and daylight science, and the urban environment design will lack the necessary geometry to achieve compliance with the BBR.

The assessments of the daylight factor requirement of some urban projects have demonstrated how this problem affects the Swedish planning and design process. This relates partly to the division between “technical” and “local” (“design”) criteria already observed in the divisions of PBA 2010. The municipality checks the daylight metric at a late stage through the permit to commence work. Daylight is not included in the more general requirements on planning process in the PBA, neither in establishing the detaljplan (local plan) or bygglov (building permit/detailed planning permission). The problem emerges in part due to insufficient understanding of the daylight metric among those responsible for the earlier stages of urban and building design. In order to produce early-stage design work (and indeed urban-level planning work) that takes the requirements into account, the planner and architect either need to know how to analyse daylight geometrically or through calculations. Visualising the assessment of a performance requirement in numerical results instead of in a geometrically-based
analysis will create the need for calculation, today often digital. The digital calculation requires time and a high degree of detailing of the design into a three-dimensional digital model. This detailed work is related directly to the precision of the assessment method. When using a calculation instead of a geometrical analysis, these detailed digital models need to be produced much earlier in the design process than was the case with previous prescriptive assessments.

The second article illustrates how prescriptive regulation from 1874 until the 1960s provided explicit guidance regarding the urban geometrical relations needed for daylight, and sunlight, availability indoors. The article also illustrates how the building regulations have been silent regarding urban geometry since the 1970s. It could be argued that the understanding of daylight has declined as the architectural knowledge that was embodied within the prescriptive building regulation has been lost, and as daylight requirements have been articulated via the numerical building science metric of the daylight factor.

**Multiplication of specialists assessing the performance requirements**

The use of a numerical focus of the daylight factor metric has led to a new branch of specialists who digitally assess the daylight factors. A number of Swedish architectural practices now have daylight specialists: two examples are White arkitekter AB and Byrån för arkitektur och urbanism – BAU (Boverket 2017, 30-36). Lund University offers a master’s course in energy efficient buildings including advanced daylighting modelling (LU 2019).

I argue that when an architect outsources the full assessment of the design of specific building characteristics, as in the case of daylight, s/he risks losing the understanding of fulfilling the code requirement, as well as of balancing the code requirement with other qualitative aspects of the design. The objectives of societal concern are expressed explicitly rather than implicitly (within a solution) in Swedish building regulation, and these objectives are presented separately in sections as functional statements or performance requirements in the BBR. Even if carefully formulated, the sections and the detailing of requirements into performance requirements can create the need for new specialist domains. As these requirements often refer to building science standards in definitions, calculations, or testing methods, there is also a risk that these specialists are the only ones who fully understand them. As a consequence, many more competences will be involved in creating synthetic design solutions, although only a few will have the drive and responsibility to create a synthesis. As mentioned in the
literature review, the building regulation researcher Emma Street argues that the way in which performance-based building regulation is expressed creates a market for specialist consultants and for outsourcing responsibility from the architect to other actors. She notes that fulfilling performance requirements requires the use of interfaces that architects might lack the inhouse expertise to deal with, creating fragmentation in the role of the architect whilst creating market opportunities for specialist consultants. Street also expresses that in its entirety, the system of governance that accompanies the performance-based regulation, assessment, and compliance risks undermining the role of someone in charge of a holistic solution to the societal objectives (Street 2018).

**Knowledge transfer – from advanced modelling to rule of thumb**

The relationship and need for knowledge sharing between daylight designers and those engaged in daylight research and assessment have been addressed in research (Reinhart 2005; Sattrup 2012; Strømann-Andersen 2012). Christoph Reinhart is a daylight researcher who has expressed the ambition to draw the architectural and the engineering community closer together around daylight by creating a common ground between advanced daylight metrics called daylight autonomy, which addresses both diffuse light and sunlight, and a classic rule of thumb. Most daylight literature mentions a basic rule of thumb that regards the parametric relationship between window and floor heights and room depth necessary to create appropriate daylight levels. Reinhart’s study confirmed the relationship between rules of thumb used in these standards and daylight autonomy (DA) as roughly consistent. Reinhart concludes that the consistency between the results of his study and what he calls “conventional design wisdom” is relevant for the simulation community as well as the broader design community (2005).

The vast amount of digital calculations that are carried out in practice are not necessarily systematically collected, apart from the accumulation of personal experience among the specialists who perform the calculations. There is however certainly potential for creating knowledge feedback that could inform design teams as a whole, rather than remaining the tacit conserve of individual specialists. Systematised accounting of this kind would reintroduce generalised knowledge from digital calculations into common rules of thumb, graphical mathematical relations or other methods used in early design stages in order to create understanding of daylight principles. As an example, the appended
competition (Lundgren et al., 2014) shows how building science research can be used to extract rules of thumb for the early stages of a competition project to avoid using advanced modelling during a phase in which time is limited.

I argue that architects need to develop knowledge in relation to these performance requirements, driven by the interests of architectural design as well as the knowledge outcomes of the building science community. Additionally, architects who want to utilise the full design freedom of carefully formulated performance requirements need to cultivate an understanding of the daylighting consequences of particular kinds of formal proposition, as well as about design outside the range of the most frequent building and room typologies.

**Architectural and building science, representational modes**

The second article illustrated a potential course of action to remedy a lack of understanding of performance requirements in the BBR and other performance-based regulations based on building science. In this section, three guiding concepts relating to architectural methods of understanding and developing knowledge and designs will be discussed. They are as follows:

- architectural representation will be understood both as a knowledge act and a vehicle to represent an idea of the architectural end result (Weimarck 2003, 13-15);

- context-dependent knowledge will be understood as knowledge that is attained through the inquiry into particularities rather than inquiry into general theories; and

- architectural repertoire will be understood as the architect’s knowledge about methods, techniques and approaches together with experience and knowledge attained through dealing with particular cases, in particular traditions of practice.

Historically, architectural representational methodology lies in the acts of imagining, drawing, illustrating, and building models. Since the 1990s however, digital modelling has become mainstream, and different digital calculations of digital models have become more and more common. Teams working with design today often have at their disposal a broad range of competences forming:
complex sets of ‘collaborative constellations’ that produce and share knowledge and methods through cooperation between many disciplines as ways to deal with the complex issues of the contemporary world (Nilsson 2013, 8).

Often, different disciplines within or collaborating with an architecture practice can have very different ways of communicating and developing knowledge. Representation is thus key to the discussion on how to understand and assess performance requirements that are based in building science. Representation is central in architecture; the architectural task is complex, and representation has a generative role. Architects are acutely aware of the nuances through which representation gives room for imagination – which can be very rudimentary or highly detailed – as well as how it spans from rhetoric and exploration.

Systems and conventions of representation characterise all disciplines that share knowledge as a matter of course. These representations do not necessarily relate to what is drawn, but can be tables or graphs in building science with intricate connectivity between different parameters. Nevertheless, all of these systems of representation have their own syntax – they are ways to communicate and understand findings, and they are informative in relation to what they describe. In his article on “The Making Disciplines”, the professor of architecture theory and methods Fredrik Nilsson presents a vast number of ways in which visual communication has been used in engineering and the natural sciences, and its importance for both understanding and communication (2013, 7-8).

The use of representation when assessing daylight performance

The daylight exhibition reviewed in the second article was in itself an act to reconcile the problem of the division between different representational methods that emerges between the conventions of architectural design and those of building science. In the exhibition, the daylight metric was illustrated through architectural representations based in traditional architectural drawings. This was done in effect to link an understanding of the system of assessment to an understanding of architectural geometry. The representational approaches used were chosen to help an architect understand both whether the performance requirement in the BBR was being met in a particular spatial configuration, and crucially, to clarify in architectural terms which urban and building design factors in the specific cases have facilitated or hindered compliance with the BBR. Compliance with daylight metrics of the Swedish Building Code in the exhibition was illustrated by geometry, in obstruction angles and no-sky lines, and
these geometrical constructs were linked to a presentation of the results in daylight factor shown on a plan. The daylight factor point is inscribed in relation to a border between areas of compliance or non-compliance, indicated by a line on the plan. This graphic representation bears little resemblance to the graphics generated by digital daylight calculation tools in real-life projects, which have no pedagogical intentions.

Quantitative performance requirements aim at establishing numerical assessments. The representation of these assessments is thus often derived from mathematical abstractions of real-world phenomena. The knowledge contained in the prescriptive building regulation was collected from an extended repertoire of cases that pooled the experience of architects, engineers, craft and construction specialists. It was thus derived using various methods. The requirements outlined in planning and building acts between 1874 and 1960 were formulated as geometrical relations, either in a fixed section or in a parametrical relationship between building heights and the street; this communicated directly to the planner and the architect. Numerical performances based on calculation, which are often derived from digital calculation today, are not transparent for a planner or an architect. The article shows how unfolding the metric into geometrical relations creates the possibility to use the same representational means as those used when designing urban areas and buildings. The resulting numerical value of a daylight factor in a specific case is a result of the geometrical prerequisites of the urban, the building, and the room design. The daylight exhibition room thus also sought to present daylight in terms of the complexity that constitutes it, not in numerical values. To that aim, the Arkdes exhibition used different representational means linked to the different scales of daylight in a room (represented through video films and architectural plans and sections), which varied to show the daylight impact of design decisions on the building scale (such as the impact of balconies) and urban scale (such as orientation and the proximity of buildings in relation to sunlight).

During the work with the second article, an opportunity arose to compare the representational means used in the exhibition i.e., of five cases, and those used to perform a numerical study of several cases in building science. The numerical study was carried out by the daylight researcher and associate professor Marie-Claude Dubois and the PhD student Iason Bournas at the Division of Energy and Building Design, Lund University. In the latter case, advanced digital daylight calculation was used to study 36 cases in a numerical study. These cases were in turn a part of a larger study of 54 cases (Dubois and Bournas 2018). The case studies presented in the Arkdes exhibition and the numerical
study were from the same periods in the twentieth century. All cases were chosen according to a method developed by my co-author for the second article, Malin Alenius, and myself (Bournas et al. 2017), and we selected the 36 specific cases calculated by Bournas and Dubois together with another colleague at White, the urban planner Lovisa Kihlborg. Since they were first published in a conference paper, appended to this thesis, the numerical study and its findings have been published and further developed in a Swedish report and an international journal (Bournas and Dubois 2019).

Before going further into a discussion on representation within building science in relation to architectural research and practice, the type and the relationship between the two studies will be discussed. According to Rolf Johansson, there are two principal types of case studies: the first focuses on the specific case itself, i.e., the intrinsic case study, while the second is driven by an aim to attain general knowledge, i.e., the instrumental case study. The intrinsic case study is typical for architectural history studies (2000; 2003). I argue that the instrumental case study, which concentrates on specific parameters or variables that recur in multiple cases, is very common in environmental science studies carried out in relation to architecture and energy. There are also case studies somewhere in between, where the intrinsic case study method and the will to generalize coexist (Johansson 2000; Johansson 2003). The five exhibition cases in the second article of this thesis can be situated in between the two modes of case studies – the intrinsic and the instrumental – with an aim to use applicable architectural methods to design with and assess daylight in architecture. The numerical analysis carried out by researchers Dubois and Bournas can be defined as an instrumental case study based in building science, whose aim is to reach a verifiable and general conclusion.

Other instrumental case studies may aim at offering concrete instruction and rules of thumb (Johansson 2000 and 2003). This thesis acknowledges that environmental inquires carried out as instrumental case studies to offer concrete instructions and rules of thumb risk creating architectural restrictions. Thus, studies often deal with a specific typology, although instructions may be presented as more generally applicable. When performance requirements are interpreted through generalized knowledge in such a manner, there is therefore a risk that the design freedom that carefully formulated performance requirements can offer is limited.

The first of three concepts introduced in the beginning of this section is architectural representation, understood both as a knowledge act and a vehicle to represent an idea of the end result. When understood as a knowledge act,
drawings, models and other representational means develop and refine ideas and possible solutions to a problem. I argue that rather than serving as mere descriptions, representations in building science deal with the understanding and an iterative refinement of that understanding.

These two studies share a single research question: How do the 2014 Swedish legislative demands on daylight availability relate to the daylight availability in a representative selection of Swedish residential building multi-family blocks from the twentieth century? The respective main focuses of the two studies, however, were different. As mentioned earlier, the Arkdes exhibition aimed to show the daylight factor metric in a way that was intelligible to planners and architects in order to enhance understandings of daylight by disseminating carefully chosen cases from history in their complex context. The main objective of the numerical study by Bournas and Dubois was to be informative with regard to writing performance requirements on daylight. Daylight levels in historic building stock were thus assessed to provide scientific information that could inform a reformulation of the daylight requirement in the building code that took into account recent urban trends (Bournas and Dubois, 2018). The daylight factor metric (in a point) in the BBR was also evaluated in comparison to other daylight factor metrics (average and median) with a larger sample of 54 buildings; thus, the study’s anticipated readers were not primarily planners and architects. The visual approaches used in the paper, report, and journal were intended to communicate with an audience accustomed to numerical studies, and thus adheres to this tradition of representation. The results are mainly presented through tables and in numbers in text; see Appendix II. The tables presenting daylight availability disseminated findings in relation to either room sizes, or to room heights, room depths, etcetera, in separate diagrams. Fourteen housing developments, with 36 buildings and 8,573 rooms, were presented in tables (Bournas et al. 2017). Because of the large sample, there were no individual room presentations in which the combined room depth, height and size could be followed, and which would have been interesting for an architect. The figures can be difficult to read without an engineering background; for example, there is a table on the cumulative frequency of a) sky exposure factors, b) window areas, c) room depths and d) room areas (Bournas et al. 2017, Figure 6.). The article and report aim to present results on a general level, mostly using numerical values for each factor separately. I would argue that a presentation of some well-chosen examples from the numerical study in which the relation room depth, room height, window-to-wall ratio and obstruction angle were presented in a series of drawings would augment an architect’s understanding of daylight.
The report from 2018 presents a table of the compliance with 2014 building code for each decade on the level of room, apartment, and building. Together with knowledge about the buildings selected, illustrated in the conference paper (Bournas et al. 2017), the table can give a good understanding of the relationship between different decades of building design and compliance (Dubois and Bournas, 2018). This can be used with ease by an architect in relation to his or her own experience relative to the design trends of these periods.

While the different choices of representational means between the exhibition and the numerical study relate partly to their different aims, these choices also reflect different representational traditions in architecture and building science, and reading and understanding them requires different skills. While the Arkdes exhibition presented the daylight factor through architecture representational case study material to show the particulars of each case and give the architect an understanding for correlating spatial relations to daylight, the numerical study presented the trends of daylight availability in the twentieth century, forming new general and theoretical knowledge about daylight metrics.

**Context-dependent knowledge – a base for architectural practice**

The building science representations of the numerical study relate to a tradition that illustrates the abstractions and generalisations of real-world phenomena (Lewis 2017, 1156). As quantitative performance requirements in building codes are often based in building science, an interesting question is how to inquire into and disseminate such requirements in another tradition. The discussion thus comes to the relation between context-independent knowledge, i.e., generalised knowledge, and context-dependent knowledge (drawn from cases and particularities of real-world phenomenon). The Danish researcher and professor of planning Bent Flyvbjerg (2006) described these two knowledge concepts in relation to in-depth case studies, which Johansson also calls intrinsic case studies. Flyvbjerg identifies several falsities in relation to the way in which various disciplines use case studies. One myth, he argues, is that generalised knowledge is more valuable than context-dependent knowledge; another is that individual cases, independently, cannot be a base for generalisation, proposition, or theory building (2006, 221). The architecture researcher Inge Mette Kirkeby makes use of these two concepts when looking at how research findings can be disseminated better to practitioners within architecture. Inquiring into the knowledge that

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2 In an article by Alan Lewis on the mathematisation of daylighting, he uses terms borrowed from the work of Edmund Husserl. Husserl describes the relation between a mathematical science enquiry and the world as experienced. He calls the abstractions and generalisations exact essences and defines them as ‘mathematical idealisations of the real world’ in contrast to morphological essences derived from empirically-drawn conclusions relating to real world experiences. In his inquiry, Lewis compares standards and legislation based on daylight building science, in the form of exact essences, with simple principles such as rules of thumbs that can be experienced in real life.
is actually used in the design process, Kirkeby writes that context-dependent knowledge gathered from personal experience, understanding and observing case studies, has a generalised value for groups of collaborators who use these experiences to determine the best possible outcomes in ambiguous circumstances. (Kirkeby 2009, 307-308). Kirkeby presents some of her findings from semi-structured interviews with architects, some of whom highlighted the importance of drawings in the process of constructing and sharing knowledge (Kirkeby 2009, 309).

Design as an act involves many competences, and many kinds of knowledge – both context-dependent and context-independent – will inform the process. I argue for not giving precedence to a context-independent understanding of issues regarding performance-requirements; instead, performance requirements need to be disseminated both as cases in a context and through general theory.

**Performance informed by repertoire**

Kirkeby addresses how research can contribute valuable knowledge aimed at practice, as well as knowledge that emerges from accumulated repertoire. She considers repertoire-building relevant for design when new design situations may “be seen as familiar situations, cases, or precedents” (Kirkeby 2009, 308). The concept repertoire describes when empirical studies of cases are stored in the mind and activated as a support to the solution-finding process (Jansson 1995, 52-53). Creating a relevant repertoire in relation to a subject (such as building science and the nearly zero-energy discussed earlier, and building physics, climate and comfort) requires a body of analysed historical and contemporary architecture cases. I argue that for an architect, understanding daylight requires more than rule-based calculation about daylight factors presented as generic results. Architects need to activate their interest and their understanding of daylight in relation to real-life cases, to historical and contemporary cases analysed with other methods that architects understand. The example in the article illustrates how to create a more in-depth relation to the performance-based metrics of building science. For architects’ understandings of factors based in building physics, precedent and repertoire-building are of importance in education, as well as in practice and continuing professional development.

The tradition of architectural history analysis and architectural theory strategies in relation to building physics is shorter than those concerning the relationship between architectural expression and structural properties. As mentioned in the introduction to this thesis, this fact is presented in different ac-
counts by Reyner Banham ([1969] 1984) and Dean Hawkes ([2008] 2014; 2012). Banham and Hawkes both criticised the increasing professional specialisation in regard to, and the increased standardisation of, comfort and climate. Creating a comfortable indoor climate they both also consider to be among the architects’ essential tasks (Banham [1969] 1984; Hawkes, [2008] 2014). Banham’s criticism of architectural training in 1969 is still applicable to Swedish education in 2019, although some attempts have been made to address aspects both internal and external to the building from the architectural disciplinary viewpoint. As one part of the traditional architectural training is repertoire-building, where the focus is on case studies, the potential for increasing teaching about building physics and comfort is growing with Hawkes’ and Dahl’s contributions.

I suggest that such teaching is a natural contribution to existing educational curriculum. The notion of a repertoire of buildings is familiar in the teaching of architectural history, although it is related to quite different types of reading. The potential of using the repertoire method to study building physics and in relation to needs of daylight, heating, and building envelope is completely complementary to this tradition.

**Concluding discussion Article II**

Comparing the outcomes of different knowledge traditions, as in the case of the second article and discussion, the complexity of a few carefully chosen case studies can bring the architectural practice necessary knowledge about building physics to complement the guidance provided by general theory produced within building science research. The knowledge gained in the architectural design process interrelates closely to the working methods being used. As the codes, standards and certification systems in Sweden and various other countries are expressed as quantifiable standards, the act of assessing daylight (which has become more significant with the increased potential for computer-based calculations of such values) has come to the fore. At the same time, knowledge related to quantifiable standards derived from digital calculations cannot necessarily be used in a knowledge feedback loop to inform the early design stages, where more crude design methods are used. The precise conclusions of very accurate simulation, requiring highly advanced degrees of completion in the architectural models simulated, need to be (re)converted into rules of thumb, graphical geometrical relations, or other methods to support the understanding of building science at an in-principle level. I argue that this would improve understanding for those in the planning- or project process who do not perform the computa-
tions themselves. Discussions between designers and specialists would benefit, as would their projects.

There remains nevertheless a need for architects to address the issue of how to attain knowledge that positions the individual performance requirements within design knowledge as a whole. A certain level of context-dependent knowledge regarding the aspect addressed in a performance requirement is necessary in order for architects to be innovative. The second article addresses the issue of how to work with quantitative and qualitative aspects of daylight in the architectural design process and how to use architectural systems of representation combined with the potentials of building science calculation to reinstitute daylight as a vital design parameter.

A continued interest from the architectural practice and research into performance from a context-dependent knowledge horizon would also create a broader range of precedent- and repertoire-building. As building science – especially building physics – has yet to receive such attention from the architectural community, an architectural research interest in this area would truly enhance architects’ understanding of performance-based building and its relationship to building science and building physics.
JUXTAPOSITION
In the twenty-first century, the representational methods used to encapsulate ideas are increasingly being framed and assessed within a building science representational mode. Depending on how they are interpreted, various societal changes can put strain on or offer opportunities for architecture. The global climate crisis is one of the major societal challenges. One legislative objective in response to this has been the implementation of nearly zero-energy buildings, which use minimal resources whilst generating energy. This objective is now inscribed in an EU-directive, as well as in the Swedish building code BBR. Traditional architectural research has been relatively uninterested in the understanding of and knowledge inquiry into building physics required by nearly zero-energy design. In my 18 years of practice in Sweden, I have found it necessary to translate between the architectural and engineering professionals regarding energy and comfort in order to facilitate communication, and I have frequently noted the lack of a common understanding of building physics. This rather problematic situation can be contrasted with the – by no means perfect, but slightly more productive – ways in which architects and engineers discuss knowledge of structures. In the latter case, although the disciplines are disparate, and those engaged in the discussion have varying levels of expertise, the common understanding appears to be sufficient for discussion.

This common understanding can be examined further using a term coined by Peter Downtown, professor emeritus at RMIT University Melbourne, who presents three categories of knowledge necessary for design practice (Downton 2003, 62-63). The terms are the “knowing-how”, that one must practice; the theoretically studied “knowing-that”; and the “knowing-of”, when one is acquainted with a phenomenon (Downton 2003, 62-63). Swedish architects are traditionally trained in the principles of structures and therefore have acquired the “knowledge-of” and “knowledge-that” when it comes to structural design. Although architects are seldom trained in “knowing-how” to carry out a structural calculus, the “knowing-of” and “knowing-that” create an understanding that benefits the collaboration between architects and structural engineers. A similar base in building science and building physics would also benefit the architect.

However, while the relationship between architecture and the statics of material and structure have been studied extensively, a parallel discourse surrounding building science, building physics, and architecture is notably harder to find. As discussed earlier, a handful of prominent researchers have devoted their work to this relationship. A question for this juxtaposition, which concludes the discussions of the thesis, then, is: from where could one generate a discourse which, read from an architectural perspective, could help create a more vital discourse on energy, building physics
and architecture? Standing before a grand challenge to mitigate climate effects, architects today especially need a “knowledge-that” building physics has architectural implications and a “knowledge-of” the building physics aspects that are addressed in the performance-based, building science-inspired code. There is a need to rectify the separation of architecture and technology, to create a common language for collaboration and spur architects’ interest in knowledge about building science and building physics. Looking back through history, there is one example in which similar problems regarding the creation of a common language to allow the prerequisite for collaboration led to a particular development in architectural discourse.

Tectonics as a basis for collaborative interaction

When it comes to construction and structures, there is a long history of knowledge-sharing between architects and engineers. In his study *Architect and Engineer – a Study in Sibling Rivalry* (2007), the professor of architecture Andrew Saint looked at how professionalism developed among consultants involved in building projects in Venice from 1500 until today. He suggests that during the Renaissance, the terms architect and engineer related more to the work performed than to an educational background: the design of secular and religious buildings was the domain of the architect, and the design of forts, walls, towns, ports, canals and war machines was the realm of the engineer. While this simple dichotomy could be questioned, it is clear that two differing professions emerged. It is also equally clear that for a long period in history, both architects and engineers had the technical capacity to design certain structures; this is particularly associated with masonry structures. In the plurality of material systems that began to be used during the nineteenth century, engineering consultants begin to advise architects on structures more frequently, although as late as the 1880s, the iron frames of American skyscrapers could still be designed by architects alone (Saint 2007, 486-488). This transition from the domination of masonry to the introduction of new materials with unknown structural properties created challenges for the architectural profession. At stake was the interplay between the material core, architectural history and architectural expression. It was in this context that an architectural discourse on a concept called tectonics emerged. Many studies date the birth of tectonics in the early 1800s, linking it to the Industrial Revolution (Schwarzer 1993; Wolf 1996; Wallenstein 2004, 17-33; Mallgrave 2009). The concept provides a historical precedent that illustrates how, in a set of circumstances similar to the challenges posed to architects
today, a discursive framework within the discipline of architecture was created to address an interdisciplinary challenge that emerged from societal changes. It became a significant term in architectural discourse again during the 1980s and 1990s, in a period during which – similarly to the early nineteenth century – the boundaries between the agency of architects and other actors in the building process were being tested, and when the hegemony of many architectural values was being questioned. In the book *Studies in Tectonic Cultures – the Poetics of Construction in Nineteenth and Twentieth Century Architecture*, the architecture historian and professor Kenneth Frampton revitalised the discourses on tectonics. Dean Hawkes argued that there is an implicit challenge for historians and theoreticians to develop a parallel account of Frampton’s poetics of construction, for something he refers to as *the architectural environment*. In 2013, Anne Beim, professor in architecture and head of Centre for Industrialized Architecture (CINARK) at the Royal Danish Academy of Fine Arts (KADK), addressed tectonics in relation to the growing industrialisation of construction and the rise of the digital, as well as in relation to ecology and resource use, in a book that she co-edited with the associate professor Ulrik Stylsvig Madsen at KADK; here, tectonics is explored as a productive concept in relation to addressing ecology and resource use (Beim and Stylsvig Madsen, 2014). In the following section, the emergence of the concept of tectonics will be used as a productive example for the contemporary situation through the review of the writings of several historians: from architecture, Harry Francis Mallgrave, Detlef Mertins, Mitchell Schwarzer and Scott C. Wolf, and from intellectual history, Anders Burman and the philosopher Sven-Olof Wallenstein.

### Tectonics

Architectural discourse in the mid-nineteenth century was influenced by aesthetic philosophy, archaeology, architectural history and ground-breaking technological innovations for architecture such as the introduction of iron into a material tradition of building (Schwarzer, 1993). The same period also saw the emergence of industrialisation and the rise of engineering as a discipline. In Prussian aesthetic philosophy, the fine arts were distinguished by the relationship of the art form to external matters (for architecture, e.g. mass, gravitation, economy, programme and politics) and the internal mind (excelling the conscience). The arts that were more closely related to external matters, such as architecture, were ranked lower than those related to the internal mind, such as
painting (Schwarzer 1993; Wallenstein 2004, 17-33; Burman 2016, 49-52). When
the hierarchy between art forms began to dissolve, a possibility was created for
architectural theory to reinvent its position and deliver a new theory of archi-
tectural expression. This grew to be interlinked with the emergence of new
material practices and constructions (Schwarzer 1993; Wallenstein 2004, 17-33;
Wolf, 1996). The concept of tectonics, as introduced by Karl Friedrich Schinkel
and Karl Bötticher, presented a possible synthesis between the material dimen-
sion of architecture and the representational (idea and expression) (Schwarzer

Schinkel … differentiated architecture from mere building through the elaboration
of its constructive forms with aesthetic feeling (Schwarzer 1993, 269).

…tectonics struggled to create an integrative system for art and structure within
architecture… (Schwarzer 1993, 271).

Bötticher conceived artistic symbolism in architecture as dependent upon consider-
atations of need, material, and technological innovation. Bötticher’s idea that artistic
representation exemplifies (not dominates) the qualities of materials and lineaments
of static forces reversed aesthetic hierarchies (Schwarzer 1993, 273).

Bötticher was a trained architect and archaeologist, whilst Schinkel was both an
architectural theorist and an influential practicing architect of the time (Mallgrave
2009). Bötticher had employed his theories when working with the new iron
material. He addressed the tectonic qualities of building elements, such as the
synthesis of matter and expression of the loadbearing pillar and its representa-
tion in details of a cornice, but he was also concerned with the spatial character-
istics of tectonics. According to Bötticher, the character of architectural space
evolves from the architect’s synthetic solution to functional needs, including the
social aspects of programme and physical forces, the latter including climate.
This side of tectonics reveals the focus on the interrelationships between plan,
roofing and support, and the enclosure of space. The spatial impression is con-
ected to the tectonics of elements (Schwarzer 1993).

All decorative characteristics of the parts of built structure are perceptible demon-

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1 Bötticher defined architectural tectonics quite simply as the activity of forming a building. Unlike most architectural
theory until that point, which focused on the imitation of objects (either directly or through analogies), Bötticher’s
tectonics investigated architecture through the processes that comprised building. Architecture was no longer conceived
of as a finite world of forms; rather, it became a dynamic and infinite universe of forces. Instead of starting a design
with a model in mind, Bötticher recommended that architects begin a building with an analysis of social and physical
forces: the needs that instigate its plan, the roof covering, and the vertical supports, that together result in the creation
of architectural form and space. Tectonics was hardly limited to issues of construction. It embodied an integrated
study of function, structure, and symbolism. In regard to the explication of building forces through artistic symbols,
for example, Bötticher proposed that Hellenic ornaments depict the actively changing technological forces of building
(Schwarzer 1993, 267).
strations of their functions, essence, physiognomic beginning, development, turns, conclusions, and connections. In short, art is an explication of the organicism which connects the whole with its parts (Bötticher, “Entwicklung der Formen,” 328, translated by Schwarzer 1993, 273).

The tectonics developed by Bötticher, then, concern both structural forces and climatic forces and their relation to material, volume and space. Tectonics is determined by the enclosure of space and the detailing of enclosure, and as such, detailing often reveals the actual means to protect the inside from the outside. As a concept it thus quite logically concerned the very forces that are today defined as the province of building physics – that is to say, forces produced by temperature variation, humidity, air flow and radiant heat.

A successor to Schinkel and Bötticher, Gottfried Semper, linked the theory of tectonics expressly to the frame of a covering, clothing or dressing (Bekleidung) displaced from the masonry (Mallgrave 2009; Wallenstein 2004, 17-33). Like Bötticher and Schinkel, Semper talks about merging technology and architectural expression into a single whole. At the same time, Semper introduces the differentiation between the enclosure and enclosed, creating a new way of defining space (Wallenstein 2004, 17-33). Although Semper did not translate his theories into “a suitable architectural dress” for new materials and constructions, the professional community in Chicago used the dressing metaphor in 1880s to develop the constructional device the “curtain wall” (Mallgrave 2009).

Tectonics has been a contested concept, used differently by different contingents of the architectural research community and practice since its theoretical entry in the early nineteenth century. Kenneth Frampton reflects on this scope in the introduction to his 1995 book Studies in Tectonic Cultures – the Poetics of Construction in Nineteenth and Twentieth Century Architecture. He speaks of the relation between the topos (the site), the typos (the building type) and the detailing of tectonics and the craft of constructing (1995, 1-27), and acknowledges the crucial role that structural engineering played in modern day notions of the term (1995, 335). Frampton provides both a historical exposé of the concept of tectonics and an in-depth analysis of the relationship between constructional form, material character and architectural expression in works by a selection of architects from the twentieth century (Beim 2004, 177). In Frampton’s exposé, the relationship between architecture and structure (as opposed to architecture and building physics) is reinforced.

A special issue of ANY on Tectonics Unbound: Kernform and Kunstform revisited!, edited by architecture historian Mitchell Schwarzer, relates both to the concept
that emerged in the mid-1800s and to the relationship between emerging digital methodologies and tectonics (1996). The potential within the concept of tectonics to dramatize or resolve an architectural expression in relation to structural prerequisites is brought to the fore as a concept. From this perspective, the ambiguity of the concept and its reception during the twentieth century become central. In 1996, Mertins and Schwarzer argued that the duality within the concept of tectonics has been reinterpreted over time; they suggest that there are two camps: one that emphasises truth to structure as a principle for architectural articulation, and another where tectonics can express playful contradictions. As Schwarzer writes, however, both camps accept the rhetorical aspect of representation within the concept of tectonics, and both camps accept without question the primary relation between tectonics and structural expression.

In 2004, Anne Beim related the representational meaning of tectonics to the ideas and intentions implemented into the building through rhetoric by the architect. She draws a parallel between what architecture is made of – its substance, processes, cultural and historical setting – to making, its human activities and practices. Like her contemporaries, Beim examined tectonics in terms of structure, construction and technology:

In present architectural vocabulary, the term tectonic is commonly used, primarily referring to aesthetic questions in building construction. However, it is also used to describe material nature and intentions in construction solutions as well as structural systems and principles of organization (Beim 2004, 45).

In one of her case studies however, she also addresses aspects of climate adaptation, involving the interplay of building physics and mechanical systems with structure as the material of tectonic expression (Beim 2004, 151-159).

A broadened concept of tectonics

In 2008, Dean Hawkes addressed Kenneth Frampton’s arguments and concern with tectonics as the poetics of construction, suggesting that it contained an implicit challenge for historians and theoreticians of the architectural environment. Hawkes responded to this in The Environmental Imagination ([2008] 2014, xix). Hawkes focuses on how architects have established a relationship between the elements of architecture, defining these as space, form, material and mechanical systems for heating, ventilation and lighting. He calls these elements the technics of the architectural environment, which, with the act of imagination,
will be brought to bear in the service of poetic ends (Hawkes [2008] 2014, vi). Hawkes points out that the “enterprise of building – or architectural – science has received relatively little attention from the historians” (Hawkes [2008] 2014, xiii). This contrasts with the impact on architectural practice that the same science has had. As Hawkes puts it:

It is now possible to design buildings in which quantitatively and precisely specified environments can be delivered by calculated configurations of building fabric and mechanical plant (Hawkes [2008] 2014, xiii).

Hawkes also points at how this “development of strategies of environmental management is paralleled by a process of codification of degrees of temperature, ventilation, illuminance, noise levels and so on, that have, in contemporary practice, rendered the environment within buildings almost entirely a matter of calculation realised through the mechanisms of engineering” ([2008] 2014, xvi).

A wholly different dimension that he wishes to highlight is the complex sensory experience of an architectural environment (Hawkes [2008] 2014, xvi). Hawkes speaks of atmosphere – the pervading tone or mood of a place – as a non-scientific concept that can capture the poetic qualities of architecture (2008, xvi). Distinguishing between the technics and the poetics of the architectural environment, Hawkes relates these terms to the objective and quantitative on the one hand and the subjective and qualitative on the other (Hawkes [2008] 2014, xvi, 2012, 1).

Adding on to Hawkes’ ambition, one can suggest that there is a need for increased architectural attention to the elements of architecture – space, form, material – in terms of their building physics properties, as these can dictate the need for the mechanical systems for heating, ventilation, lighting, and vice versa. Such a case is eloquently presented in the book Climate and Architecture by Torben Dahl (2010). I argue that engaging building design and its passive performance potentials through the concept of tectonics and the interaction between energy transfer and physical structures calls for the “knowledge-of” and “knowledge-that” in building physics, as well as in material energy transfer through conduction, convection, radiation and humidity. An architectural discourse that developed these ideas in terms of a tectonics of material enclosure, of structural indoor mass and thermal balance, along with tectonics of natural light or of acoustic character, would capture key phenomena that comprise what Hawkes calls atmosphere. Indeed, it would render this very synthetic notion of building experience in terms that allowed its key components to be understood by
CONCLUSION
In the following, I will summarise some conclusions drawn regarding the relationship between architecture and innovation in this era of performance-based regulation. In the first discussion of the exegesis, the historic turn from prescriptive to performance-based regulation can be identified as affecting the architectural prerequisites. Actions to be taken when formulating performance requirements were suggested both to avoid competing objectives – which make a holistic design difficult to achieve – as well as to avoid limiting architectural freedom. The entry of building science models quantifying societal goals is visible in the history of performance requirements in Sweden from the late 1960s. A separation of technology and architecture can be seen in the language used in the Planning and Building Act of 2010, as well as in the consequences of this separation in the building project process. It illustrates a pattern that is repeated in the Swedish Building Code, BBR, where architectural consequences are not assessed for so-called technical characteristics. While the prescriptive regulation incorporated knowledge from several fields at once – architecture, engineering, craft and construction – the performance requirements lean on building sciences, with abstract numerical metrics and calculations with claims of objectivity.

In this thesis, I have also argued that as the authority that issues the code, Boverket needs to perform a form-related impact assessment of the so-called technical characteristics, as they will have architectural design impacts. Treating the so-called technical characteristics as merely technical has proven counterproductive in the case of energy in relation to daylight. The thesis also shows that a lack of understanding of the abstract daylight metrics has affected the process of building compliance with the BBR. I argue that as performance requirements in the BBR will meet other requirements on architectural form and expression in the local planning process (Sveriges Riksdag 2010, chap. 2 and 8), this calls for a framing and formulating of the performance requirement so that they are as neutral as possible in relation to form and architectural expression. This is due to the – supposedly objective – relation between the BBR requirements, to the requirements in the planning and building act that are to be judged with respect to the local spatial and cultural environment, as well as the requirements regarding demonstrating a good effect of form and shape. I thus argue in favour of Boverket’s definition from 2004 that performance requirements should not limit material, design or method from being put in effect when formulating requirements for the so-called technical characteristics in the BBR.

The second article highlighted yet another issue with performance requirements, connected to how the code is utilised and assessed in practice by design teams comprising individuals from different educational backgrounds. The
article shows the differences between systems of representation favoured by architectural training and systems of representation favoured in more strictly building science-based disciplines. These were placed in relation to performance requirements. For the practice and for the benefit of architectural design innovation, there is a need for an architectural repertoire that addresses building science metrics to a much higher degree than today.

Andrew Saint points out that in the history of the education and practice of architects and engineers, there was a steady separation in skills between architect and engineer that started in the nineteenth century and emphasized the mathematico-scientific aspect of engineering. In the juxtaposition, I suggest reconciling the separation between technology and architecture by establishing a renewed discourse of tectonics where the dualism of technology and architecture is in focus, informing us about the complex artistic relation between the underlying natural scientific aspects of the matter, be they statics or building physics, and the architectural expression. In relation to this, additional architectural research into performance metrics and an active architectural discourse on tectonics regarding building science and building physics would help practicing architects to be innovative about mitigating climatic impact through their designs. The concept of tectonics addresses the relationship between the parts and the whole, the result of the act combining the fundamental physical possibilities and ambitions regarding architectural expression. The tectonic relationship between building physics and architectural expression relates to the detailing of the enclosure of the building volume, its façade, ground, and roof with respect to the transmission of energy through materials and the balancing between energy conservation – i.e. encapsulating heat – and daylighting needs and daylight as free energy, contributing to electric lighting savings. With an understanding of the principles of building physics comparable to the architects’ understanding of the principles of structure engineering, architectural knowledge can develop when analysing in-depth cases from this perspective and add a new layer of knowledge to the architectural repertoire when working with precedents in education as well as practice. This knowledge, which relates to energy use and the mitigation of climate emissions, is directly related to societal concerns of global dimensions.

The suggestions in Discussion I – on the writing of the BBR – and in Discussion II, on the assessing of performance requirements, as well as in the Juxtaposition, on enhancing an architectural discourse on tectonics, relate to a critique that form has become invincible in the abstraction of building science metrics, and the multifaceted nature of design, reaching into both organisatio-
nal, technical and expressional concerns, has thus been forgotten.

In conclusion, if performance regulation is to be a base for architectural design innovation, the architectural community must be active. In this thesis, I have addressed the need to scrutinize the consequences of the lack of form analysis of performance requirements for so-called technical characteristics of building and construction work. This work must be continually carried out by the architectural community for each new formulation of performance requirements. Thus, architects must first direct efforts towards Boverket regarding the consequences of the formulation of architectural performance requirements. Secondly, the architectural community needs to find ways to assess performance requirements in early stages by understanding the principles behind these requirements, be they daylight metrics, energy transfer or something else. One way was presented in the second article of this thesis and in Discussion II. This is necessary in order to understand architectural design challenges in the early stages, and also in order to create a productive dialogue with specialists that is based on both the architects’ and other professionals’ understanding. Thirdly, I argue that the concept of tectonics, read from a building science- and building physics perspective, will be valuable in creating a more vital discourse on energy and architecture, and that this would help practicing architects to be innovative about using repertoire for mitigating climate effects as well.
SAMMANFATTNING


Utifrån frågeställningen om frihet i avseende på arkitekturlösningar i funktionskravbaserade byggregler analyseras därtill i diskussionen som följer på artikel I formuleringarna av energikraven i BBR med motsvarande avsnitt i komparation med danska och tyska byggregler så som de såg ut 2016. I jämförelsen
mellan tre länders olika tolkningar av energiprestandakravet framgår att de styr utformning olika. Med grund i den jämförelsens analys diskuterar jag att tidigare forskningsrön, om att abstrakt funktionskrav ger större lösningsfrihet (Foliente 2000), inte nödvändigtvis gäller i avseende på frihet för arkitekturlösningar. I avhandlingens forskningsöversikt och diskussionen som följer på artikel I framgår att funktionskravs konsekvenser för arkitekturutformning är ett underutforskat område.


av tolkning i de fall dessa kan beräknas och är uttryckta kvantitativt. Artikeln och diskussionen visar samtidigt att bestämningen av ramarna för funktionskraven, exempelvis systemgränser för energiberäkningen och formuleringar av respektive funktionskrav, innehåller avvägningar som i sig omfattar och påverkar utformningsbeslut och det lösningsutrymme som följer. I artikeln visas att formuleringarna av funktionskravet för energiprestanda leder till negativa konsekvenser för friheten i utformning av arkitekturlösningar. Jag argumenterar för att konsekvensanalyser behöver genomföras vid regelgivning av funktionskrav i BBR av flera skäl, bland annat för att undvika att onödiga restriktioner i utformning skapas och för att enskilda funktionskrav inte ska krocka i BBR eller leda till konflikter mellan olika krav i de olika regelhierarkierna BBR och PBL. Detta gäller särskilt mellan funktionskrav i BBR och krav där i PBL, där hänsyn i arkitekturutformningen krävs till plats och omgivning (2 kap. 6 § 1 och 8 kap. 1 § 2). Jag argumenterar även för att Boverkets egen definition från 2004, om att funktionskrav ska formuleras så att de inte begränsar valet av utformning, material och metoder, är relevant för byggregelverket och för att nå formuleringar av funktionskrav som uppfyller denna behövs formanalyser av funktionskrav tillämpas inför Boverkets regelgivning.


Både utställningen och den numeriska studien undersökte hur hög grad dagens funktionskrav, som i ett allmänt råd till föreskriften anger en dagslusfaktornivå, uppnås i flerfamiljshus byggda under 1900-talet.

I utställningen undersöktes fem byggnader uppförda mellan 1917 till 2016 i
relation till såväl dagsljuskravet som solljuskravet (Boverket 2018 c). Dagsljuskravet beräknades och solljusförutsättningarna har undersökts genom skuggstudier. Dagsljus och solljus har även studerats utifrån ett upplevelseperspektiv i en film med sekvenser för varje vardagsrum om 6 sekunder per timma över ett dygn. De fem byggnadernas utformning har även beskrivits i relation till den vid uppförandet rådande lagstiftningen om dagsljus.

Till den numeriska studien gjordes ett större urval relaterat till tidsepok och byggnadstakt för respektive tidsepok och i den numeriska studien genomfördes avancerade dagsljusberäkningar av Bournas (2017, 2019) som även undersökte olika former av dagsljusindikatorer (Bournas och Dubois 2018). Även om utställningen och den numeriska studien har olika fokus och olika publiker är de intressanta att jämföra ur ett disciplinärt perspektiv med avseende på hur kvantitativa funktionskrav kan utvärderas och i relation till hur utvärderingsformen samverkar med designprocessen i dess olika skeden. Tyngdpunkten i artikel II ligger på hur arkitekters förståelse för funktionskravets kvantitativa precisering i allmänt råd (dagsljusfaktorn) inverkar på arkitekturutformningen. Den övergripande forskningsfrågan som behandlas i artikel II och den tillhörande diskussionen är: Vilken kunskap behövs för att utvärdera funktionskrav formulaterade efter byggnadsfysiska modeller, så att de bidrar till snarare än begränsar arkitekturutformning, byggnadernas program, uttryck och kreativitet och innovation? I relation till denna fråga illustrerer artikeln vikten av arkitektens egna metoder i utvärderingen av byggnadsfysiskt beskrivna funktionskrav. Genom den geometriska redovisningen i utställningen av de fem byggnaderna tydliggörs att grunderna för dagsljusfaktorn ligger i geometri och att arkitektens vanliga ritmetoder med fördel kan samverka med geometriska analyser av dagsljus, som no-skyline och avskärmningsvinklar, särskilt i tidiga skeden av planprocessen. Även tidigare forskning har pekat på viken av att arkitekter ges möjlighet att utvärdera dagsljuset i relation till arkitekturutformningen utan att i varje läge behöver beräkna densamma (Lewis 2017, 1172). I jämförelsen mellan utställningsmaterialet och redovisningen av den numeriska studien framgår att för dagsljusstillgången är avskärmningsfaktorn den avgörande faktorn, redovisade genom en tvådimensionell avskärmningsfaktor i utställningen och en tredimensionell avskärmningsfaktor i konferensartikeln. I jämförelsen av utfallet i dagsljusfaktor mellan olika decennier är resultatet samstämmigt, vilket illustreras i den numeriska studien genom större urval och i utställningen genom det partikulära i de presenterade fem fallen. I den efterföljande diskussionen till artikel II i kappan diskuteras relationen mellan generell kunskap, utifrån teori och instrumentella fallstudier, och partikulär kunskap, kopplad till specifika fall och kontextbeskrivningar (Johans-

Det är av vikt att arkitekter medverkar i utvecklingen av frågeställningarna och ramarna för de teorier som utvecklas, så att ett tillräckligt antal typologier, rumstyper, program och fasadutformningar undersöks om resulatena ska generalisera förutsättningarna för desamma. Samtidigt finns en begränsning i vad som kan undersökas på detta sätt. I kappan utvecklas diskussionen kring varför båda dessa former av kunskapsinhämtning har sin plats i designprocessen och att det är av största vikt, särskilt i relation till funktionsbaserade byggregler, att inte låta den generella kunskapen dominera utan att hitta en balans mellan generell och partikulär kunskap från specifika fall.

Det finns ven förutsättningar för att arkitektens verktyg i högre grad kan användas för att både utvärdera de kvantitativa krav som ställs i BBR och för att skapa en större förståelse för dem. En ökad integration av utvärdering av byggnadsfysiska funktionskrav genom arkitektens traditionella verktyg skapar även större möjligheter för en designprocess som behandlar funktionskrav och samtidigt tar in de aspekter av utformning som inte kan kvantifieras.

Sammanfattningsvis visar artikel II att ett noggrant urval av fallstudier som presenteras i sin ursprungliga kontext och komplexitet kan ge arkitekten kunskap om byggnadsfysiska arkitekturförutsättningar som komplement till den vägledning som generell teori kan ge. På grund av kvantifiering och avancerade beräkningsverktyg har dagsljuskraven i svenska byggregler på senare år kommit att bli en vardag för arkitekter. Dagsljuskraven i sig, och dess utvärderingar, ger dock inte nödvändigtvis ny kunskap till arkitekten om inte en erfarenhetsåterföring i relation till dessa systematiseras och relateras till skissprocessen, särskilt med avseende på tidiga skeden. Ett sådant exempel finns redovisat i appendix II där generell teori från forskning gav en kunskapsgrund i form av tumregler för ett tävlingsarbete. Även om erfarenhetsåterföring ökar kring beräkningar återstår ett behov för arkitekturpraktiken att utveckla kunskap som placerar de individuella funktionskraven i designuppgiften och designkunnandet som helhet, vilket kopplar till tidigare argument för behov av kunskap som ackumuleras genom en repertoar baserad på det partikulära och som är grundad i arkitektens egna verktyg och då särskilt fallstudien. I fallet med dagsljus behöver den kvantitativa utvärderingen sättas i relation till kvalitativa aspekter av dagsljus som traditionellt har utvecklats som ett kunnande hos arkitekten genom betraktande av byggnader och rum under verkliga dagsljusförhållanden.

Till de två artiklarna och dess diskussioner läggs ytterligare ett perspektiv genom den avslutande diskussionen (”Juxtaposition”) om en möjlig väg till en forskningsdiskurs om byggnadsfysik ur ett arkitekturperspektiv. Inledningsvis diskuteras förutsättningarna för ett samtal mellan designprofessioner utifrån tre

Sammanfattningsvis visar avhandlingens två delar och avslutande diskussion på ett behov av en arkitekturdiskussion om tektonik och en ökad forskningsin-
sats i relation till byggnadsfysik och de förklaringsmodellerna och indikatorer som används i funktionskrav i byggregler. Detta för att synliggöra den relation mellan arkitektur och byggnadsfysik och andra naturvetenskapliga aspekter (exempelvis byggnadinstallationer och ventilation som ligger utanför denna avhandling) som idag verkar vara bortglömd, såväl i formuleringarna och utvärderingarna av byggregler som hos arkitektpraktik och forskning. Jag hävdar att det är nödvändigt att utifrån arkitekturprofessionens egna verktyg, såsom fallstudier av det partikulära, skapa en relation mellan teori och arkitekturutformningsmöjligheter, det vill säga skapa en kunskapsutveckling kring byggnadsfysik för att ta vara på den innovationsfrihet som funktionskravsregelverk utlovar. Arkitekter behöver även engagera sig i hur byggregler formuleras och i relation till Boverket så att formaspekter inte styrs oavsiktligt och i konflikt med plan- och bygglagens intentioner om volym, form, färg och materialverkan (PBL 2 kap. 6§ och 8 kap. 1§2).
References

Government publication and public documents


**Author publications**


Appendix I

Conference Paper I

Appendix II

Conference Paper II

Appendix II

Questions to unpublished report


Questions relating to the national interpretation of the EU-directive of nearly zero-energy buildings were introduced as comments on:

- The framework for energy performance as formulated in the EU-directive of nearly zero-energy buildings (EPBD 2010).
- What is your analysis of the German interpretation of the EU-directive?
- Any comments on the DIN V 18 599?
- The German interpretation for offices includes lighting. Any comment?
- Any comment on the German law model for energy performance of reference building comparison?
- Code in relation to the goal of minimizing the use of energy, or CO2?
- Code in relation to architectural aspects?
- Any comment on legislation on urban planning scale and its importance in relation to nearly zero-energy architecture (more on the non-technological aspects)?
- Any regulation in any country that you have encountered that you find exemplary?
- In relation to legislation, a lot of countries relate to Passive House standards – do you have any reflections on that?
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Biography

Marja Lundgren, architect SAR/MSA, graduated at Chalmers University of Technology 1999 with additional training in building physics. Since, she has worked with focus on sustainable design and architectural technology as a partner at the Scandinavian architectural firm White arkitekter. With the dual interest of practice and research Lundgren has been a part-time industrial doctorate at at the School of Architecture, KTH Royal Institute of Technology in Stockholm. Between 2017 and 2019 Marja has been working in The Building Rules Modernisation Committee at the Government Offices of Sweden.